ASCEMI
American Society of Civil Engineers Michigan Section
Founded 1916

September 17, 2009

Ms. Carol Reese
History & Heritage Committee
ASCE National
1801 Alexander Bell Drive
Reston, VA 20191-4400

RE: Nomination of the Mackinac Bridge for a National Historic Civil Engineering Landmark

Dear Ms. Reese,
On behalf of the Michigan Section of ASCE, it is with great pleasure to provide this nomination package for the Mackinac Bridge to be recognized as a National Historic Civil Engineering Landmark. This nomination package replaces the previous information submitted in January 2009.

After decades of planning, construction began on the bridge in May 1954 and the bridge was opened to traffic on November 1, 1957. The bridge was historically significant to not only the Great State of Michigan but also the nation as a whole, providing a faster connection between the upper and lower peninsulas of Michigan (eliminating up to 36-hour delays with the ferry system), and expanding an international trade route to Canada.

The design and construction of the 'Mighty Mac' was a major engineering accomplishment following the 1940 failure of the original Tacoma Narrows (Gallopin' Gertie) Bridge. Studies of the aerodynamics of the Mackinac suspension bridge by design engineer David B. Steinman showed the design to be able to withstand unrealistic winds loads in excess of 600 mph. Steinman referred to the structure as "100 percent safe aerodynamically".

In 1958, the Mackinac Bridge was dedicated as the world's longest suspension bridge between anchorages, by-passing the Golden Gate Bridge and the suspended western section of the San Francisco – Oakland Bay Bridge. To this day, the Mighty Mac still holds the prestige of being the longest suspension bridge between anchorages in the western hemisphere.

The Mackinac Bridge Authority, owner of the Mackinac Bridge, fully supports this nomination. If you have any questions, please contact us. We look forward to working with you.

Sincerely,

Thomas G. Maxwell, P.E.
President, ASCE Michigan Section
Direct: (248) 454-6349
E-mail: tmaxwell@hrc-engr.com

Tess Ahlborn, PhD, P.E.
Assoc. Professor, Civil & Environmental Eng
Michigan Technological University
Phone: (906) 487-2625
Email: tess@mtu.edu

A nomination package for the

Mackinac Bridge

to be recognized as a

National Historic Civil Engineering Landmark

by the ASCE History and Heritage Program

September 2009

Historic Civil Engineering Landmark Nomination

This form may be printed. Please submit one copy for each committee member of all materials relating to the nomination. If more space is required to provide full response, please include additional documentation.

To: History & Heritage Committee
ATTN: Carol Reese
1801 Alexander Bell Drive
Reston, VA 201914400

Date: Sept 17, 2009 ASCE Section: Michigan

This is to nominate the following for designation as a Historic Landmark: National or Local/State
Mackinac Bridge
Previously nominated for National: Yes No; If Yes, when Spring 2009
Located at: The Straits of Mackinac, connecting the upper and lower peninsulas of Michigan at Mackinac City and St. Ignace County: Mackinac State: Michigan

The latitude and longitude to the nearest minute (or U.T.M. coordinates). Attach detailed local and vicinity maps that show access from a major city or the interstate. 45.8166°N 84.7277°W (Locator map in Section 1)
The proposed landmark's owner: The Mackinac Bridge Authority / State of MI

In support of this nomination the following information must be provided:

1. Date of construction (and other significant dates).

(See SECTION 1)
David B. Steinman selected as Engineer: January 1953
Construction begins: May 7, 1954
Open to traffic: November 1, 1957
100 millionth crossing: June 25, 1998

2. Names of key civil engineer and other professionals associated with project.

(See SECTION 2)
Information is provided for Dr. David B. Steinman and Senator Prentiss M. Brown.

3. Historic (national or local) significance of this landmark.

(See SECTION 3)
The Algonquin Native Americans called the straits and the surrounding area "Michilimackinac", meaning "the jumping-off place" or "great road of departure". Section 3 provides several references regarding the historical significance of the Mackinac Bridge, including historical reports on the proposed crossing, and articles on the bridge opening and 25th and 50th birthday celebrations.

4. Comparable or similar projects, both in the United States and other countries.

(See SECTION 4)
Similar bridges include the Golden Gate Bridge (NHCEL 1984), Verrazano-Narrows Bridge, the George Washington Bridge, the Akashi Kaikyo (Japan) and the Humber Bridge (England). Section 4 includes a list of historical landmark bridges.

5. Unique features or characteristics which set this proposed landmark apart from other civil engineering projects, including those in #4 above.

(See SECTION 5)
Facts and figures, as well as bridge statistics are included in Section 5.

6. Contribution which this structure or project made toward the development of: (1) the civil engineering profession; (2) the nation or a large region thereof (part 2 is necessary for an NHCEL).

(See SECTION 6) – Built with the lessons learned from the Tacoma Narrows Bridge failure in Washington, the Mackinac Bridge was designed to withstand unimaginable conditions, providing testament to what is conceivable by

mankind. Aerodynamic stability reports provided in Section 6 were significant in furthering the knowledge of design for suspension bridges in the civil engineering profession.

7. A list of published references concerning this nomination.

(See SECTION 7) In addition to references noted previously, several additional references are suggested for technical information (but not included herein).

8. A list of additional documentation in support of this nomination. (Please list all enclosed documents, publications, photographs, and supporting historical evidence. Digital images and one 5" x 7" black & white glossy photo are required for publicity and presentation purposes.)

(See SECTION 8) In addition to numerous technical documents about the Mackinac Bridge cited in previous sections, the following references provide detailed documentation of the bridge construction (documentaries), and further the biography of David B. Steinman by providing selected pages from a children's book that he wrote for his grandchildren. Furthermore, nine copies of a CD titled "Mackinac Bridge: Images from Construction to the Present" (MDOT Photography Unit, 517-322-5641) were previously submitted to ASCE in January 2009.

9. The recommended citation for HHC consideration.

The Mackinac Bridge is being nominated for designation as a National Historic Civil Engineering Landmark – SECTION 9.0

10. A statement of the owner's support of the nomination.

An owner's letter of support is included in SECTION 10.

If this nomination is approved for designation as a National Historic Civil Engineering Landmark by the Board of Direction of ASCE, we understand that the Section will have the major responsibility for the public presentation ceremony of the plaque and for plaque maintenance.

Chairman, Section History & Heritage Committee_____

Section Secretary Mike Guter P.E.

Section President Jim G Maxwell P.E.

*Note: For State Historic Civil Engineering Landmark designation, the other Section presidents from the state should sign the nomination form or concur with the nomination in writing. If all Sections affected by the nomination agree on dedicating this landmark, the nominating Section should inform the HHC of their decision and send one (1) copy of the nomination package to the staff contact for the HHC

Note: Designation by ASCE as a National Historic Civil Engineering Landmark carries no legal commitment on the part of ASCE, the owner or the governmental jurisdiction in which it is located.

Section 1

Construction Dates

Built between 1954 and 1957 at a cost of $100,000,000, the Mackinac Bridge took the title of world's longest suspension bridge (between anchorages) from the Golden Gate. Though it has recently surrendered the worldly honor, it maintains the title for the western hemisphere and it long ago secured its place as one of the most impressive engineering feats of the 20th century.

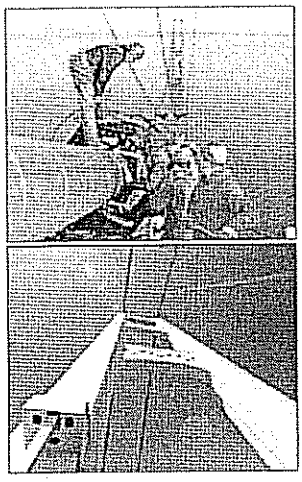
Nine copies of a CD titled "Mackinac Bridge: Images from Construction to the Present" (MDOT Photography Unit, 517-322-5641) were previously submitted to ASCE in January 2009.

While hundreds of sources, from documentaries to tourist guidebooks, are available on the Mackinac Bridge, the following sources summarize some key facts about the bridge and its construction. In particular, the financing and bridge construction was approved by the Michigan Legislature in April 1952. By January 1953, Dr. David B. Steinman was selected as the engineer. Preliminary plans, estimates and contract negotiations were only months later. Bids for the sale of bonds were received by the end of that year, and construction began in May 1954. Three and a half years later, including three hard northern winters in the Straits, the bridge was open to traffic on November 1, 1957.

1. "About the Bridge." *The Mackinac Bridge*. Michigan Department of Transportation. n.d. August, 2009. http://www.mackinacbridge.org
2. Hyde, Charles K. Historic Highway Bridges of Michigan. Detroit: Wayne University Press, 1993. (selected pages)
3. Mackinac Bridge. (2009, September 1) In *Wikipedia, the free encyclopedia*. Retrieved Sept. 2009, fm http://en.wikipedia.org/wiki/Mackinac_Bridge.
4. Rubin, Lawrence A. "The Story of the Mackinac Bridge." Holy Mackinac! January 4, 1983.
5. McMaken, Linda "Building the Mighty Mac." Michigan History: The Mighty Mac at 50. 91 no. 4 (July/August 2007) 36-49.

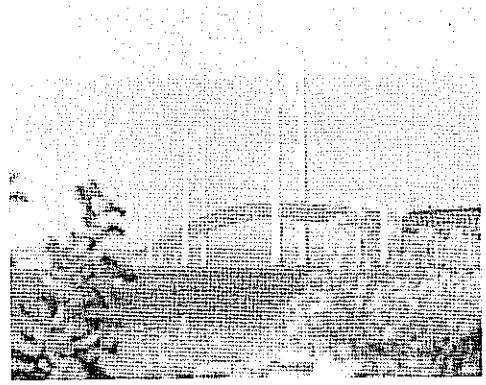
- Not included herein, but also noted are photos from the construction album of the photo gallery found on the Mackinac Bridge web site < http://mackinacbridge.org/historical-construction-album-31/ >

About the Bridge



About the Bridge

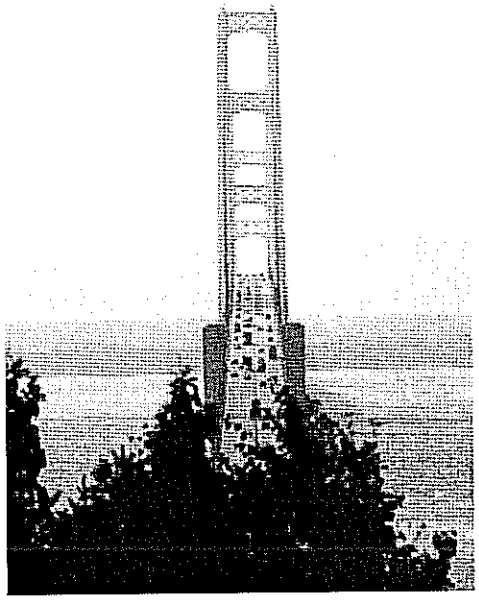
The Mackinac Bridge is currently the third longest suspension bridge in the world. In 1998, the Akashi Kaikyo Bridge in Japan became the longest with a total suspension of 12,826 feet. The Great Belt Bridge in Halsskov-Sprogoe, Denmark, which also opened in 1998, is the second longest suspension bridge in the world with a total suspension of 8,921 feet. The Mackinac Bridge is the longest suspension bridge in the western hemisphere. The total length of the Mackinac Bridge is 26,372 feet. The length of the suspension bridge (including anchorages) is 8,614 feet. The length from cable bent pier to cable bent pier is 7,400 feet. Length of main span (between towers) is 3,800 feet.



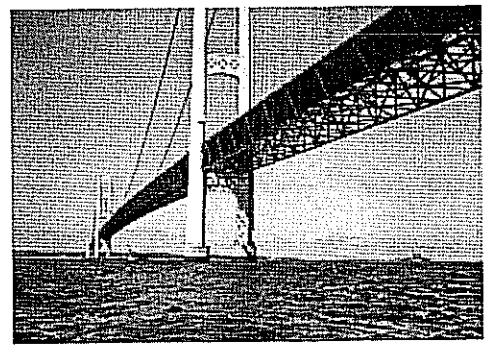
The width of the roadway is 54 feet. The outside lanes are 12 feet wide (2), the inside lanes are 11 feet wide (2), the center mall is 2 feet wide, and the catwalk, curb and rail width is 3 feet on each side - totaling 54 feet. The stiffening truss width in the suspended span is 68 feet wide making it wider than the roadway it supports.

The height of the roadway at mid-span is approximately 200 feet above water level. The vertical clearance at normal temperature is 155 feet at the center of the main suspension span and 135 feet at the boundaries of the 3,000 ft. navigation channel.

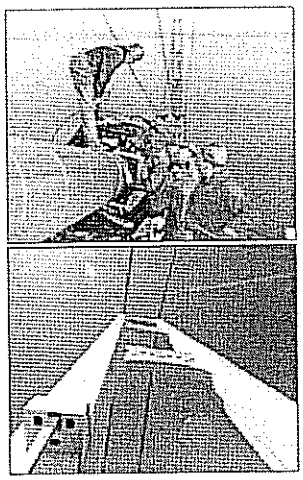
All suspension bridges are designed to move to accommodate wind, change in temperature, and weight. It is possible that the deck at center span could move as much as 35 feet (east or west) due to high winds. This would only happen under severe wind conditions. The deck would not swing or "sway" but rather move slowly in one direction based on the force and direction of the wind. After the wind subsides, the weight of the vehicles crossing would slowly move it back into center position.



The steel superstructure will support one ton per lineal foot per roadway (northbound or southbound). The length of the steel superstructure is 19,243 feet. Each direction will, therefore, support 19,243 tons. The answer is 38,486 tons (2 x 19,243 tons).

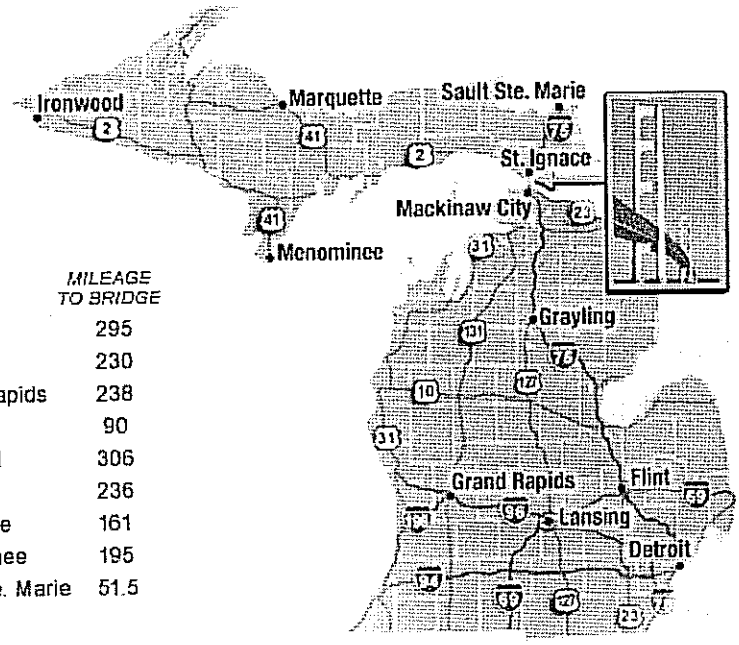


Location

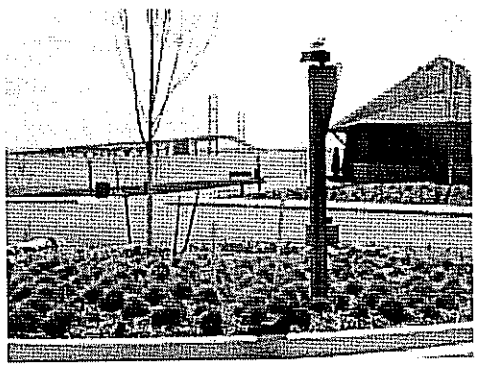


Location

The Mackinac Bridge is located on Interstate 75 in northern Michigan at the Straits of Mackinac. The bridge connects Michigan's upper and lower peninsulas. Mackinaw City is located at the south end of the bridge. St. Ignace is located at the north end of the Mackinac Bridge.



CITY	MILEAGE TO BRIDGE
Detroit	295
Flint	230
Grand Rapids	238
Grayling	90
Ironwood	306
Lansing	236
Marquette	161
Menominee	195
Sault Ste. Marie	51.5

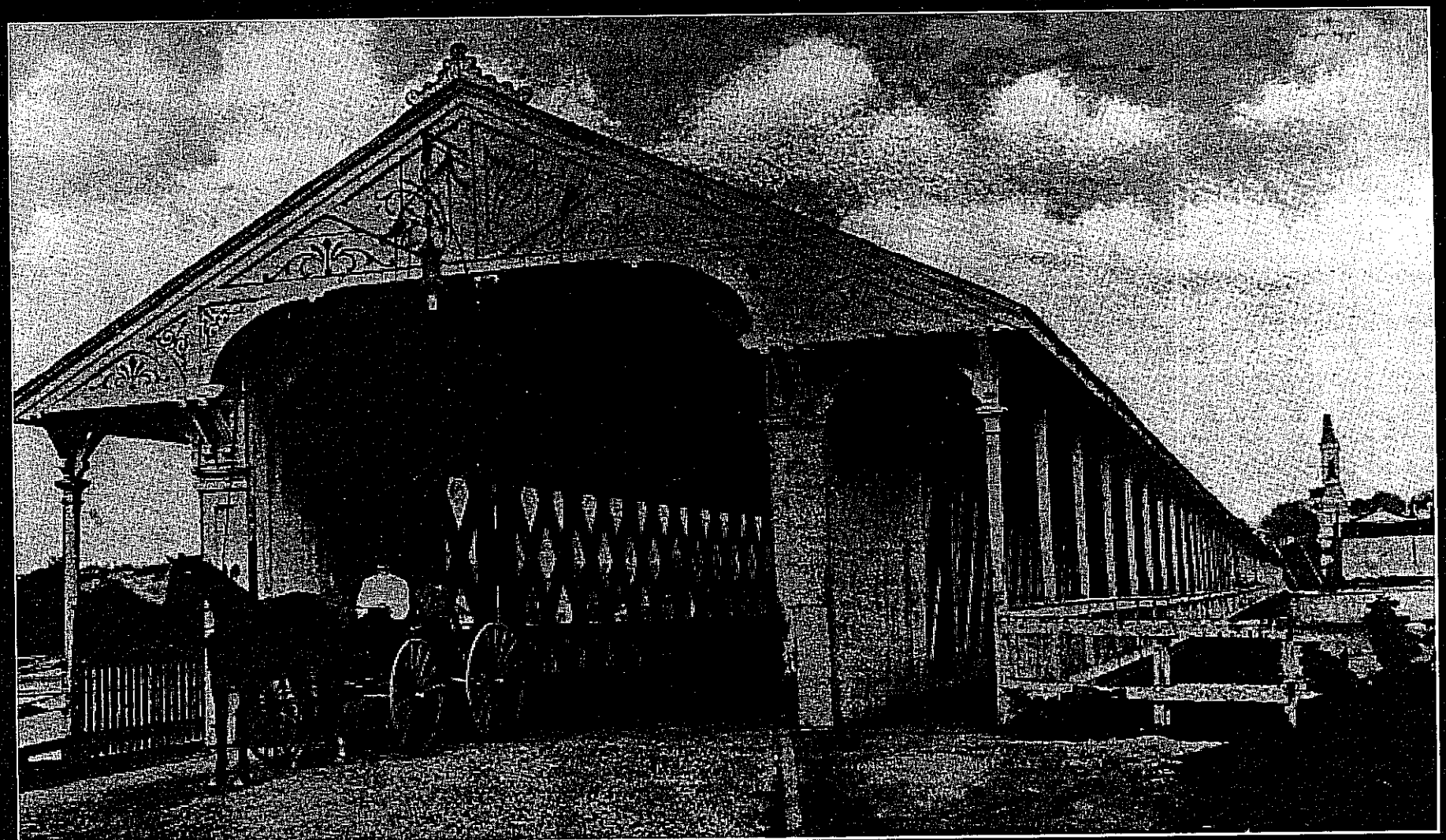


Area attractions include the Fort at Michilimackinac in Mackinaw City, and camping and recreational opportunities on both sides of the bridge.

The Mackinac Bridge Authority opened the eight-acre Bridge View Park on June 12, 2002. The park, on the north side of the bridge, is a spectacular place to view and photograph the "Mighty Mac."

Historic Highway Bridges of Michigan

CHARLES K. HYDE



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Library of Congress Cataloging-in-Publication Data

Hyde, Charles K., 1945–
Historic highway bridges of Michigan / Charles K. Hyde.
p. cm. —(Great Lakes Books)
Includes bibliographical references and index.
ISBN 0-8143-2448-7 (pbk. : alk. paper)
1. Historic bridges—Michigan.. 2. Bridges—Michigan—Design and construction—History. I Title. II. Series.
TG24.M45H93 1993
624'.2'09774—dc20 92-37712

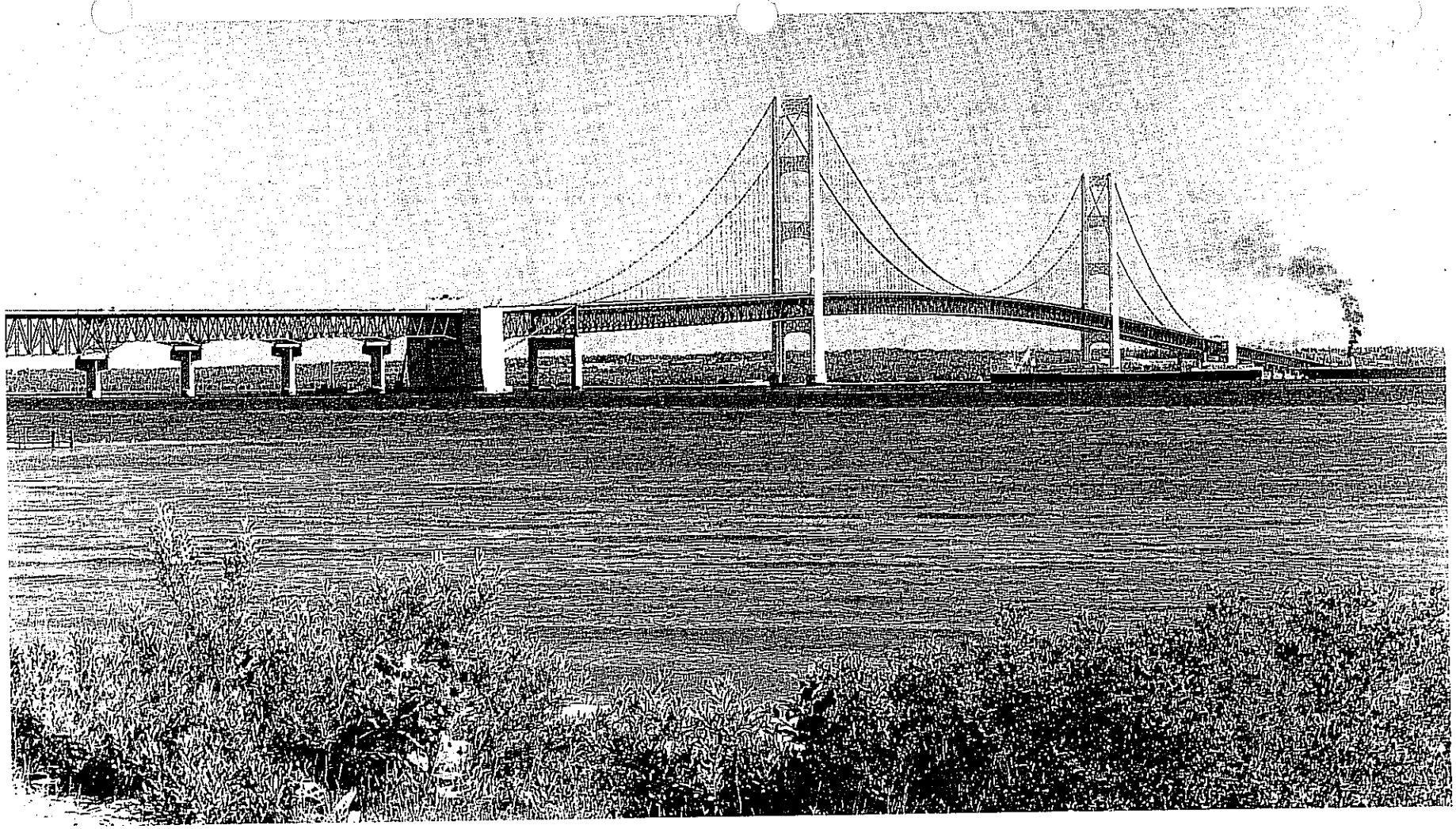
Cover photo: Leonard Street bridge (1879) over the Grand River, Grand Rapids. Courtesy of the State Archives of Michigan.

Back cover photos: Upper left hand corner is the Mortimer E. Cooley Bridge (1934) over the Pine River, Manistee County. Photo courtesy of MDOT. *Lower right hand corner* is a bowstring arch bridge, assembled in downtown Owosso, Shiawassee County, January, 1895. Courtesy of the State Archives of Michigan.

Title page photo spread: Insterstate 75 (Mackinac Straits) Bridge. Courtesy of MDOT.

Special Acknowledgment: Grateful acknowledgment is made to the Mackinac Bridge Authority for financial assistance in the publication of this volume.

Contents



Interstate 75 (Mackinac Straits) Bridge. Courtesy of MDOT.

77 Interstate 75 (Mackinac Straits) Bridge (1958) over the Straits of Mackinac, Emmet and Mackinac counties. This is one of only two suspension bridges built in Michigan. It is one of the monumental suspension bridges of the world, with an total length of 17,918 feet, a center span of 3,800 feet, two side spans of 1,800 feet, and two backstay spans of 472 feet, giving it a total length of 8,614 feet between anchorages, the longest in the world at the time of completion. David B. Steinman designed the bridge for the Mackinac Bridge Authority. The American Bridge Division of the United States Steel Corporation won the steel superstructure contract, while the substructure contract went to the Merritt-Chapman and Scott Corporation of New York City. C. E. Haltenhoff served as the project engineer, while Steinman retained G. B. Woodruff as a consulting engineer. This engineering monument opened to traffic on November 1, 1957, with all work completed in September 1958.

The Houghton-Hancock Bridge is a double-deck structure, with a four-lane roadway on the upper deck and railroad tracks on the lower deck. The bridge has a total length of 1,310 feet, with a lift span 268 feet long, supported by twin steel towers 180 feet tall. When trains use the bridge, it remains in its lowest position, and highway traffic uses the automobile level. When the railroads are not using the bridge, the operator leaves the structure in an intermediate position, with vehicular traffic using the railroad deck, allowing small boats to pass underneath. For the passage of large ships, the main span can be raised to provide clearance of 104 feet. Portage Lake is part of the Keweenaw Waterway, which bisects the Keweenaw Peninsula and offers Great Lakes vessels a sheltered passage from storms, especially the gales of November.

International Bridge

A railroad bridge linked the twin cities of Sault Ste. Marie in Michigan and Ontario in 1887, but ferries carried automobile traffic over the St. Mary's River, which divided the two cities until this bridge opened in 1962. The government of Ontario and the Michigan state legislature created the International Bridge Authority in 1935 to plan and finance a highway bridge, but nearly one-quarter of a century passed before construction began. The New York engineering firm of Steinman, Boyton, Gronquist, and London designed this structure, which cost $20 million.

This was an ambitious project because the bridge crossed two navigation canals, one on each side of the international boundary, and the St. Mary's River. The main segment, which rests on sixty-two concrete piers, is 9,280 long, the American approach is 2,471 feet in length, and the Canadian approach spans are 2,942 feet long; thus, the two-lane bridge is nearly three miles long. The most impressive part of the structure is the four-span cantilevered truss, some 1,260 feet long, over the American canal. To avoid interrupting ship traffic, the contractor built the main truss segment without falsework through the balanced addition of steel members as work progressed. The Canadian crossing has a simpler truss span 830 feet long. The entire bridge required 114,000 tons of concrete and 11,000 tons of structural steel for completion.

Mackinac Straits Bridge

The five-mile stretch of water separating Michigan's two peninsulas, the result of glacial action some twelve thousand years ago, has long served as a major barrier to the movement of people and goods. The three railroads that reached the Straits of Mackinac in the early 1880s, the Michigan Central and the Grand Rapids & Indiana Railway from the south, and the Detroit, Mackinac and Marquette from the north, jointly established the Mackinac Transportation Company in 1881 to operate a railroad car ferry service across the straits. The railroads and their shipping lines developed Mackinac Island

into a major vacation destination in the 1880s, an effort that culminated with opening the Grand Hotel on the island in 1887. One of the hotel's directors, Commodore Cornelius Vanderbilt, observed on July 1, 1888: "What this area needs is a bridge across the Straits."

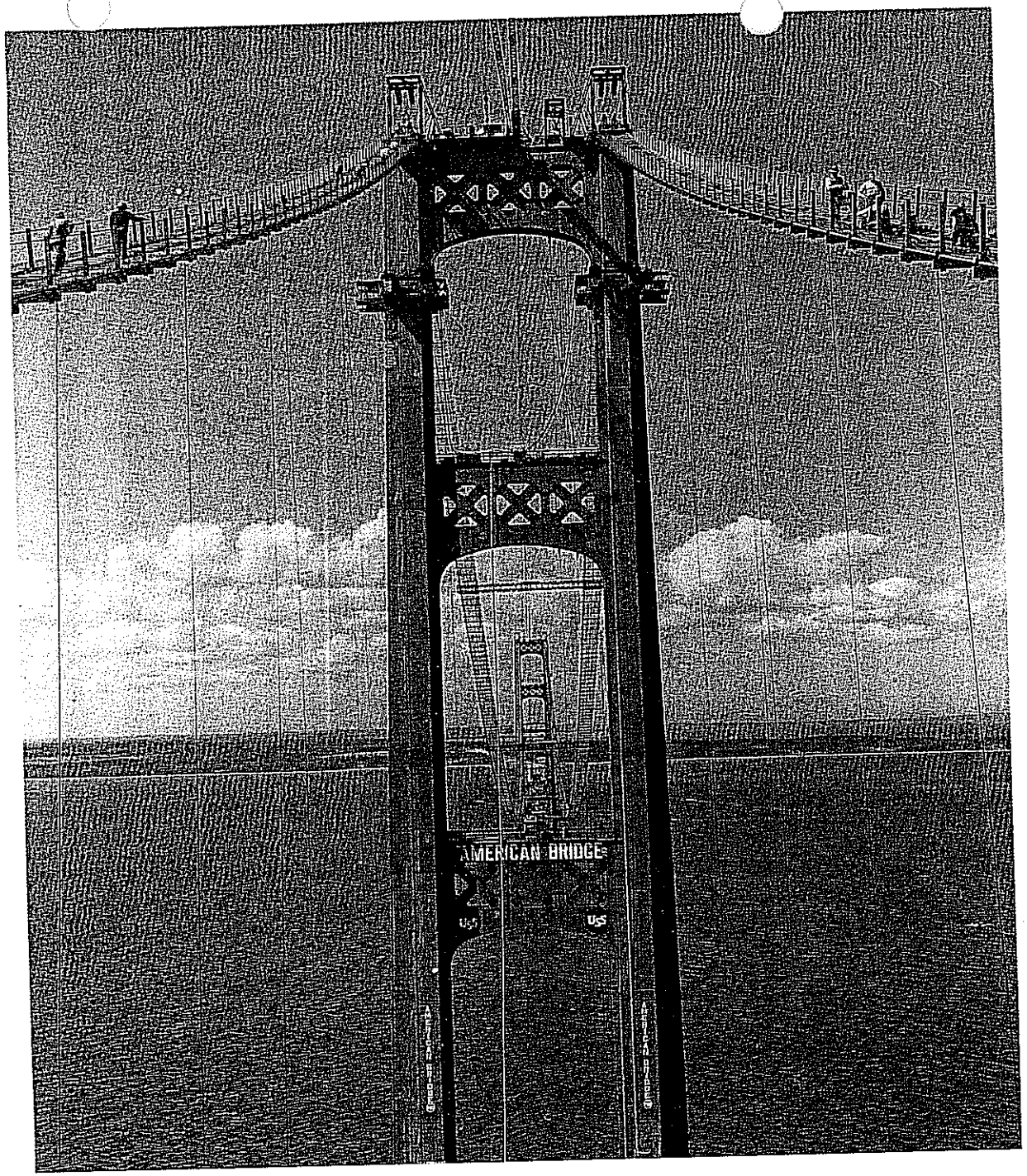
Improved highways along the eastern shores of Michigan's lower peninsula brought increased automobile traffic to the straits region starting in the 1910s. The state of Michigan initiated an automobile ferry service between St. Ignace and Mackinaw City in 1923 and eventually operated eight ferry boats. In peak travel periods, particularly during deer season, five mile backups and delays of four hours or longer became common at the state docks at Mackinaw City and St. Ignace.

With increased public pressure to break this bottleneck, the Michigan legislature, with Governor William A. Comstock's approval, established a Mackinac Straits Bridge Authority in 1934, with the power to issue bonds for bridge construction. Prentiss M. Brown served as the authority's legal counsel. The bridge authority supported a proposal first developed in 1921 by Charles Evan Fowler, the bridge engineer who had previously promoted a Detroit-Windsor bridge. Fowler's plans called for an island-hopping route from the city of Cheboygan to Bois Blanc, Round, and Mackinac islands, thence to St. Ignace, along a twenty-four-mile route. The bridge authority requested loans and grants from the federal Public Works Administration (PWA) in August 1934 for the project, which the PWA flatly rejected eleven months later.

The Mackinac Bridge Authority then hired Francis C. McMath and James E. Cissell to draw up a plan for a direct crossing from Mackinaw City to St. Ignace and submitted this to the PWA in September 1935. Chase Osborne, a former Michigan governor, asked President Franklin D. Roosevelt to support a Mackinac bridge. Roosevelt requested the Army Corps of Engineers study the idea and the Army Corps reported that a bridge was technically and economically feasible. The PWA nevertheless rejected the bridge authority's request for funding.

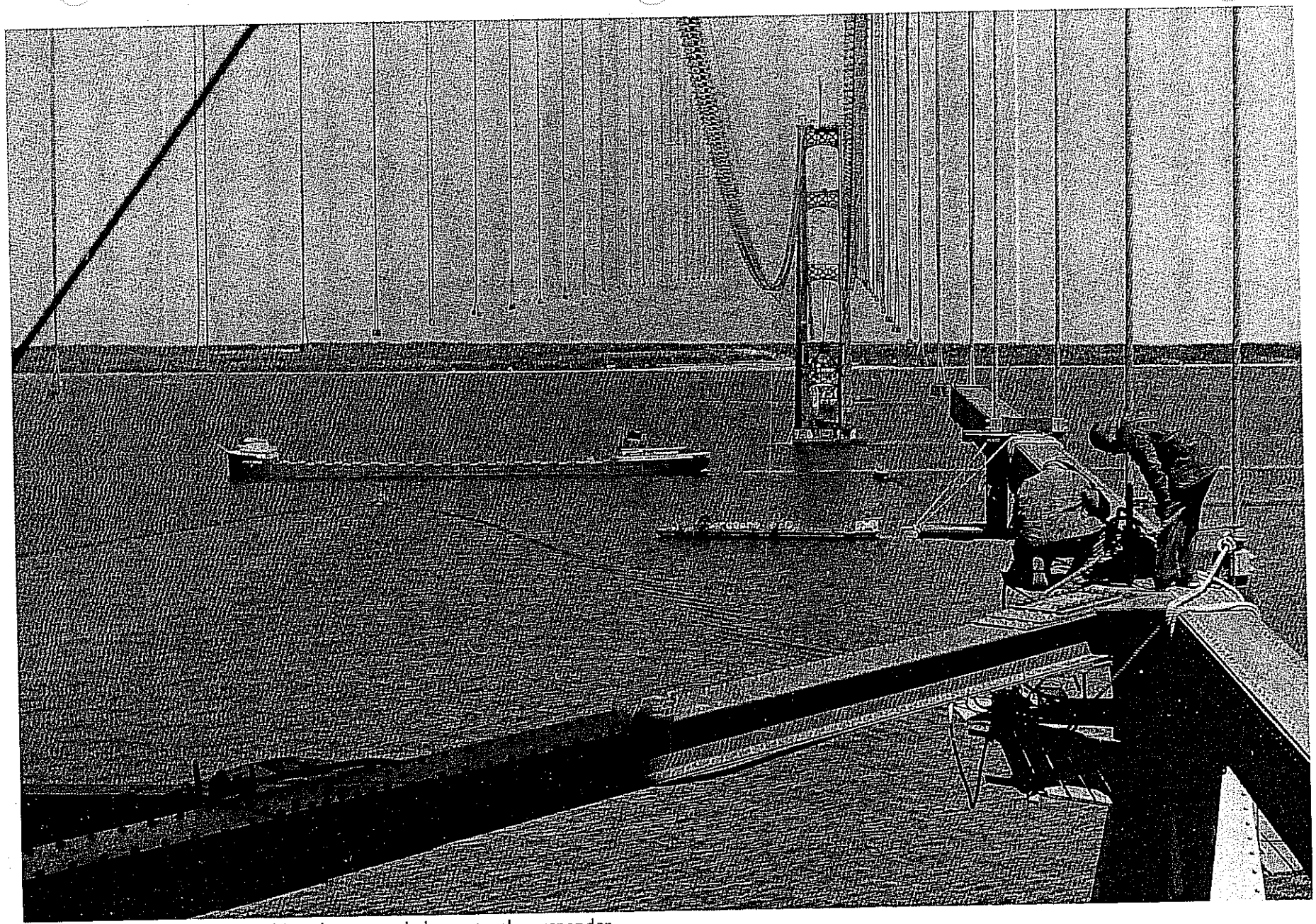
In 1938, the bridge authority engaged Fred Masters of the prominent engineering firm of Modjeski and Masters to develop a new design proposal. Masters hired Leon S. Moisseiff, who in 1940 submitted a plan for a suspension bridge with a main span of 4,600 feet. This was simply a larger version of Moisseiff's ill-fated Tacoma Narrows Bridge in Washington State, a structure destroyed by high winds on November 7, 1940. Although that disaster delayed any further action, the activities of 1938–1940 nevertheless produced some important results. The bridge authority conducted a series of soundings and borings across the straits and built a causeway extending out 4,200 feet from the St. Ignace shore. The Second World War ended any additional work, and the Legislature abolished the bridge authority in 1947.

William Stewart Woodfill, president of the Grand Hotel on Mackinac Island, almost singlehandedly resuscitated the dream of a bridge across the Straits of Mackinac. Woodfill formed the statewide Mackinac Bridge Citizens Committee in 1949 to lobby for a new bridge authority, which the legislature

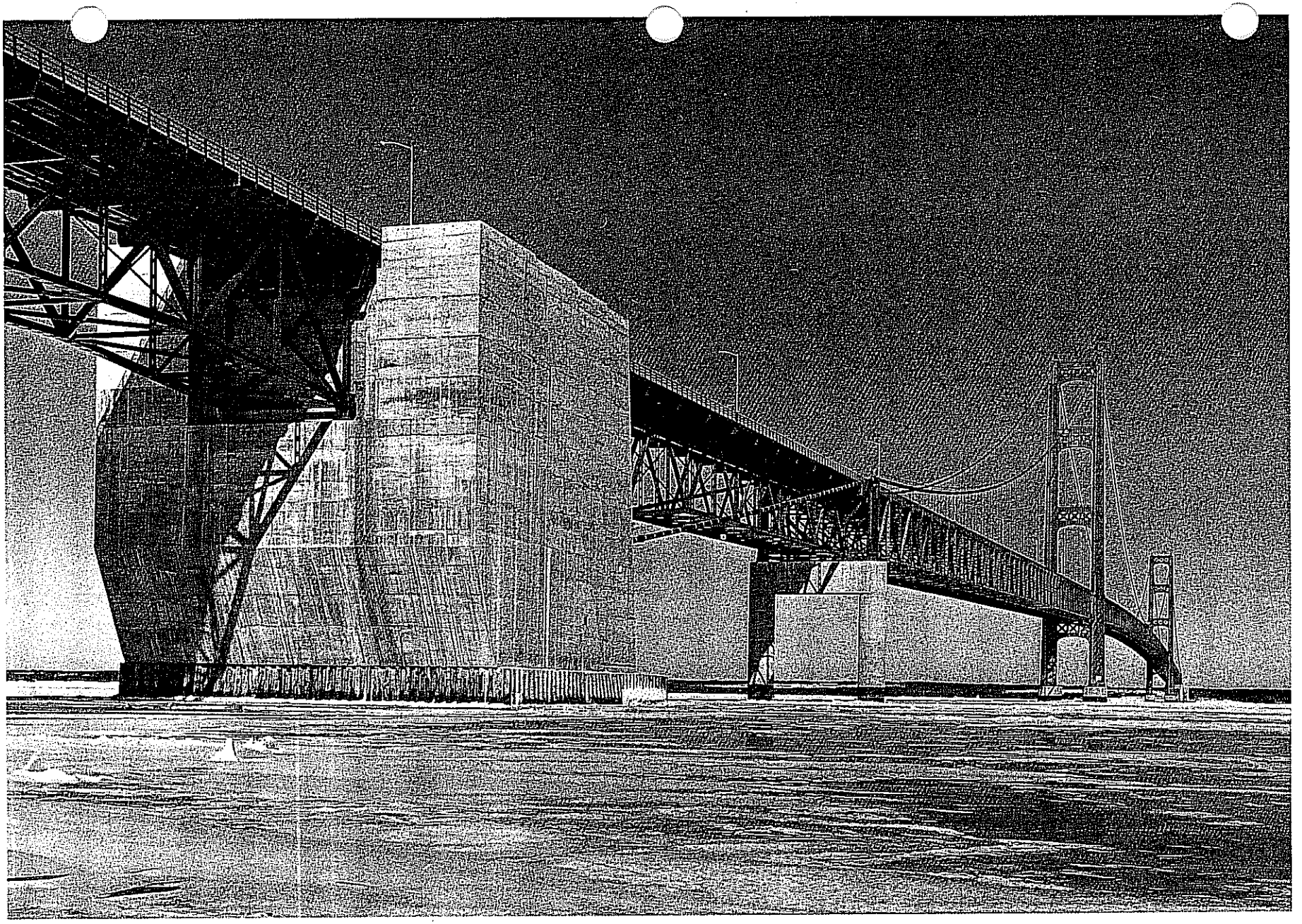


Mackinac Straits Bridge. Temporary ca[illegible]s in place, early in the 1956 construction season, before the stringing of the main suspension cables. Courtesy of State Archives of Michigan.

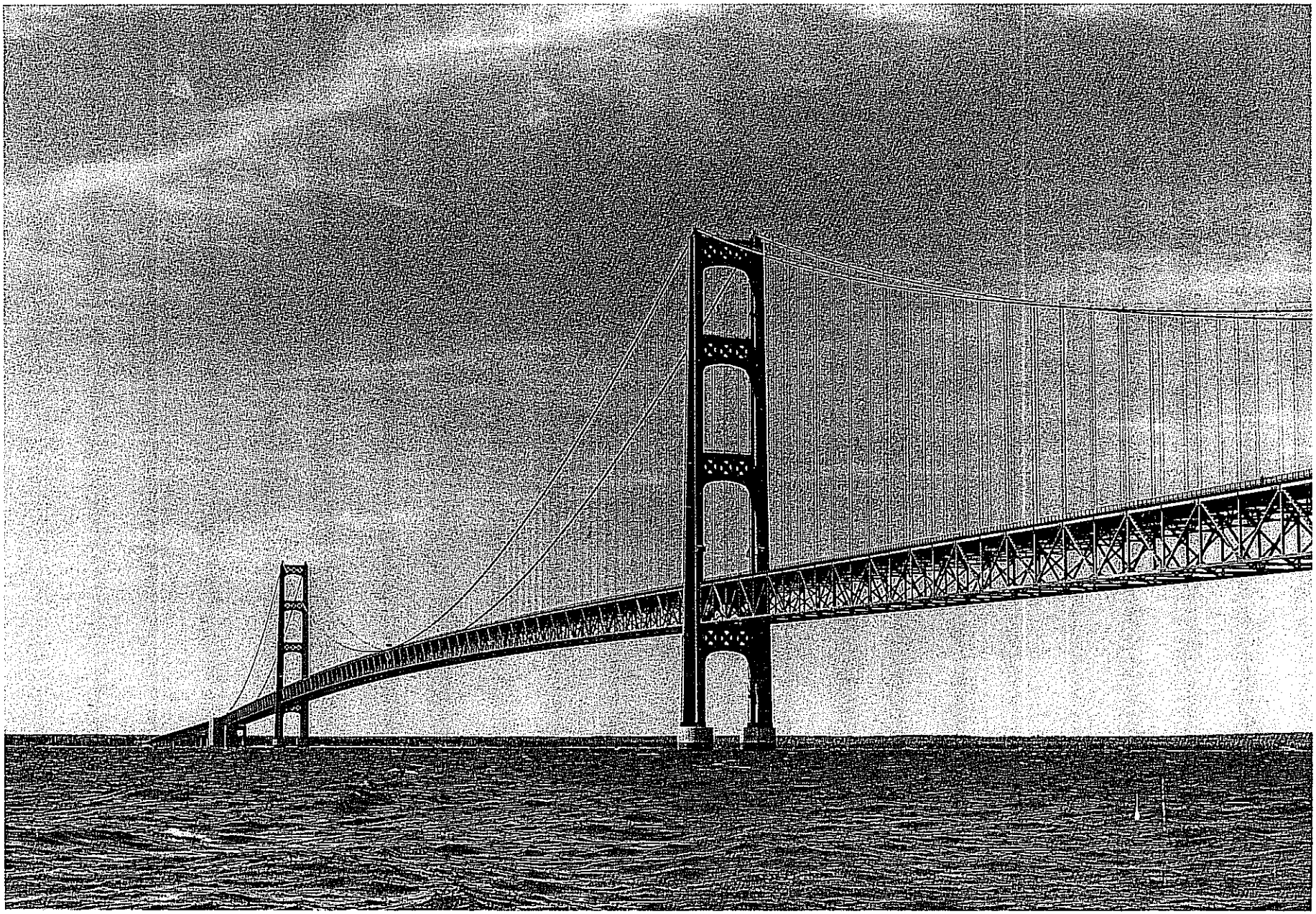
created in 1950. Governor G. Mennen ("Soapy") Williams appointed State Senator Prentiss M. Brown as chairman of the new Mackinac Bridge Authority. A panel of three prominent engineers—Othmar H. Ammann, David B. Steinman, and Glenn B. Woodruff—conducted a feasibility study and made recommendations to the bridge authority on the location, structure, and design of the bridge. The State Highway Department, which had just placed a $4.5 million ferryboat, *Vacationland,* into service at the straits in January 1952, remained hostile to the bridge plan. In April 1952, the Michigan legislature authorized the bridge authority to issue bonds for the project, choose an engineer, and proceed with construction. The authority selected David B. Steinman as the chief engineer in January 1953 and tried unsuccessfully to sell the bridge bonds in April 1953, but by the end of the year, the authority had sold the $99.8 million in revenue bonds needed to begin construction.



Mackinac Straits Bridge. Attaching the suspended span to the suspender cables, hanging from the main cables, early in the 1957 construction season. Courtesy of State Archives of Michigan.



Mackinac Straits Bridge. From left to right, the massive concrete anchorage, backstay span, side span, and main suspended span.
Courtesy of State Archives of Michigan.



Mackinac Straits Bridge. Photograph of nearly completed bridge, May 21, 1958.
Courtesy of State Archives of Michigan.

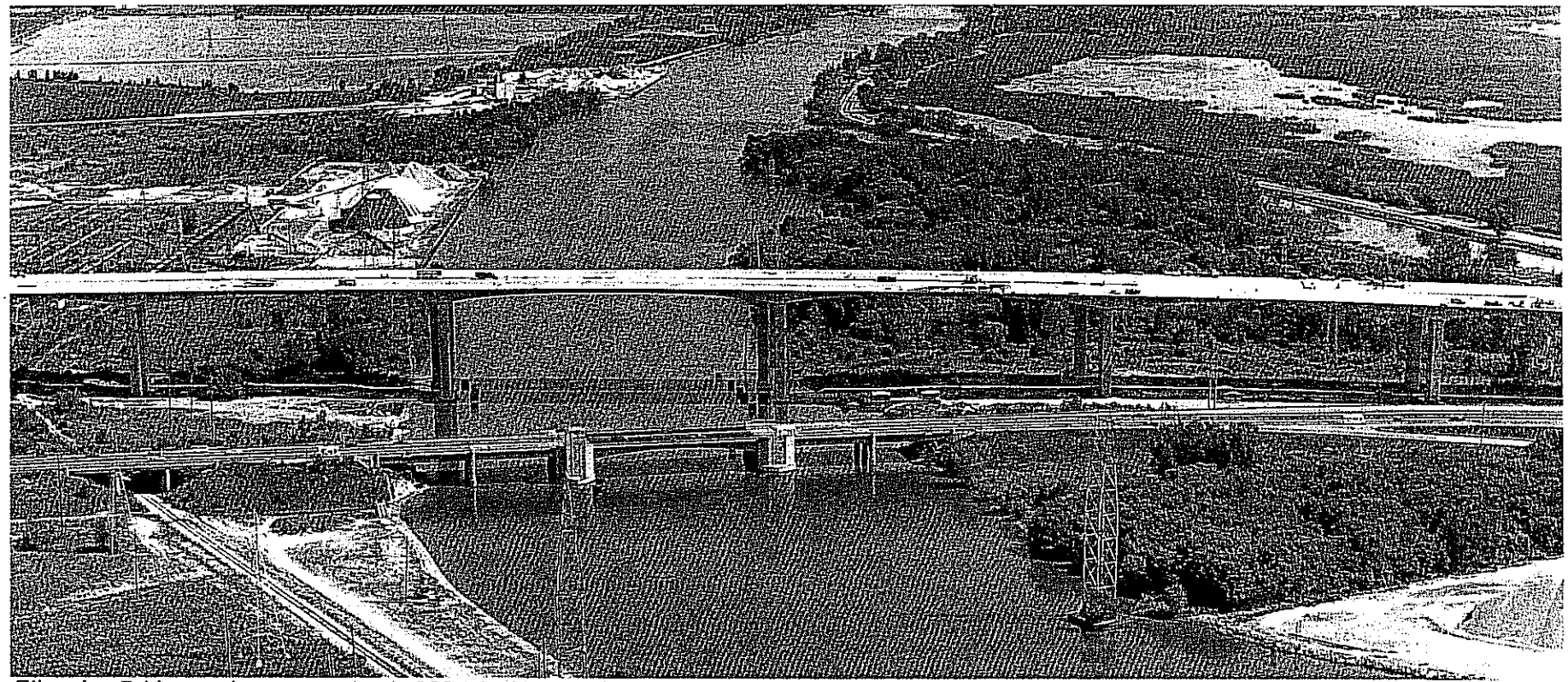
Besides selecting Steinman, the bridge authority awarded two major contracts—one to the Merritt-Chapman and Scott Corporation of New York for all substructure work, in the amount of $25.7 million, while the second contract went to the American Bridge Division of the U.S. Steel Corporation for the steel superstructure, in the amount of $44.5 million. During construction, Grover C. Denny served as project manager for substructure work, and C. E. Haltenhoff was the project engineer. Steinman retained Glenn Woodruff as a special consulting engineer and J. W. Kinney as his resident engineer.

The major construction achievement of 1954 was the erection of the bridge's six principal piers, including those for the two towers, the anchorages, and the backstay spans. Merritt-Chapman sank enormous steel caissons into the mud under the straits and then drove them to bedrock. After removing all the mud and loose rock, Merritt-Chapman poured the enormous reinforced-concrete piers, which extended to bedrock, more than 200 feet below the water surface. In 1955, Merritt-Chapman built the remaining twenty-eight piers and completed the anchorage, while American Bridge built the two main towers and installed the backstay spans. The Mackinac Bridge began to take shape in 1956, when American Bridge strung the main cables and built the twenty-eight truss spans that made up the approaches.

The four-year construction effort ended in 1957, with the erection of the main suspension span and paving of the roadway. The new bridge opened to traffic on November 1, 1957, although the contractors did not complete all the work until September 1958. The official bridge dedication ceremonies began on June 25, 1958, when Governor Williams completed the first "Governor's Walk" across the bridge, and ended four days later. The faith and hard work of men such as Prentiss M. Brown, G. Mennen Williams, and David Steinman finally produced results.

The annual Mackinac Bridge Walk began as a walking race sanctioned by the International Walkers Association. The first walk, in June 1958, involved only sixty walkers including Governor Williams. Later bridge walks took place on Labor Day and the number of participants increased rapidly from about 2,500 in 1962 to more than 15,000 in 1966–1968. After Williams's walk, the next governor to participate was George Romney in 1966. Since then, the bridge walk has become a mandatory political event for governors and gubernatorial candidates. In 1970, more than 20,000 completed the walk and the numbers reached 70,000 in 1990. The Mackinac Bridge Walk is as much an integral part of Labor Day in Michigan as parades and picnics.

The sheer size and beauty of the Mackinac Straits Bridge still impress first-time viewers—a main suspension span of 3,800 feet, two sidespans of 1,800 feet, and two backstay spans of 472 feet each, giving the bridge a total length between anchorages of 8,614 feet, the longest in the world. The total length of the steel superstructure is 19,205 feet, while the total length of the bridge, with approaches, is 26,444 feet, slightly more than five miles. The towers stand 552 feet above the water line, and the bridge provides 155 feet of clearance at



Zilwaukee Bridge, under construction in 1987, looking north, up the Saginaw River. The new bridge dwarfs the older bascule bridge (1960) in the foreground. Courtesy of MDOT.

midspan. Each of the two main cables, with 348 galvanized steel wires, is 25.25 inches in diameter and consists of 37 strands. The main cables contain 12,580 miles of wire, with a total weight of 11,840 tons.

Zilwaukee Bridge

This structure replaced a four-lane double-leaf bascule bridge (drawbridge) completed in 1960 to carry Interstate 75 over the Saginaw River. From its opening day the Zilwaukee drawbridge caused serious problems for traffic on both I-75 and the Saginaw River. The drawbridge provided a narrow channel of only 150 feet at a point where the Saginaw River turns sharply, creating a significant hazard to navigation. Over the years, several ships have struck the bridge or its protective pilings and occasionally forced the closing of I-75. To make matters worse, ship traffic on the Saginaw River increased fourfold in the 1960s and early 1970s. The more serious problem was the disruption of traffic on I-75 every time the bridge opened. Since its original construction, traffic greatly exceeded projections; thus, this problem became severe, especially on holiday weekends, when four-hour delays at the bridge were not uncommon. One of only two drawbridges on the entire interstate highway system, it was the worst bottleneck and hazard on the entire 1,800 miles of Interstate 75.

The Michigan Department of Transportation decided to build a replacement high-level bridge just north of the drawbridge, a decision approved by the Federal

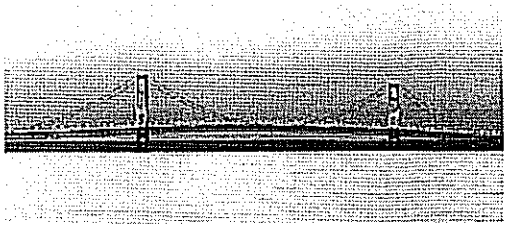
Mackinac Bridge

Coordinates: 45.816558333°N 84.72769444°W

From Wikipedia, the free encyclopedia

The **Mackinac Bridge** (pronounced /ˈmækɨnɔː/, approximately mack-in-awe), is a suspension bridge spanning the Straits of Mackinac to connect the non-contiguous Upper and Lower peninsulas of the U.S. state of Michigan. Envisioned since the 1880s, the bridge was completed only after many decades of struggles to begin construction. Designed by engineer David B. Steinman, the bridge (familiarly known as **"Big Mac"** and **"Mighty Mac"**) connects the city of St. Ignace on the north end with the village of Mackinaw City on the south. It is the longest suspension bridge between anchorages in the Western hemisphere.

Mackinac Bridge



AKA	*Mighty Mac* or *Big Mac*
Carries	4 lanes of I-75
Crosses	Straits of Mackinac
Locale	Mackinaw City and St. Ignace, Michigan
Maintained by	Mackinac Bridge Authority[1]
Design	Suspension bridge
Longest span	3,800 feet (1,158 m)
Total length	26,372 feet (8,038 m)
Width	68.6 feet (20.9 m) (total width)[2] 54 feet (16 m) (road width) 38.1 feet (11.6 m) (depth)[2]
Height	522 feet (159 m)
Vertical clearance	200 feet (61 m)
Clearance below	155 feet (47 m)
AADT	11,600
Opening date	November 1, 1957
Toll	$1.50 per axle for passenger vehicles ($3.00 per car). $3.50 per axle for motor homes. $3.50 per axle for commercial vehicles.[3]

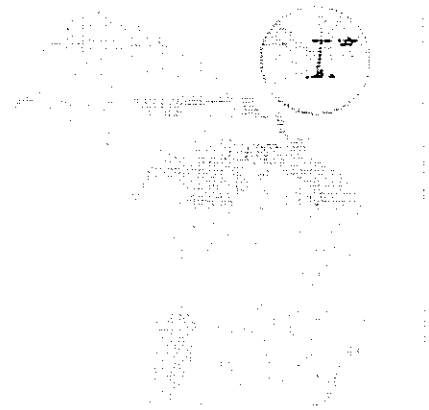
Contents

Length

The bridge opened on November 1, 1957, ending decades of the two peninsulas being solely linked by ferries. A year later, the bridge was formally dedicated as the world's longest suspension bridge between anchorages. This designation was chosen because the bridge would not be the world's largest using another way of measuring suspension bridges, the length of the center

span between the towers; at the time that title belonged to the Golden Gate Bridge, which has a longer center span. By saying "between anchorages", the bridge could be considered longer than the Golden Gate Bridge and also longer than the suspended western section of the San Francisco – Oakland Bay Bridge. (That bridge has a longer total suspension but is a double bridge with an anchorage in the middle.)

Connects: **Mackinaw City and St. Ignace**



Coordinates 45.816558333°N 84.72769444°W

At 8,614 feet (2,626 m), the Mackinac Bridge is the longest suspension bridge with two towers between anchorages in the Western Hemisphere.[4] Much longer anchorage-to-anchorage spans have been built in the Eastern Hemisphere, including the Akashi-Kaikyo Bridge in Japan (12,826 feet (3,909 m)). However, because of the long leadups to the anchorages on the Mackinac, from shoreline to shoreline it is much longer at 5 miles (8.0 km) than the Akashi-Kaikyo (2.4 miles (3.9 km)).

The length of the bridge's main span is 3,800 feet (1,158 m), which makes it the third-longest suspension span in the United States and twelfth longest worldwide.

History

The Algonquin Native Americans called the straits and the surrounding area "Michilimackinac", meaning "the jumping-off place" or "great road of departure". These Native Americans moved around the straits rather than crossing them. The straits were the end of the trail.[5]

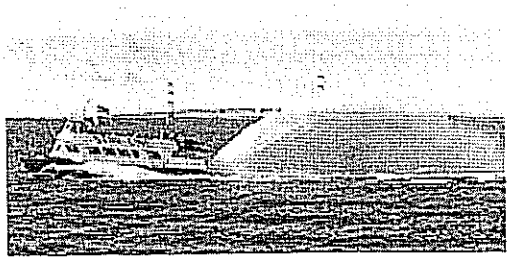
As Europeans settled in the area, the straits became an important area for trade and commerce. The clean air, abundant fish, and beautiful views attracted people from all over the area to the straits. Still, the only way to cross was by ferry.

Typically, a fleet of nine ferries could carry as many as 9,000 vehicles per day. Traffic backups sometimes stretched 16 miles (26 km) to Cheboygan, Michigan. Year-round boat service across the straits had been abandoned as impractical because of the cold winters that would often freeze the water across the entire strait. After the opening of the Brooklyn Bridge in 1883, local residents began to imagine that such a structure could span the straits. In 1884, a store owner in St. Ignace published a newspaper advertisement that included a reprint of an artist's conception of the Brooklyn Bridge with the caption "Proposed bridge across the Straits of Mackinac".

The idea of the bridge was discussed in the Michigan Legislature as early as the 1880s. At the time, the area was becoming a popular tourist destination, including the creation of Mackinac National Park on Mackinac Island in 1875.

Despite the perceived necessity for the bridge, several decades elapsed with no formal plan. In 1920, the Michigan state highway commissioner advocated the construction of a floating tunnel across the straits. At the invitation of the state legislature, C. E. Fowler of New York City put forth a plan for a long series of causeways and bridges across the straits from Cheboygan, 17 miles (27 km) southeast of Mackinaw City, to St. Ignace, using Bois Blanc, Round, and Mackinac Island as intermediate steps.

In 1923, the state legislature ordered the State Highway Department to establish ferry service across the strait. More and more people used ferries to cross the straits each year, and as they did, momentum to create a bridge grew even stronger. Chase Osborn, a former governor, wrote, "Michigan is unifying itself, and a magnificent new route through Michigan to Lake Superior and the Northwest United States is developing, via the Straits of Mackinac. It cannot continue to grow as it ought with clumsy and inadequate ferries for any portion of the year."[5]



A Mackinac Island ferry passing in front of the Mackinac Bridge.

By 1928, the ferry service had become so popular and so expensive to operate that Michigan Governor Fred Green ordered the department to study the feasibility of building a bridge across the strait. The department deemed the idea feasible, estimating the cost at $30 million.

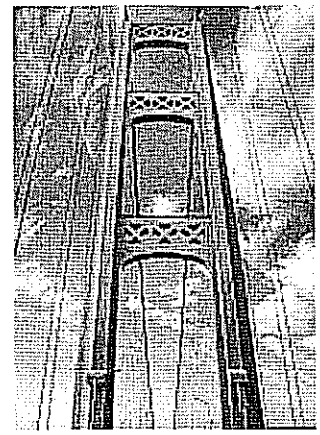
In 1934, the Michigan Legislature created the *Mackinac Straits Bridge Authority* to explore possible methods of constructing and funding the proposed bridge. The Legislature authorized the Authority to seek financing for the project. In the mid 1930s, the Authority twice attempted to obtain federal funds for the project but was unsuccessful, despite the endorsement of the United States Army Corps of Engineers and President Franklin D. Roosevelt. Nevertheless, between 1936 and 1940, a route was selected for the bridge, and borings were made for a detailed geological study of the route.

The preliminary plans for the bridge featured a 3-lane roadway, a railroad crossing on the underdeck of the span, and a center-anchorage double-suspension bridge configuration similar to the design of the San Francisco – Oakland Bay Bridge. Because this would have required sinking an anchorage pier in the deepest area of the Straits, the practicality of this design may have been questionable. A concrete causeway, approximately 4,000 feet (1,219 m), extending from the northern shore, was constructed in shallow water from 1939 to 1941. At that time, with funding for the project still uncertain, further work was put on hold because of World War II. The *Mackinac Straits Bridge Authority* was abolished by the state legislature in 1947, but the same body created a new Mackinac Bridge Authority three years later in 1950. In June 1950, engineers were retained for the project. After a report by the engineers in January 1951, the state legistature authorized the sale of $85 million in bonds for bridge construction on April 30, 1952. However, a weak bond market in 1953 forced a delay of more than a year before the bonds could be issued.

G. Mennen Williams was governor during the construction of the Mackinac Bridge. He began the tradition of the governor leading the Mackinac Bridge Walk across it every Labor Day.[6]

Engineering and construction

David B. Steinman was appointed as the design engineer in January 1953. By the end of 1953, estimates and contracts had been negotiated, and construction began on May 7, 1954. The American Bridge Division of United States Steel Corporation was awarded a contract of more than $44 million to build the steel superstructure.


A closer look at the north tower of the bridge

Construction, which utilized the 1939-41 causeway, took three and a half years (four summers, no winter construction) at a total cost of 100 million dollars and the lives of five men who worked on the bridge. It opened to traffic on schedule on November 1, 1957, and was formally dedicated on June 25, 1958. The bridge officially achieved its 100 millionth crossing exactly forty years after its dedication, on June 25, 1998.

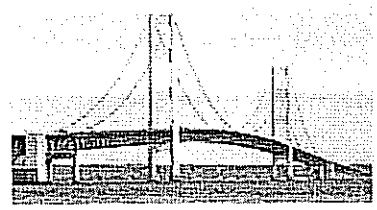
The 50th anniversary of the bridge's opening was celebrated in a ceremony hosted by the Mackinac Bridge Authority at the viewing park adjacent to the St. Ignace causeway on November 1, 2007.

History of bridge design

The design of the Mackinac Bridge was directly influenced by the lessons of the first Tacoma Narrows Bridge, which failed in 1940 because of its instability in high winds. Three years after that disaster, Steinman had published a theoretical analysis of suspension-bridge stability problems, which recommended that future bridge designs include deep stiffening trusses to support the bridge deck and an open-grid roadway to reduce its wind resistance. Both of these features were incorporated into the Mackinac Bridge. The stiffening truss is open to reduce wind resistance. The road deck is shaped as an airfoil to provide lift in a cross wind, and the center two lanes are open grid to allow vertical (upward) air flow, which fairly precisely cancels the lift, making the roadway stable in design in winds up to 150 miles per hour (240 km/h).

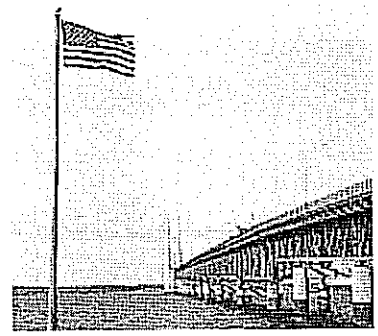
Facts and figures

The Mackinac Bridge is currently a toll bridge on Interstate 75. Prior to the coming of I-75, the bridge carried US 27. It is one of only two segments of I-75 that is tolled; the other is Alligator Alley in Florida. The current toll is $3.00 for automobiles and $3.50 per axle for trucks. The Mackinac Bridge Authority has proposed raising the rate to $4 for cars and $5 per axle for trucks to fund a $300 million renovation program, which would include completely replacing the bridge deck.[7]



Every Labor Day, two of the lanes of the bridge are closed to traffic and open to walkers for the Mackinac Bridge Walk.

Painting of the bridge takes seven years, and when painting of the bridge is complete, it begins again.



View of the bridge looking north across the Straits of Mackinac

- Length from cable bent pier to cable bent pier: 7,400 feet (2,256 m).
- Total width of the roadway: 54 feet (16.5 m)

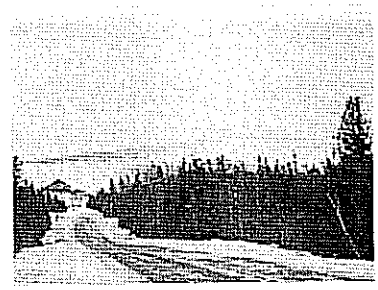
  Two outside lanes: 12 feet (3.7 m) wide each
  Two inside lanes: 11 feet (3.4 m) wide each
  Center mall: 2 feet (0.61 m)
  Catwalk, curb and rail width: 3 feet (0.91 m) on each side

- Width of stiffening truss in the suspended span: 68 feet (20.7 m).
- Depth of stiffening truss: 38.1 feet (11.6 m)[2]
- Height of the roadway at mid-span: approximately 200 feet (61 m) above water level.
- Vertical clearance at normal temperature:

  155 feet (47 m) at the center of the main suspension span.
  135 feet (41 m) at the boundaries of the 3,000 feet (914 m) wide navigation channel.

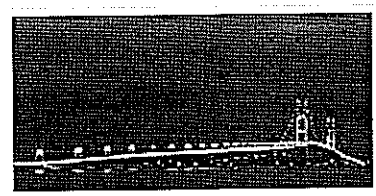
Mackinac Bridge at night

- Construction cost: $99.8 million (1957 USD; adjusted for inflation, approximately $732 million, 2007 USD)
- Height of towers above water: 552 feet (168 m)
- Max. depth of towers below water: 210 feet (64 m)
- Total length of wire in main cables: 42,000 miles (68,000 km).
- Total vehicle crossings, 2005: 4,236,491 (average 11,608 per day)
- Speed limit: 45 miles per hour (72 km/h) for passenger cars, 20 miles per hour (32 km/h) for heavy trucks. Heavy trucks are also required to leave 500 feet (150 m) spacing ahead.



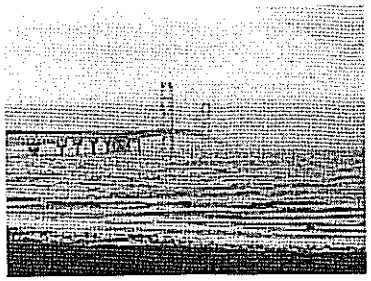
Mackinac Bridge during a snowstorm(Picture taken from a road that leads up to the Bridge View Park).

Work and major accident fatalities



Another picture of Mackinac Bridge at night

Five workers died during the construction of the bridge.


The Mackinac Bridge during a thunderstorm

- Twenty-eight-year old Jack Baker and Robert Koppen died in a catwalk collapse near the north tower on June 6, 1956. Koppen's body was never recovered. For both it was their first day on the job.
- Diver Frank Pepper ascended too quickly from a depth of 140 feet (43 m) on September 10, 1957. Despite being rushed to a decompression chamber, the forty-six-year old died from the bends.
- Twenty-six-year old James LeSarge lost his balance on October 10, 1954, and fell into a caisson. He fell 40 feet (12 m) and likely died of head injuries caused by impact with the criss-crossing steel beams inside the caisson.
- Albert Abbott died on October 25, 1954. The forty-year old fell four feet (1.2 m) into the water while working on an 18 inch (46 cm) wide beam. Witnesses speculate he suffered a heart attack.

All five men are memorialized on a plaque near the bridge's southern end. Contrary to folklore, no bodies are embedded in the concrete.[8][9]

One worker has died since the bridge was completed.

- Daniel Doyle fell 60 to 70 feet (18 to 21 m) from a scaffolding on August 7, 1997. He survived the fall but fell victim to the 50 °F (10 °C) water temperature. His body was recovered the next day in 95 feet (29 m) of water.

Two vehicles have fallen off the bridge.

- Leslie Anne Plouhar died in 1989 when her 1987 Yugo plunged over the 36 inches (91 cm) high railing. A combination of high winds and excessive speed was blamed.[10]
- In March 1997, a 1996 Ford Bronco went over the edge. It was later determined to be a suicide by driver Richard Alan Daraban.[11]

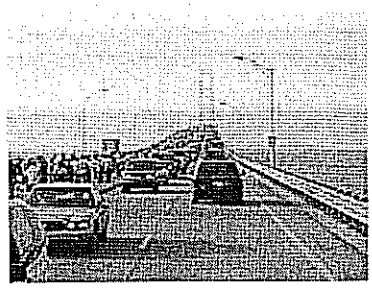
Crossing the bridge

The Mackinac Bridge Authority has a Drivers Assistance Program that provides drivers for those uncomfortable with driving across the Mackinac Bridge. Those interested can arrange, either by phone or with the toll collector, to have their cars or motorcycles driven to the other end. There is no additional fee for this service. Bicycles are not permitted on the bridge; for a fee the Authority will transport bicyclists and their vehicles across the bridge.[9]

Travelers across the Mackinac Bridge can listen to an AM radio broadcast that recounts the history of the bridge and provides updates on driving conditions.[12]

Bridge Walk

The Mackinac Bridge Walk has been held each year since 1958, when it was led by Governor G. Mennen Williams. The first walk was held during the Bridge's Dedication Ceremony held in late June, and has been held on Labor Day since 1959. Thousands of people, traditionally led by the Governor of Michigan, cross the five-mile (8 km) span on foot from St. Ignace to Mackinaw City since 1964. Before that, people walked the Bridge from Mackinaw City to St. Ignace.



The Mackinac Bridge Walk

Tourism

During summers, the Upper Peninsula and the Mackinac Bridge have become a major tourist destination.[13] In addition to visitors to Mackinac Island, the bridge has attracted interest from a diverse group of tourists including bridge enthusiasts, bird-watchers, and photographers.[14]

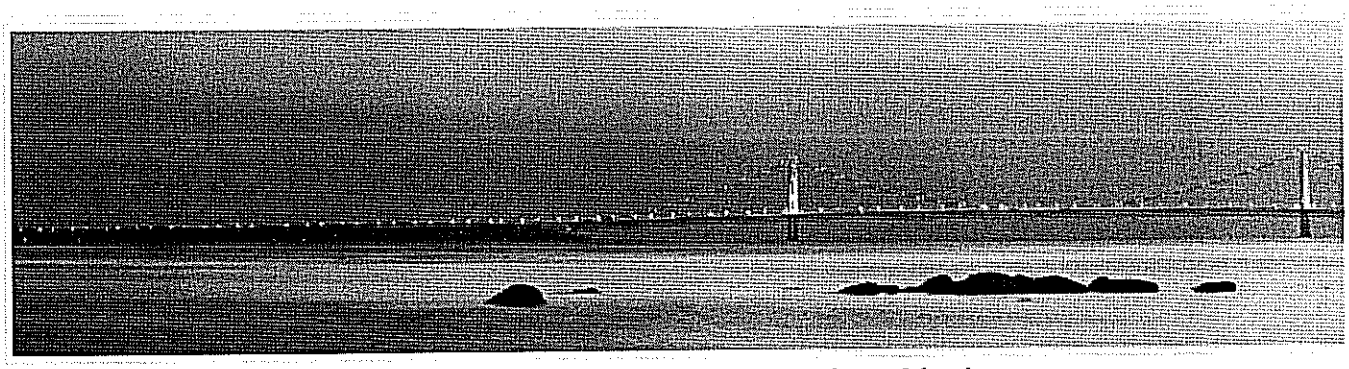
In media

A feature-length documentary entitled "Building the Mighty Mac" was produced by Hollywood filmmaker Mark Howell in 1997 and has been shown over the PBS network. The program features numerous interviews with the key people who built the structure and includes restored 16 mm color footage of the bridge's construction.

The bridge and its maintenance crew were featured in an episode of the Discovery Channel TV show *Dirty Jobs* on August 7, 2007. Host Mike Rowe and crew spent several days filming the episode in May 2007.[15]

The history and building of the bridge was featured in an episode of the History Channel TV show *Modern Marvels*.[16]

On July 19, 2007, the Detroit Science Center unveiled an 80-foot-long, 19-foot-tall scale model of the Mackinac Bridge. The exhibit was part of the state's 50th anniversary celebration of the bridge that opened to traffic Nov. 1, 1957.[17] Sherwin-Williams supplied authentic Mackinac Bridge-colored paint for the project.[18]



2008 panorama of the bridge from Mackinac Island

Further reading

- November 1, 2007-March 15, 2008: "Before the Bridge: Linking Michigan's Peninsulas Before the

Mackinac Bridge", exhibit at the Clarke Historical Library, Central Michigan University.[19]
- "The Mighty Mac at 50", *Michigan History Magazine (Special edition)*, Volume 19, No. 4, July-August, 2007.

References

1. ^ Mackinac Bridge Authority (http://www.mackinacbridge.org/)
2. ^ [a] [b] [c] Mackinac Straits Bridge (http://en.structurae.de/structures/data/index.cfm?ID=s0000141) in the Structurae database
3. ^ Mackinac Bridge Authority. "Mackinac Bridge Authority reminds motorists tolls go up March 1". http://www.mackinacbridge.org/index.php?action=archived&artid=176. Retrieved 2008-03-06.
4. ^ About the Bridge - Mackinac Bridge Authority (http://mackinacbridge.org/about-the-bridge-8/)
5. ^ [a] [b] Sigmund, Pete (2007-02-07). "The Mighty Mac: A Sublime Engineering Feat". Construction Equipment Guide. http://www.cegltd.com/story.asp?story=8153. Retrieved 2008-05-15.
6. ^ Governor G. Mennen Williams (http://politicalgraveyard.com/bio/tripp.html#S880H66X0)
7. ^ Mackinac Bridge authority proposes raising tolls to pay for renovations (http://www.freep.com/apps/pbcs.dll/article?AID=200771107060) , *[Detroit Free Press]*, November 7, 2007.
8. ^ Michigan History Magazine July/August 2007
9. ^ [a] [b] "Frequently Asked Questions". Mackinac Bridge Authority. 2008. http://www.mackinacbridge.org/faq-17/Bridge+services/. Retrieved 2008-02-15.
10. ^ Zacharias, Pat (2000-06-06). "The breathtaking Mackinac Bridge". The Detroit News. http://info.detnews.com/history/story/index.cfm?id=156&category=locations. Retrieved 2008-02-15.
11. ^ *Daraban v. State of Michigan*, 223659 (http://www.michbar.org/opinions/appeals/2002/030502/14207.pdf) (State of Michigan Court of Appeals 2002-03-05).
12. ^ WNHC787 AM 530 St. Ignace, WNHC787 AM 1610 Mackinaw City, Travelers Information Service AM Radio (http://www.michiguide.com/dials/amtis/wnhc787.html) , Michiguide.com, retrieved 2008-09-20
13. ^ Michigan Tourism Business (http://www.imakenews.com/tourism/e_article000226672.cfm)
14. ^ Mackinac Bridge Photography (http://www.mackinacbridge.org/photo-gallery-10/)
15. ^ http://www.9and10news.com/category/story/?id=117043 9&10 News: Crew from "Dirty Jobs" in Northern Michigan
16. ^ http://www.imdb.com/title/tt0905001/
17. ^ What's Happening in Detroit. (http://detroit.donyell.net/index.php/detroit-science-center-to-unveil-mackinac-bridge-replica/)
18. ^ Mackinac Bridge replica at Detroit Science Center. (http://www.prnewswire.com/cgi-bin/stories.pl?ACCT=104&STORY=/www/story/06-19-2007/0004611163&EDATE=)
19. ^ Bay City Times on Bridge exhibit. (http://www.mlive.com/features/bctimes/index.ssf?/base/features-0/119816730913490.xml&coll=4&thispage=4)

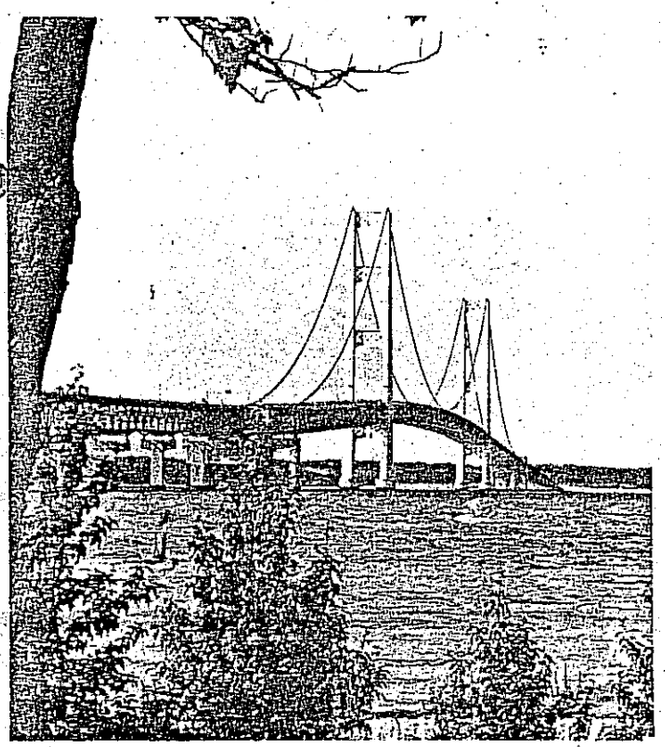
External links

- Official site (http://www.mackinacbridge.org/)
- Length Comparison (http://www.michigan.gov/mdot/0,1607,7-151-9618_11016-22026--,00.html)
- Mackinac Bridge 3c Commemorative Stamp (http://www.1847usa.com/identify/1950s/1958.htm)
- Monitoring the Mighty Mac, Point of Beginning, 2007 (http://www.pobonline.com/CDA/Articles/Cover_Story/BNP_GUID_9-5-2006_A_10000000000000209422)

Categories: Suspension bridges in the United States | Bridges on the Interstate Highway System | Bridges in Michigan | Toll bridges in Michigan | Visitor attractions in Michigan | Mackinac County, Michigan | Emmet County, Michigan | Cheboygan County, Michigan | Bridges completed in 1957 | Tolled sections of Interstate Highways | Northern Michigan | Upper Peninsula of Michigan | Interstate 75 | Towers in Michigan

Hidden categories: Articles needing additional references from August 2008 | All articles with unsourced statements | Articles with unsourced statements from September 2008 | Articles with unsourced statements from January 2009

Holy Mackinac! the Story of the Mackinac Bridge



The Chippewa and Huron Indians who first inhabited the Straits of Mackinac area of Michigan certainly must have looked longingly at opposite shores and perhaps prayed that the Great Manitou would grow a tree so tall that, when it was felled, its trunk would reach from one shore to the other. Such was the primitive method of building bridges.

Explorers, fur traders and, finally, settlers in St. Ignace and Mackinaw City must have thought of a connecting link. What man worth his salt did not look longingly at a distant shore and dream of a roadway that would allow a traveler to cross easily from one of the Michigan peninsulas to the other?

One answer lies in a microfilm print of a faded news page of the Lansing Republican, dated February 5, 1884. Under the "Miscellaneous" column there is an item from the Grand Traverse Herald stating that "the experiment to provide all-year service across the Straits by boat failed and that if a great east-west route were ever to be established through Michigan, a bridge or tunnel would be required." The editor, Tom Bates, considered both practicable. The only question in his mind was that of cost.

This conclusion might well have been inspired by the dedication of the Brooklyn Bridge in New York in 1883. A St. Ignace merchant, William Saulson, used a line drawing of the bridge in his newspaper advertising and on his wrapping paper. Above the artist's sketch of the famous New York structure was the inscription, "A glimpse of the future," and below it the caption, "Proposed bridge across the Straits of Mackinac."

Commodore Cornelius Vanderbilt, presiding over the first meeting of the board of directors of the newly opened Grand Hotel on July 1, 1888, is reported to have made the following observation: "We now have the largest, well-equipped hotel of its kind in the world for a short-season business. Now what we need is a bridge across the Straits."

If there were any discussion about a connecting link at the Straits during the next 30 years, it was not well documented. However, in 1920, State Highway Commissioner Frank Rogers suggested a floating tunnel. He invited other engineers to propose ideas for crossing the Straits.

Ambitious Plan

C. E. Fowler, a New York City engineer, submitted an ambitious plan. He proposed a series of bridges and causeways that would commence in Cheboygan, some 17 miles southeast of Mackinaw City, span the waterways to Bois Blanc and Round Islands, touch the southern tip of Mackinac Island, and leap across the deep channel to St. Ignace.

The few vehicles seeking transportation across the Straits in the early 20s were transported on the railroad ferry, which provided the only connection between Michigan's two peninsulas. Then, in 1923, the Legislature ordered the State Highway Department to establish its own ferry service. A relatively small boat, the Ariel, which had been transporting vehicles across the Detroit River between Windsor and Detroit, was purchased and placed into service at the Straits.

Within five years, the demand for crossings became so strong that Governor Fred Green ordered a bridge feasibility study. The results favored a bridge to be constructed at an estimated cost of $30 million. Some efforts were made to get the project under way.

In 1929, State Senator Seymour Person introduced a bill authorizing the Highway Department to construct the previously proposed series causeways and bridges from Cheboygan to St. Ignace, using prison labor and state highway funds and equipment.

The bill died in committee, but the idea of a Straits bridge did not. Less than five years later, backers considered the bridge project a most suitable one for the federal Progress Works Administration, an agency created to combat unemployment during the Great Depression. The Mackinac Straits Bridge Authority was created during the extra session of the 1934 Legislature. It was empowered to determine the feasibility of a bridge and finance construction by issuing revenue bonds.

Go See The Sultan

The Authority concluded that it was feasible to construct a bridge directly across the Straits at an estimated cost of $32.4 million for a two-lane highway and one-track railway structure.

The Authority made two attempts between 1934 and 1936 to obtain loans and grants from the government. Both were unsuccessful even though the U.S. Army Corps of Engineers and President Franklin Roosevelt were in favor of the project.

There is an amusing and possibly apocryphal story about Chase S. Osborn, a former Governor, the publisher of the Sault Ste. Marie Evening News, and a strong bridge proponent. When it became necessary to approach important people in Washington, he is said to have remarked that if something needs to be done "don't bother with the servants, go see the sultan." So he went directly to President Roosevelt, who is

reported to have thought the Straits were about 20 miles wide, five times the actual distance. It is within the realm of possibility that the President's support for the project was the price of silence about his geographical misconception.

During the late 30s, a feeling persisted among state highway officials that a bridge was inevitable. The Chief Deputy Highway Commissioner, G. Donald Kennedy, became chairman of the Mackinac Straits Bridge Authority. Thus, the Highway Department, with the backing of Governor and former Highway Commissioner Murrary D. VanWagoner, lent its full support to the project and managed to have considerable work completed that was ultimately of great value.

Causeway South

Borings were made, a new direct route selected, and traffic, geologic, ice and water current studies were completed. An earthen mole, a causeway jutting 4,200 feet south into the Straits from St. Ignace, was constructed. A consulting engineer was retained and plans were proposed for a double suspension span, one of which would have been 4,800 feet between towers. The possibility of a bridge became very real. But in 1939, the armies of Europe began to march. The United States was attacked in 1941, and bridge progress ground to a halt.

When hostilities ended, road and bridge builders worked overtime to make up for the construction that had lagged during the war years. The Straits bridge became a "back-burner" item and the Authority was dissolved by the Legislature in 1947. This was an affront to bridge backers.

Young Governor

W. Stewart Woodfill, then owner of the Grand Hotel on Mackinac Island, established a citizens' committee to promote legislation creating a new bridge authority. Youthful G. Mennen Williams, campaigning for Governor in the eastern Upper Peninsula, made the bridge proposition a plank in his campaign platform. As often happens in politics, when the standard bearer of one party promotes a proposition, some members of the opposite party automatically reject it. This made it more difficult than it should have been to re-establish the Authority, but Woodfill's imaginative, dramatic and daring persuasiveness and Governor Williams' newly appointed Inter Peninsula Communications Commission, chaired by John McCarthy, prevailed. In 1950 a bill was enacted creating the present Mackinac Bridge Authority. However, its role was limited to determining feasibility of a bridge.

To his everlasting credit, Governor Williams appointed a blue ribbon Authority of leading citizens. Though it was comprised by law of three Democrats and three Republicans, one would have been hard pressed to determine their political affiliation from their actions on the Authority.

Former U.S. Senator Prentiss M. Brown of St. Ignace was elected Chairman. President of the National Bank of Detroit, Charles T. Fisher, Jr., was elected Vice Chairman. Other members were William T. Cochran, General Motors dealer, Iron Mountain; George A. Osborn, publisher, Sault Evening News; Fred M. Zeder, Vice Chairman, Chrysler Motors Corp.; and former Gov. Murray D. VanWagoner, from Birmingham. They selected Lawrence A. Rubin as Executive Secretary.

The law required the Authority to consult with three of America's foremost long-span bridge engineers for advice on physical feasibility and with traffic and revenue analysts to determine financial feasibility.

DR. DAVID B. STEINMAN, who designed the Mackinac Bridge.

Six months later, in January, 1951, the consultants filed preliminary reports with the Authority, concluding that a bridge could be built and financed with revenue bonds totaling $86 million. Unfortunately, the nation's "police action" in Korea put a claim on critical materials, especially steel. The Authority consequently delayed efforts to obtain legislation to finance and build the bridge.

Salt Caverns

In the meantime, a University of Michigan geologist made public his opinion that there were uncollapsed salt caverns under the Straits and that if the huge foundations required by the bridge were built upon them, they would cave in and the bridge would crumble. To refute this allegation, the Authority retained Dr. C. P. Berkey, an engineering-geologist consultant of national reknown. He reported that the salt caverns had collapsed thousands of years ago; that the material under the Straits had consolidated, and that it could safely support the foundations.

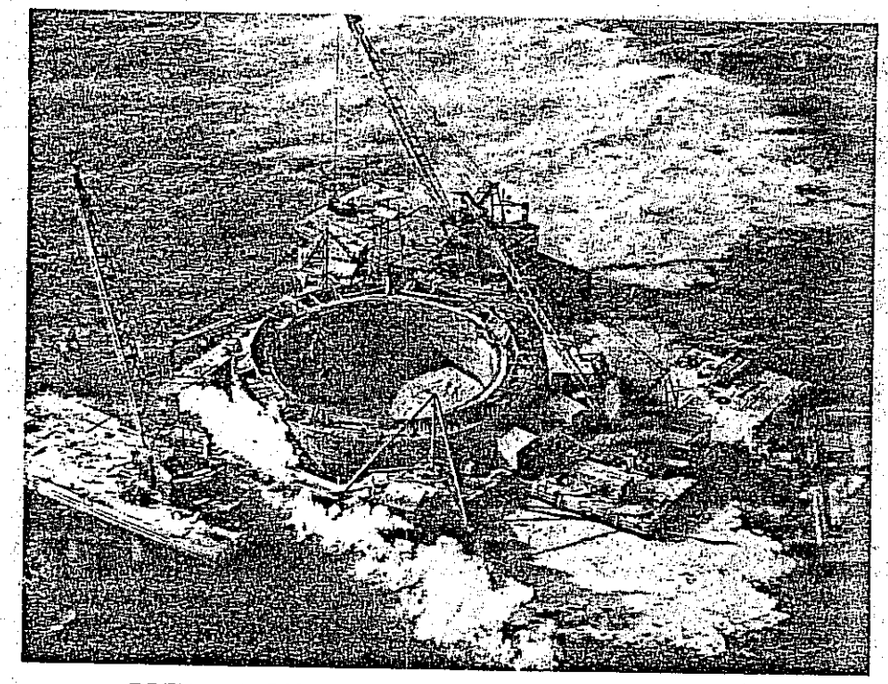
The critical steel situation eased early in 1952. The Authority then requested the Legislature to empower it to finance, build, operate, and maintain a bridge across the Straits. The Legislature finally passed the bill but appropriated exactly one dollar to the Authority to do its job.

The original legislation creating the Authority prohibited any of the three consultants hired for feasibility studies from acting as the final designer of the bridge. The obvious reason was to preclude a favorable report with the aim of obtaining a lucrative design fee. However, when the enabling legislation was passed in 1952, the prohibition was eliminated. It was realized that eliminating any of the advisory engineers would rule out the best consulting engineering counsel available.

Dr. Steinman's Risk

Immediately after the passage of the enabling legislation came the problem of selecting the bridge designer. The engineering committee of the Authority responsible for recommending the design engineer was comprised of three members, two of whom were vigorously opposed to each other's favorite. To further complicate matters, the Authority had no money with which to pay a consultant. In due course, the members began to lean toward one of the original three advisors, but his firm demanded more than $1 million up front as a portion of the fee.

Another of the three advisory engineers, who had more faith in the project, offered to provide the Authority with preliminary plans sufficient for bidding purposes with his fee contingent upon successful financing. Thus, it was that the Authority retained Dr. David B. Steinman of New York City, whose generosity and willingness to risk his own resources stood the Authority in good stead and marked him as one of the men to whom the people of Michigan should be forever grateful.



DREDGING CAISSON FOR NORTH MAIN TOWER PIER.

Finding The Financing

Now it was time to find the financing to construct the bridge. It was not an easy task. Most underwriters showed little interest in the project and one asserted that the single dollar appropriated to the Authority by the Legislature was perceived as a lack of faith in the state where the bridge was to be built. He suggested the Authority ask the Legislature to make available the nearly $500,000 the state was spending each year for maintenance of the ferry service across the Straits. That was done, despite considerable opposition from legislative leaders. but the $417,000 annual appropriation was to be contingent upon actual construction of the bridge and completion of the financing by December 31, 1953.

One obstacle succeeded another; then James Abrams of Allen & Company of New York came up with a proposal to break the financing into two parts. There would be $79,800,000 of Series A bonds, with a four percent interest rate having a first lien on fare revenues, and $20 million of Series B bonds with a five-and-a-quarter-percent interest rate and a second lien on revenues. At the time, those rates were substantially higher than the interest paid on other toll facility revenue bond issues.

After much soul searching, Authority members decided to go along with the proposition. Abrams bought the bonds for his syndicate on December 15, only about two weeks ahead of the Legislature's deadline. Two months later, on February 17, 1954, he turned over a cashier's check to the Authority in the amount of $96,440,033.33. The remaining $3.36 million covered the commission for syndicating and selling the bonds.

Dr. Steinman and his associates, a firm with worldwide experience in bridge design, had conceived for the Straits of Mackinac a bridge of great strength and rare beauty. It was to be the world's largest suspension bridge, a record that still stands in the distance between anchorages--8,344 feet. The total length, including approaches, would be five miles. Its two great towers would rise 552 feet above the straits and the tower piers would be built to a depth of 210 feet below water. The underclearance for ships in the center of the suspension span would be 155 feet. With a critical wind velocity of infinity, it represented an aerodynamic stability never before attained in a suspension bridge.

Breaking Ground

Contracts which had been awarded to Merritt-Chapman & Scott and to the American Bridge Division of U.S. Steel Corp. on a contingency basis were promptly activated. Precise surveys began in March and floating equipment was assembled for construction. Official groundbreaking took place on both sides of the Straits May 6 and 7. Construction of one of the world's great bridges was finally under way.

Work continued until the first winter shutdown in mid-January, resumed when the weather allowed and continued on that basis for three more construction seasons. It was a difficult and often dangerous construction effort.

Overcoming Hardships

But the crews overcame the hardships of water and weather, once encountering a November storm with blasts of 76 miles an hour.

Some 10,000 men worked on the project, about 2,500 at the bridge site and 7,500 at quarries, shops and mills and other sources which supplied the necessary materials. Five bridge workers lost their lives in accidents.

The bridge was scheduled to be open to traffic 42 months after work began, and so it was, on November 1, 1957. On the same day, the state-owned fleet of ferries went out of business forever after carrying some 12 million vehicles and 30 million passengers across the Straits.

Since the opening of the bridge, there have been minor financial problems, but none unmanageable. Diminishing traffic in the years immediately following the opening forced the Authority to increase fares in 1960 for passenger cars from $3.25 to $3.50 and then to $3.75.

The increases were very unpopular, especially in the areas surrounding the bridge. They did, however, improve the solvency of the project and bond redemption began in 1965. In 1968, the Legislature passed a bill reducing fares by 60 percent, from $3.75 to $1.50 for passenger cars and correspondingly lower for other vehicles. In return, the Authority receives a $3.5 million annual appropriation from the Michigan Transportation Fund. The law took effect January 1, 1969.

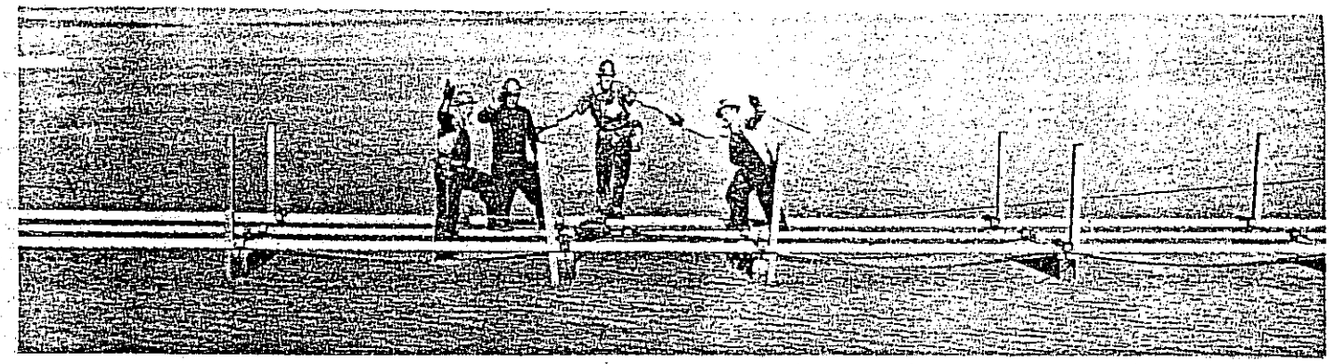
Authority Successful

During the first year of fare reduction, bridge traffic increased 22 percent. Thereafter, annual increases have averaged about four percent. Total traffic in the first 25 years of operation topped 45 million vehicles.

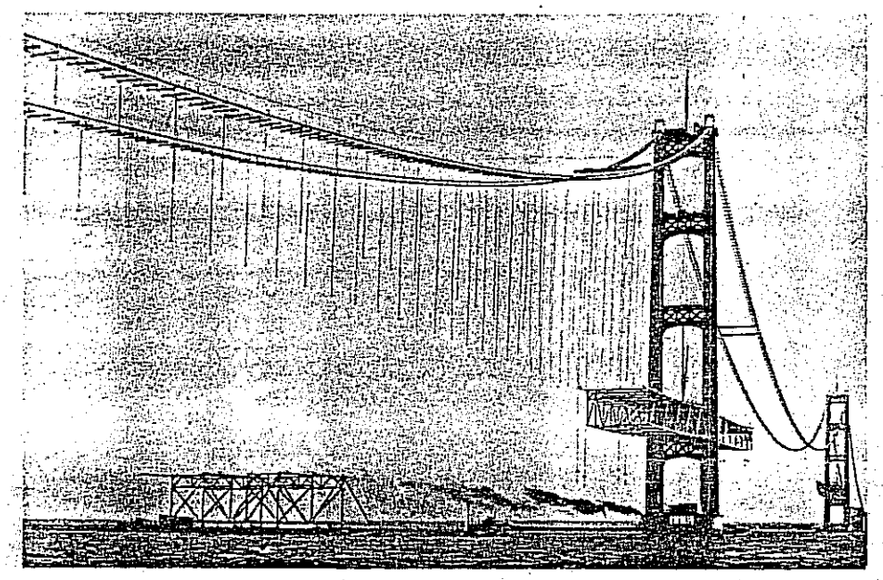
The end of 1982 marks the retirement of all Series A bonds, totaling $79.8 million. The remaining $20 Series B bonds should be called by the end of 1986. At that time, the Legislature will determine what the fares will be; and the Michigan Department of Transportation will take over jurisdiction of the bridge. The Mackinac Bridge Authority will have, at long last, successfully carried out its responsibilities and be dissolved.

This account was written by Lawrence A. Rubin, executive secretary of the Mackinac Bridge Authority since it was established in 1950.

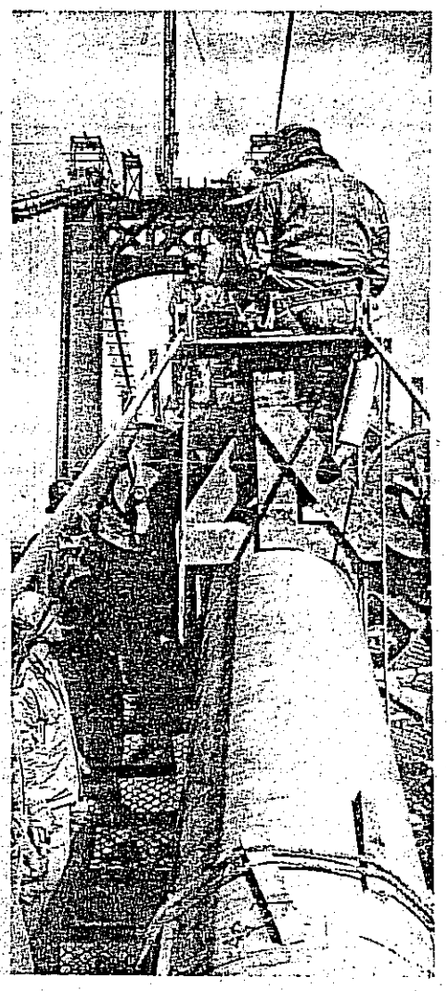
Celebration



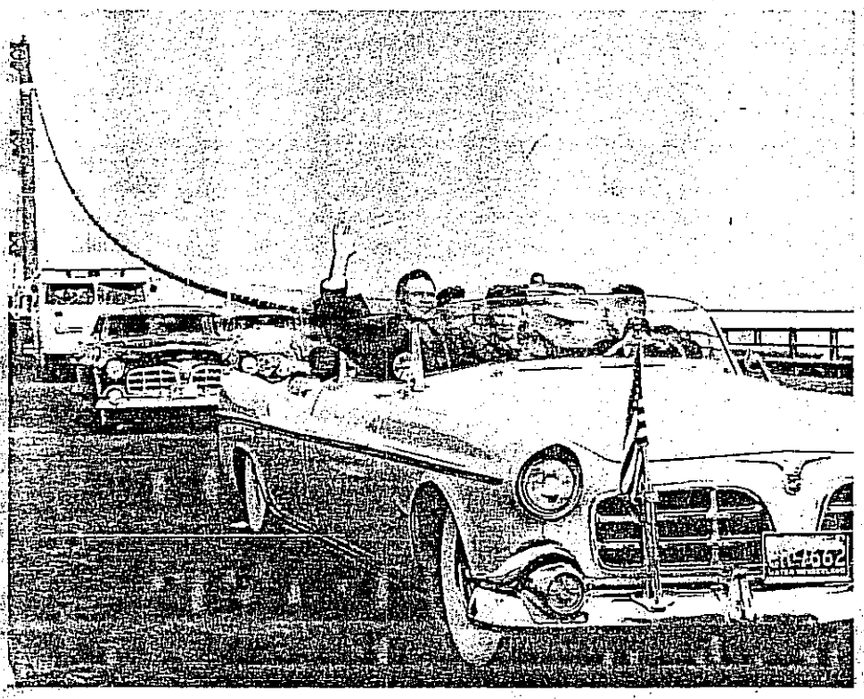
- CELEBRATING CLOSING EAST CATWALK AT CENTER OF SPAN BETWEEN NORTH AND SOUTH TOWERS.



PREPARING TO LIFT ROADWAY TRUSS SECTIONS.



WRAPPING EAST CABLE, center span, near north tower.



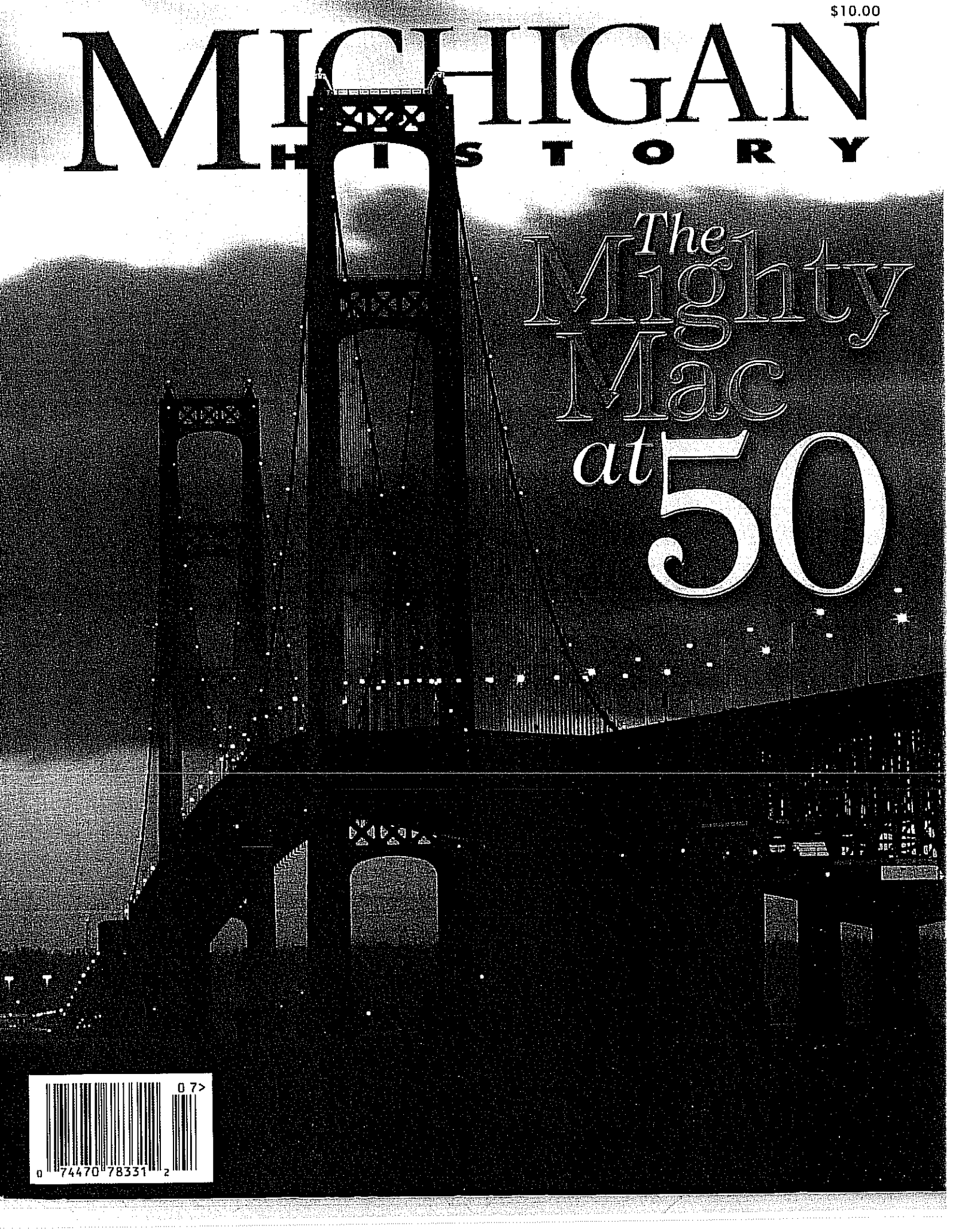
GOV. WILLIAMS and Mrs. Williams with members of the Authority celebrate the opening of the Mackinac Bridge. Highway Commissioner John C. Mackie is seen between them and Larry Rubin is at the wheel.

INTERESTING FACTS

Main Span Length	3,800 ft.
Max. Water Depth, Midspan	295 ft.
Midspan Ship Clearance	155 ft.
Total Length of Wire in Main Cables	42,000 miles
Total Weight of Bridge	1,024,500 tons
Total Number of Blueprints	85,000

$10.00

MICHIGAN HISTORY



The Mighty Mac at 50

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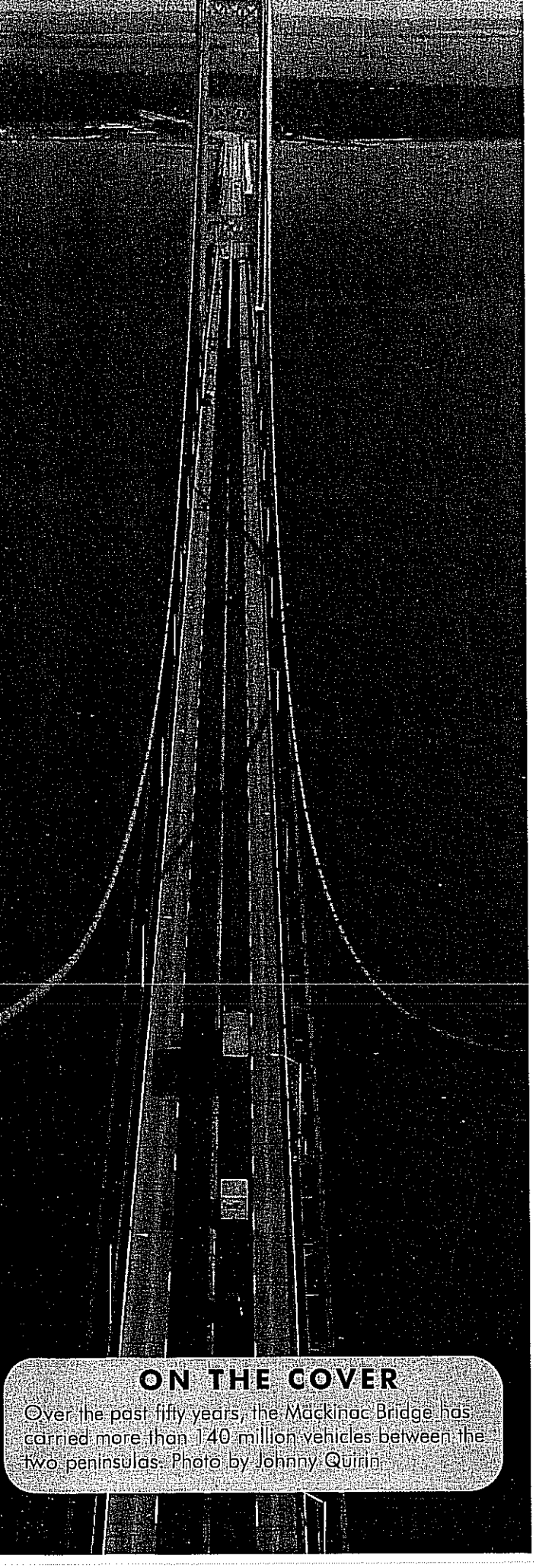
MICHIGAN HISTORY
MAGAZINE
JULY/AUGUST 2007

Johnny Quirin



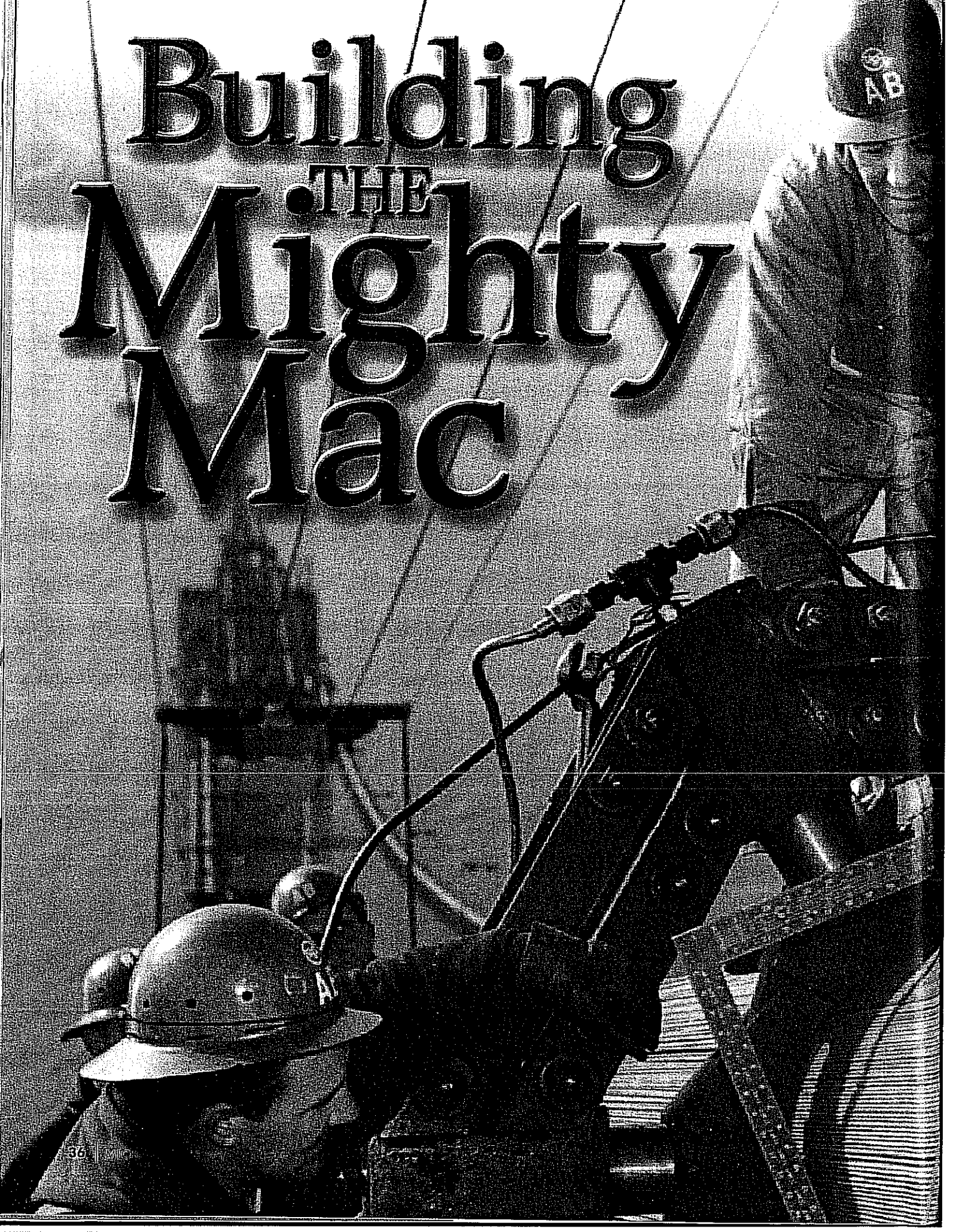
ON THE COVER

Over the past fifty years, the Mackinac Bridge has carried more than 140 million vehicles between the two peninsulas. Photo by Johnny Quirin

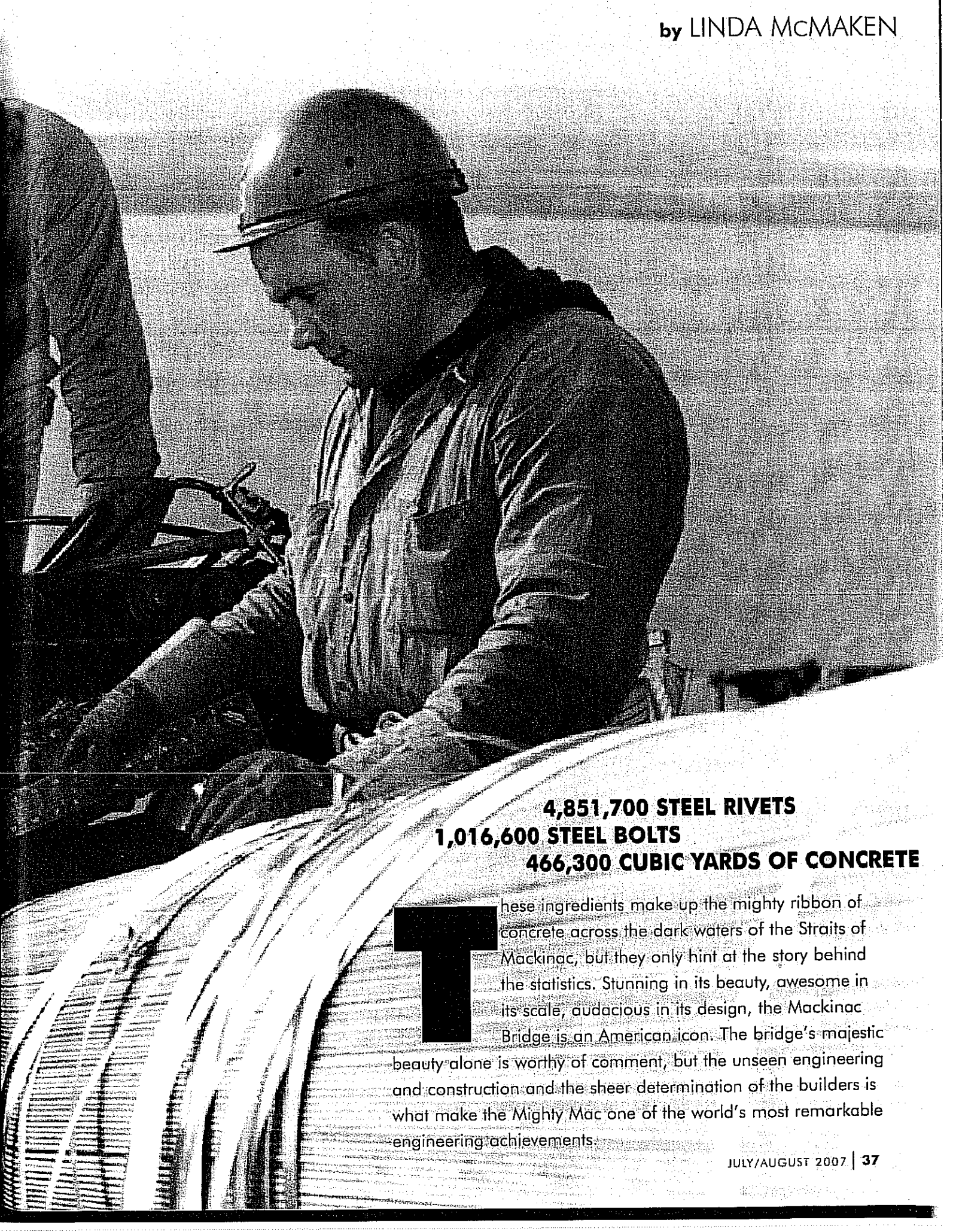
Photo Johnny Quirin

DEPARTMENTS

Building THE Mighty Mac



by LINDA McMAKEN



4,851,700 STEEL RIVETS
1,016,600 STEEL BOLTS
466,300 CUBIC YARDS OF CONCRETE

These ingredients make up the mighty ribbon of concrete across the dark waters of the Straits of Mackinac, but they only hint at the story behind the statistics. Stunning in its beauty, awesome in its scale, audacious in its design, the Mackinac Bridge is an American icon. The bridge's majestic beauty alone is worthy of comment, but the unseen engineering and construction and the sheer determination of the builders is what make the Mighty Mac one of the world's most remarkable engineering achievements.

First proposed in 1934, the Mackinac Bridge project had to beat overwhelming political and financial odds, as well as the formidable and unpredictable character of nature itself. Greatest of all was the engineering challenge of building a bridge across the Straits of Mackinac. David B. Steinman, a young man who began his love affair with bridges when he sold newspapers under the Brooklyn Bridge, took on the daunting task of chief engineer. Steinman and his team of engineers had to design a north-south bridge that could withstand broadside gale force winds (in May 2003 recorded wind speeds hit 124 miles per hour), the hammering punishment of water currents from two Great Lakes pushing into the Straits and the pressure of channel ice that can get up to four feet thick.

JUST ONE STRAIGHT LINE

While the shortest distance between two points is a straight line, creating a straight line across the ever-changing moods of the Straits of Mackinac was the first of many challenges facing the bridge builders. The Straits are about four miles wide and contain two deep glacial gorges—one more than 350 feet deep—that extend into bedrock. The bridge connects Mackinaw City (in the Lower Peninsula) with St. Ignace (in the Upper Peninsula)—a total of 26,372 feet.

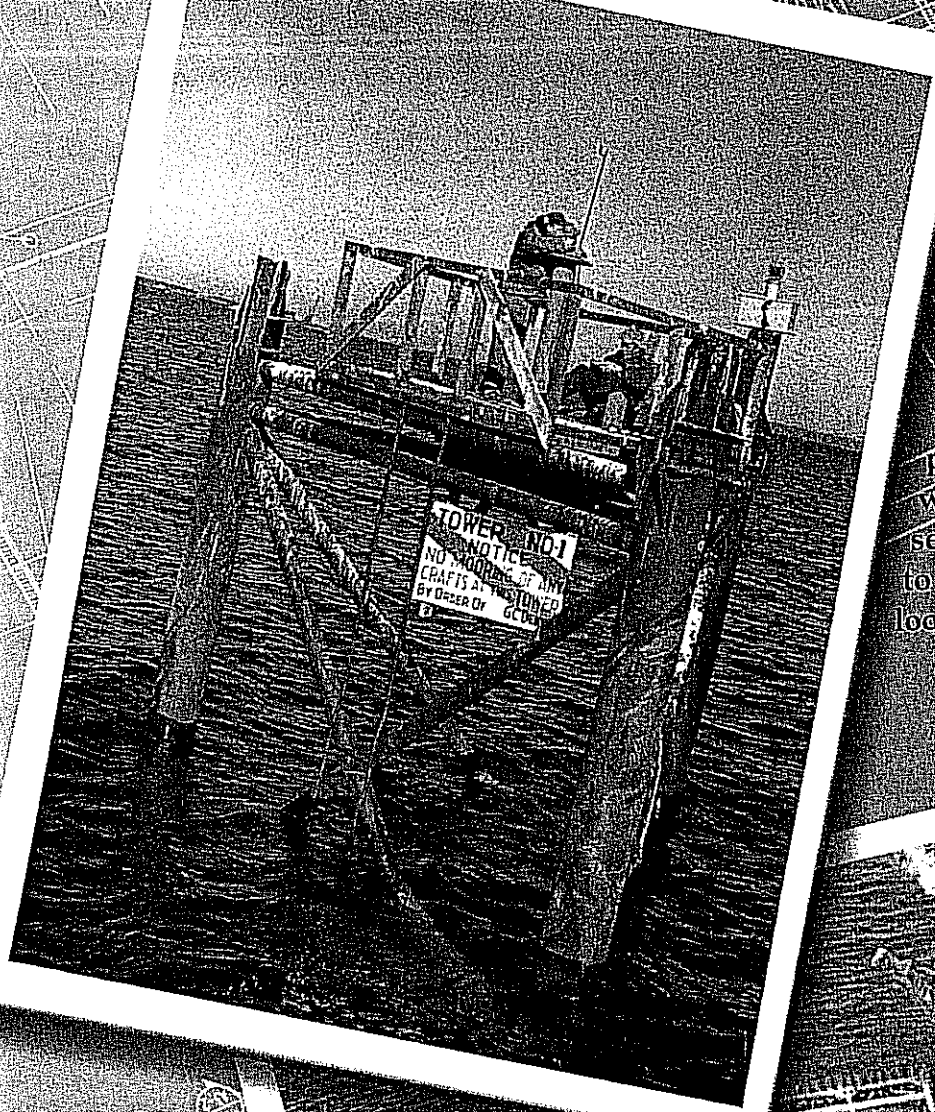
Once funding was secured, the project began with surveyors from the G. Edwin Pidcock Company of Allentown, Pennsylvania, who set triangulation points on land sites around the Straits. With assistance from the Great Lakes Coast Guard and the U.S. Coast and Geodetic Survey, these surveyors established eight points of reference. (Two points were established in Mackinaw City, three stations at St. Ignace, two of which were along U.S. 2, and one at each end of the St. Ignace causeway. Green Island was the eighth point.) Once the land points were established, the surveyors undertook the daunting task of surveying across the water.

This team provided the floating equipment required to triangulate the water sites. The six sea-stations were simple platforms constructed of three large pipes driven into the hardpan, with a slight inward slope where a platform was attached. The shallowest station sat in 25 feet of water and the deepest at nearly 100 feet. These platforms had only a ladder and safety rail, leaving the surveyors unprotected from the elements. The rigid construction of the platforms and the ceaseless waves pounding against them pitted the surveyors in a constant battle to keep their delicate transits correctly calibrated.

The sea-based platforms were three to a row; two rows extending north and south exactly parallel to the centerline of where the bridge would stand. They were placed at distances of 2,000 feet east and 2,000 feet west of the same centerline. One of the most tedious surveying operations was spot- locating the placement of the huge cofferdams. The cofferdams had to be positioned exactly along the bridge's centerline and measured to within a fraction of an inch from the nearest neighbor piers both north and south. The surveyors' measurements needed to be exact, insuring the 34 piers would fit the 71,000-ton superstructure that were manufactured and prefabricated off-site.

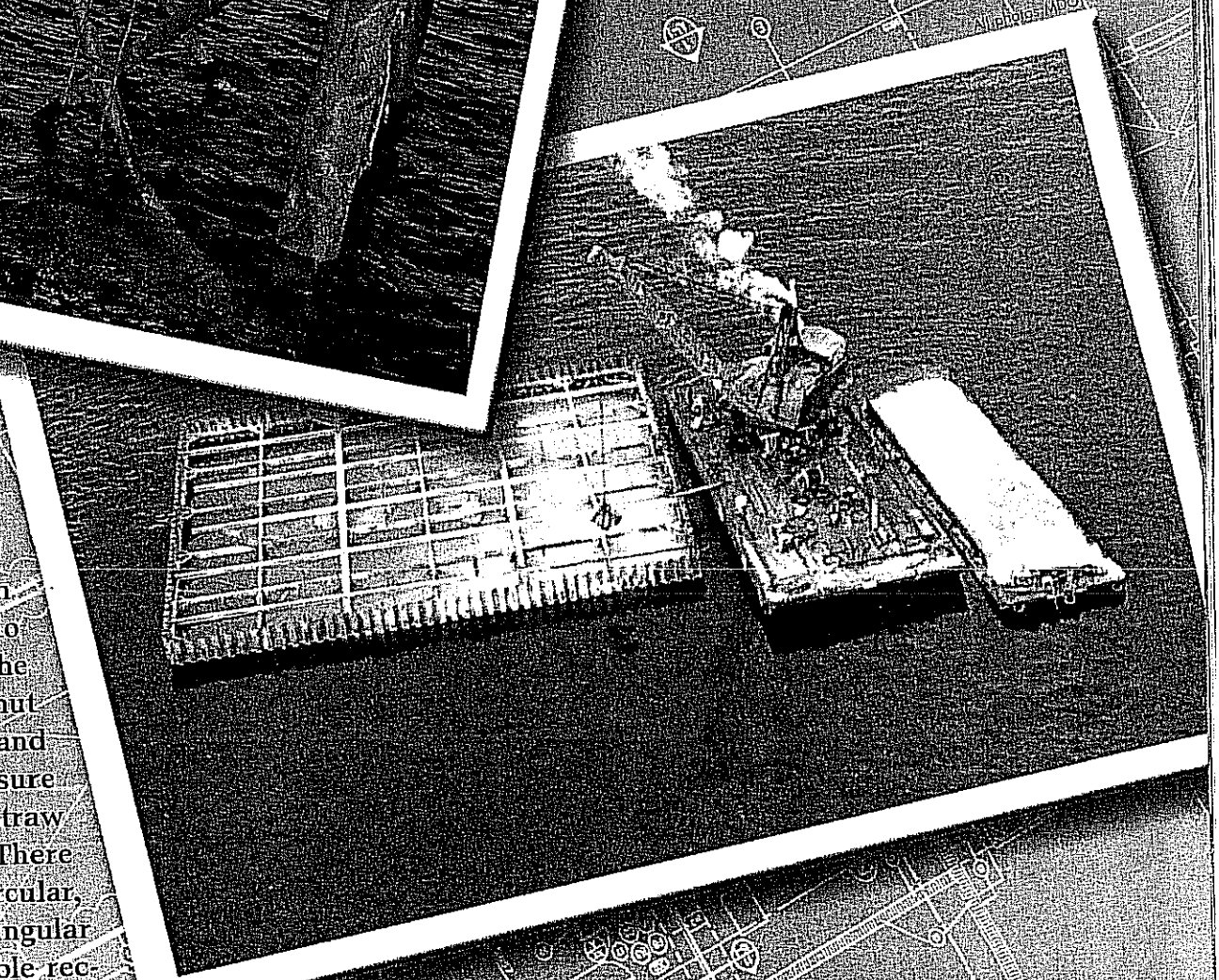
The placement of the cofferdams was coordinated through a series of "nudges," sometimes only by an inch until the coordinates matched at each of the surveying locations. Due to excessive refraction from the water, much of the triangulation work was completed at night. Pier lights were installed for both regulation and surveying. The lights flashed and pulsed to distinguish them as points of reference to keep the calculations as precise as possible.

LENGTH OF THE BRIDGE: 19,243 FEET



Running the Survey

Surveyors from the G. Edwin Pidcock Company of Allentown, Pennsylvania, plotted where the piers were to be placed. Six sea-stations were built to pinpoint their exact location.



Cofferdams form a solid fencing from the bedrock to above the waterline to shut out water and earth pressure (much like a straw in a cup). There are fifteen circular, thirteen rectangular and one double rectangular cofferdam.

Installing the Cofferdams

OF CAISSONS AND COFFERDAMS

In simplistic terms, both a caisson and a cofferdam serve as "foundations" for the bridge piers. There are a few basic differences, both in their use and in their construction. The caisson is a bottomless watertight structure, built off-site to the point of buoyancy, than floated to its intended location. The Mackinac Bridge has double-walled circular caissons, sunk to solid rock below the water's surface. Constructed like building blocks, the caissons were put together in sections and slowly and systematically sunk into place by displacing water with fill (gravel). The caisson had an open center section for "open-dredging," which allowed soil, mud and other debris to be excavated. The next section was then added, allowing workers to fit the two sections together without performing the task under water. Watertight compartments surrounded the caisson sections, keeping them level while they sank downward.

Grout from pipes were sunk into the cassion mixed with aggregate, making the interior of each solid. The layering continued, going deeper as the weight increased until the bottom of the caisson (with its cutting-edge bit) gnawed its way into over 100 feet of sand, clay and other hardpan. Caissons were used to construct piers 18, 19 and 20. Piers 19 and 20 form the foundation for the towers.

While the towers are strikingly beautiful, their engineering esthetics and massiveness were of record-setting proportions. There are 32 sections used to form each 116-foot-diameter section of caisson. Each of these sections is 24 feet high and weighs 11 tons; when stacked, they are as high as a 20-story building. There is enough steel and concrete in each to cover roughly four city lots; each weighs over 150,000 tons. At the time, they were the deepest caisson piers ever constructed on a suspension bridge.

Undaunted by the early throes of winter, construction continued through ice, snow and brutally cold temperatures, as the six central piers needed to be far enough toward completion to prevent ice from destroying them. Winter was bearing down and the process of sinking the caissons was agonizingly slow. Dynamite sped up the process, but ice began to creep in. Except for the bridge project ferryboats, all traffic on the lakes had stopped.

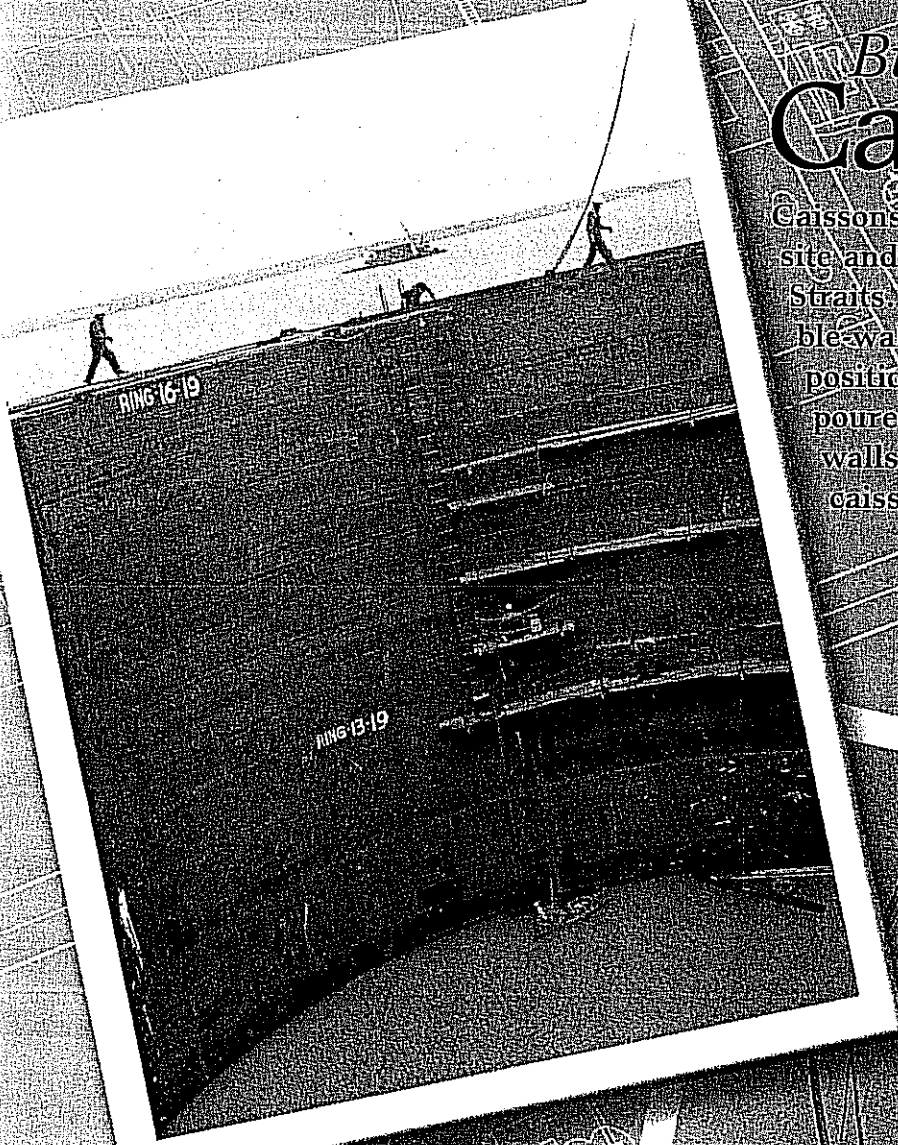
Work continued in the harsh conditions until January 14, 1955, when one of the worst blizzards on record zeroed in on the Straits. Based on the severity of the forecast, workers rushed ashore, and the floating construction equipment was secured in slips and hurriedly lashed into place against the storm. Through anxious days, the engineers and workers waited to see if the newly placed caissons, which were not yet fully resting on the bedrock, would hold up against nature's fury. Snow sliced across the water like daggers, thick ice crusted on the equipment and the partially constructed bridge, waves crashed against the incomplete piers. When weather permitted several weeks later, the engineers cautiously inspected the piers. Not one caisson had been damaged.

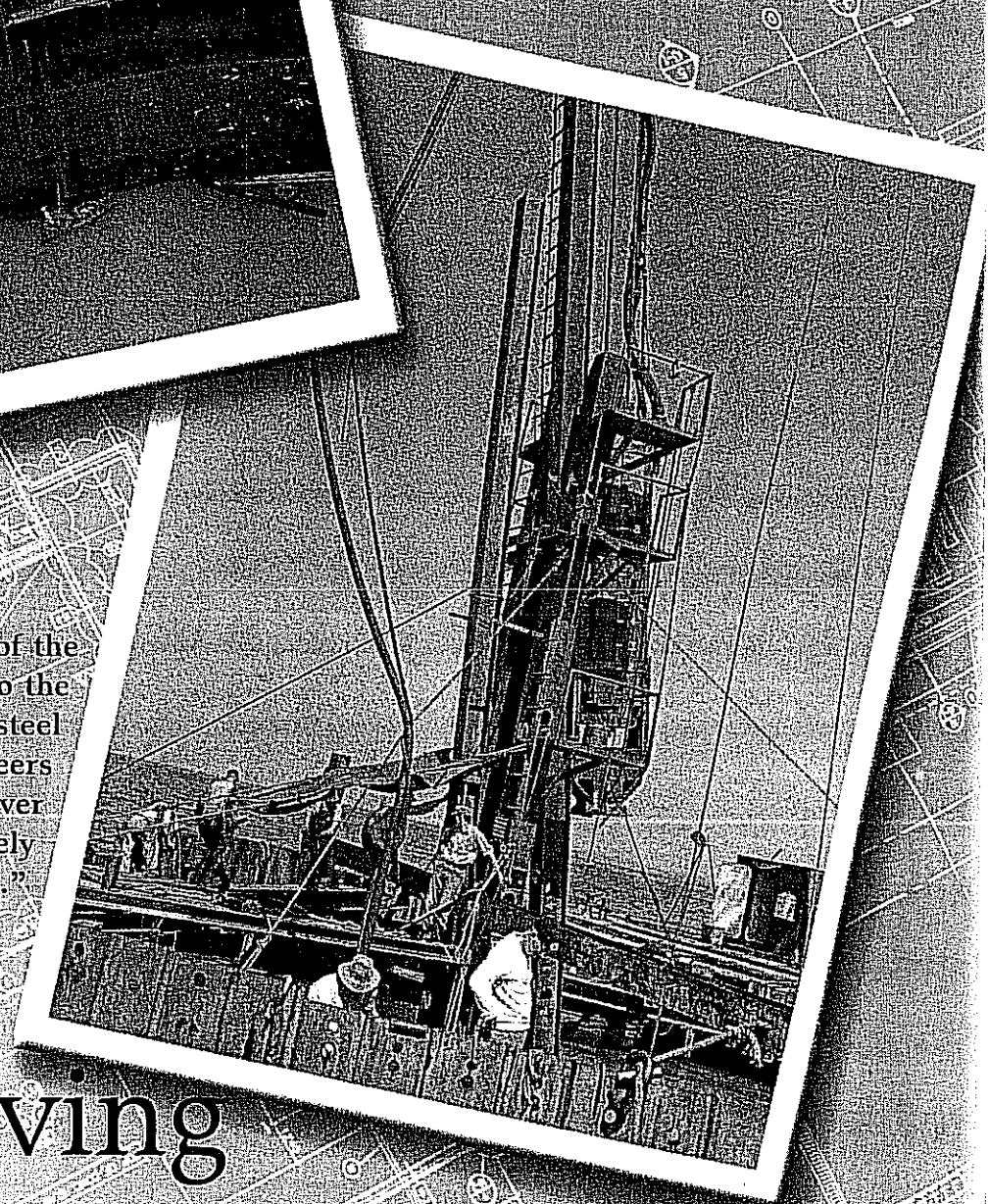
In addition to the three caissons, the Mighty Mac used 15 single-circle cofferdams, 13 single- rectangular cofferdams and one double rectangular cofferdam to construct 30 of its 34 piers. One pier was constructed on land using traditional framing methods. The cofferdams are similar to the caissons. Driven into bedrock, connected together, their interior debris was excavated and grout tubes were filled with aggregate. They were built piece by piece at the construction site creating a "watertight" fence around the work area. (Cofferdams can be nearly any shape, as long as the walls are watertight and imbedded deeply enough in the earth to prevent outside water from forcing its way inside through the bottom.) Bracing on the interior prevented exterior water pressure from crushing the cofferdams.

LENGTH OF MAIN SPAN BETWEEN TOWERS: 3,800 FEET

Building the Caissons

Caissons were built off-site and floated to the Straits. They are double-walled; once in position, ballast is poured between the walls to sink the caisson into place.





The bases of seven of the piers extend far into the bedrock using piles (steel H-beams). Engineers designed a pile driver they affectionately called "Gizmo."

Pile Driving

CONCRETE COCKTAILS

As with everything for the Mighty Mac, the volume of concrete needed was staggering—over 900,000 tons, including 600,000 tons of coarse aggregate, 250,000 tons of sand and 3 million sacks of cement. About 80 percent of this volume (360,000-cubic yards) is under water, some of it over 200 feet deep. This volume meant normal concrete construction methods were not going to work.

A newly patented type of concrete called Intrusion-Prepakt saved the project time, money and stress. Prepakt concrete mix included fly ash (an alkali) and a company-patented compound called Intrusion Aide. These additives helped control the mix's reaction, hardness and strength under water. Prepakt also provided an entirely new way to mix concrete.

Coarse aggregate was used to fill in each caisson, form and cofferdam; injecting the Prepakt followed. Two sets of vertical pipes were installed inside each caisson and cofferdam, running their entire height. The grout pipes were simply 2½ inches of welded pipe with a small 3/8-inch opening or "slot" left in it. Coarse aggregate could not enter the small opening, but grout could easily be injected through it to completely fill the small crevices between the aggregate. These pipes were raised with each subsequent pour, allowing the injection of grout for each additional section caisson. Raising them just above the fresh layer of grout, the aggregate was kept above the last grout pour. This left a built-in rough surface necessary for the next pour of grout to adhere to the previous pour. The second sets of pipes were sounding wells; these remained in the concrete. Whenever an engineer wanted to check the level of grout within the caisson or cofferdam, a sounding line with a float attached to it was lowered into the pipe. The float lay on top of the heavy grout, giving engineers an accurate reading of the grout's depth.

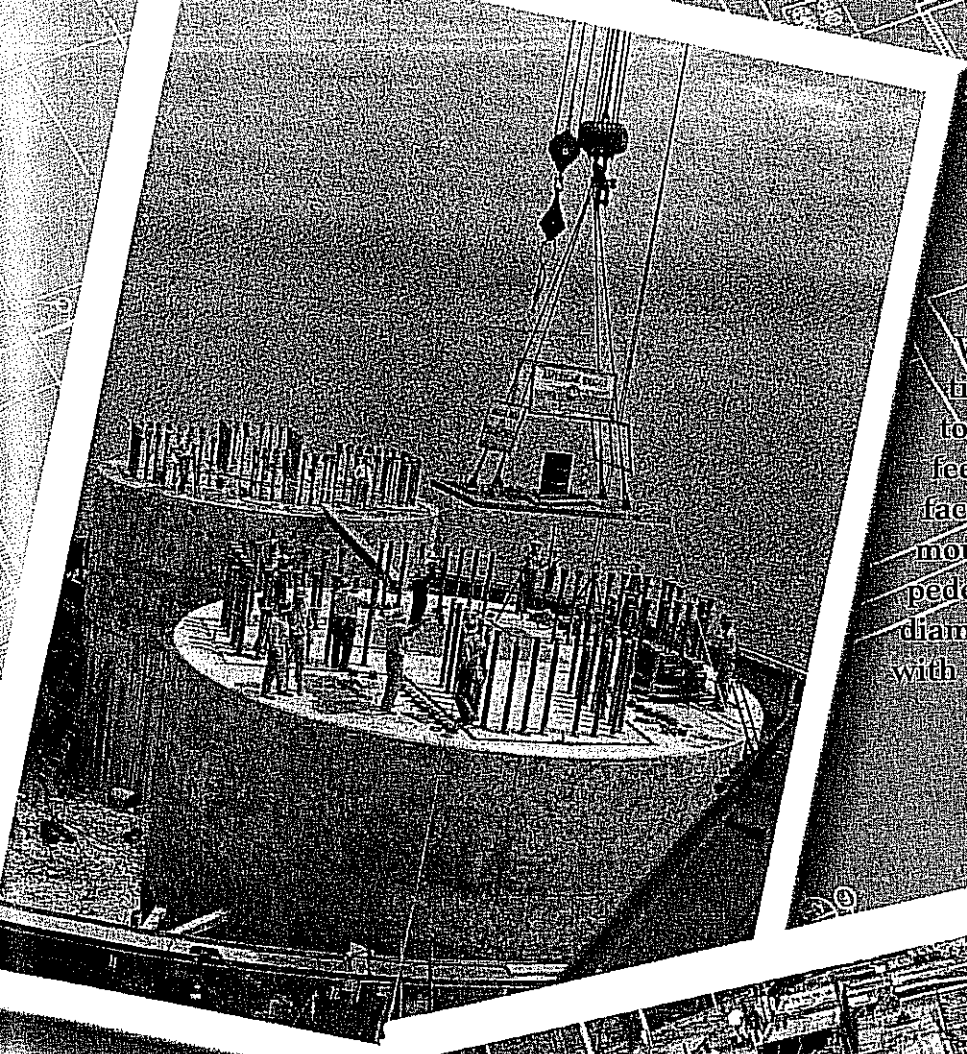
A floating mixing plant was developed to handle the enormous quantities required. This decision saved thousands of dollars and weeks of time. The derrick-barge *Algonquin* was refitted as a floating mixing plant. It had six positive displacement grout pumps from which the grout was injected through a flexible hose into the caissons. Two barges were moored on either side of the *Algonquin*; one carried sand and the other carried covered cement and fly ash. The three ships formed a self-contained mixing/pumping plant. This unique mixing plant set records for delivering a peak grout output of 260 cubic yards of coarse aggregate per hour. It placed 1,800 cubic yards during an eight-hour shift and 5,040 yards during a 24-hour day. Engineers estimated that using this Prepakt method shaved more than a year off the bridge's completion time.

GIZMO TO THE RESCUE!

A deep glacial gorge snakes through the Straits of Mackinac runs west to east. Between Mackinaw City and the northwest tip of Bois Blanc Island, the gorge turns, jutting between St. Ignace and Mackinac Island. There, it turns east and traverses along the northern shore of the island, plowing southeast along the east shore of Mackinac Island and plunging into the dark depths of Lake Huron. This gorge is 3,500 feet wide, 350 feet deep and is paralleled on the south by a second gorge, not as deep but nearly as wide. The great depth of this ancient gorge posed considerable problems for the pier construction, as the base of each pier needed to rest on bedrock

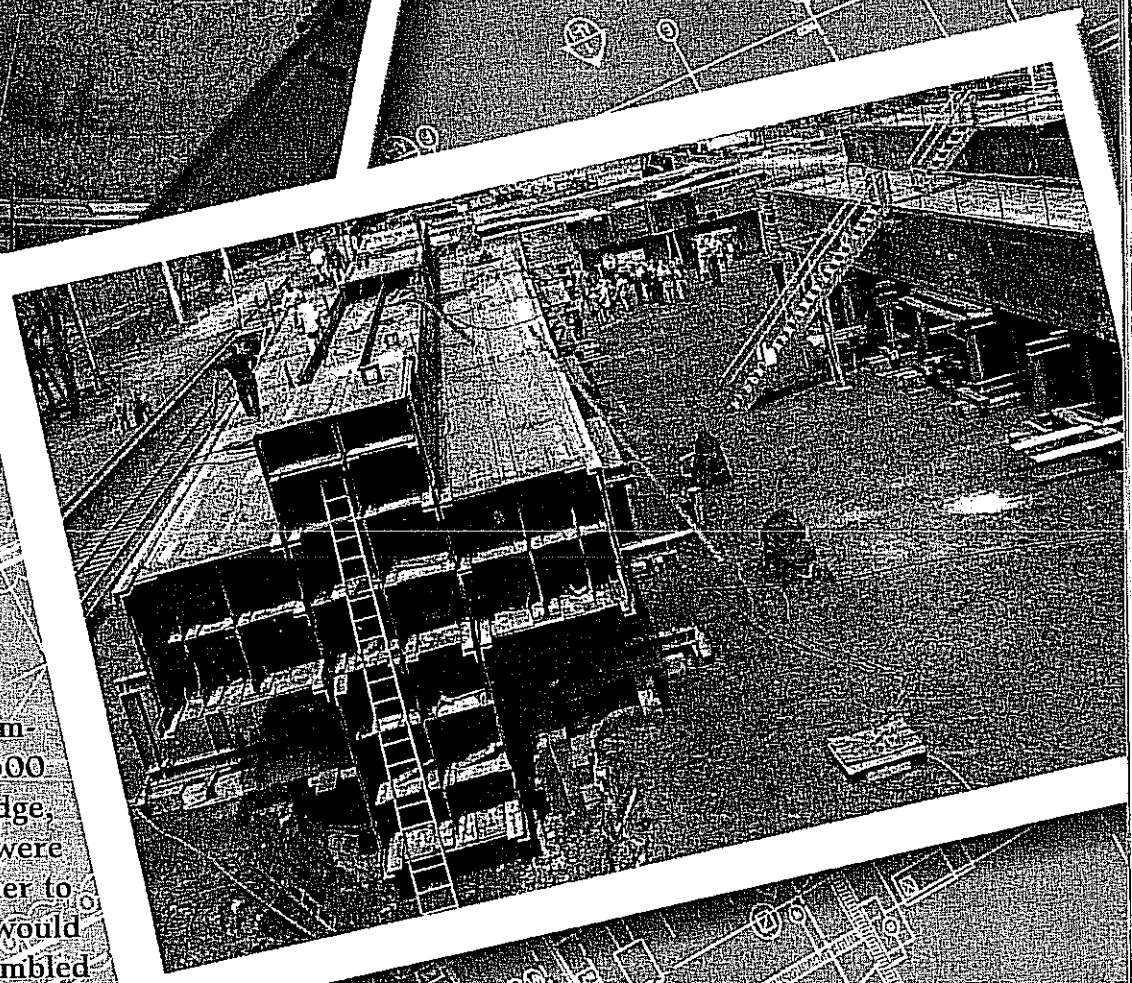
Bearing piles literally hold up the bridge, bringing the supporting piers to a consistent height. The 14-inch, steel H-beam bearing piles needed to be driven through the clay overlay to bedrock, so that the bridge could withstand the forces of water, ice and wind. Driving the piles to the precise depth proved tedious. The cost of driving each pile and the length of time required would be staggering. Two

HEIGHT OF MAIN TOWERS ABOVE WATER: 552 FEET



Supporting the Towers

When the foundations were concreted to a height of eight feet below the surface, they were mounted with pedestals 16 feet in diameter and filled with reinforcing rods.



The towers were assembled horizontally 500 miles away at Ambridge, Pennsylvania. Pieces were drift-pinned together to make sure all parts would fit properly once assembled permanently at the Straits.

Assembling the Towers

engineers from Merritt-Chapman & Scott, Jack Denny and Ed Haltenhoff, developed a remarkable answer-a device they affectionately called Gizmo.

A unique twist on a standard pile driver, Gizmo was designed to drive large H-beam piles on a slant. It drove many dozens of them (both over and under water) in a series of concentric circles; each circle had a different "angle of batter" or different angle of slant, and a different radius. Gizmo was capable of driving multiple piles in multiple circles each with a varying radius and all within the space of the cofferdam. A 10-ton steam hammer drove a 130-foot H-beam pile in just thirty minutes. When operated under water, compressed air pushed aside the cushion of water between the hammerhead and the pile. This way the hammer lost none of its striking force. Gizmo could drive 12 or more 14-inch H-beam piles from 75 to 140-feet long in a single eight-hour shift. Gizmo however, was not a quiet invention. In fact, its hammer blows were so loud many fish in the Straits were stunned and if they were unfortunate enough to swim too close during a hammer blow they went belly-up. This invention slashed the cost of a pile-driving from $100 per pile to less than $30.

Two derrick barges, one carrying bearing piles and the other supplying the compressed air and steam, were needed to operate Gizmo. The workers knew they had reached bedrock when Gizmo took 20 blows to move the beam one inch. During the summer of 1955 Gizmo drove 602 14-inch H-beam piles or nearly 12 miles of piling, more than 10½ miles of which was through the hardpan stratum blanketing the bedrock.

CREEPING UP THE STEEL

As steel construction got under way in 1955, the Mighty Mac was beginning to look like a bridge. The two beautiful towers began to rise gracefully above the water, and their massive size astonished viewers. The towers are roughly 552 feet high and weigh 6,500 tons. Columns of steel-sheathed masonry, which are 116 feet in diameter and extend below the water to bedrock 200 feet beneath the piers' top, support the towers.

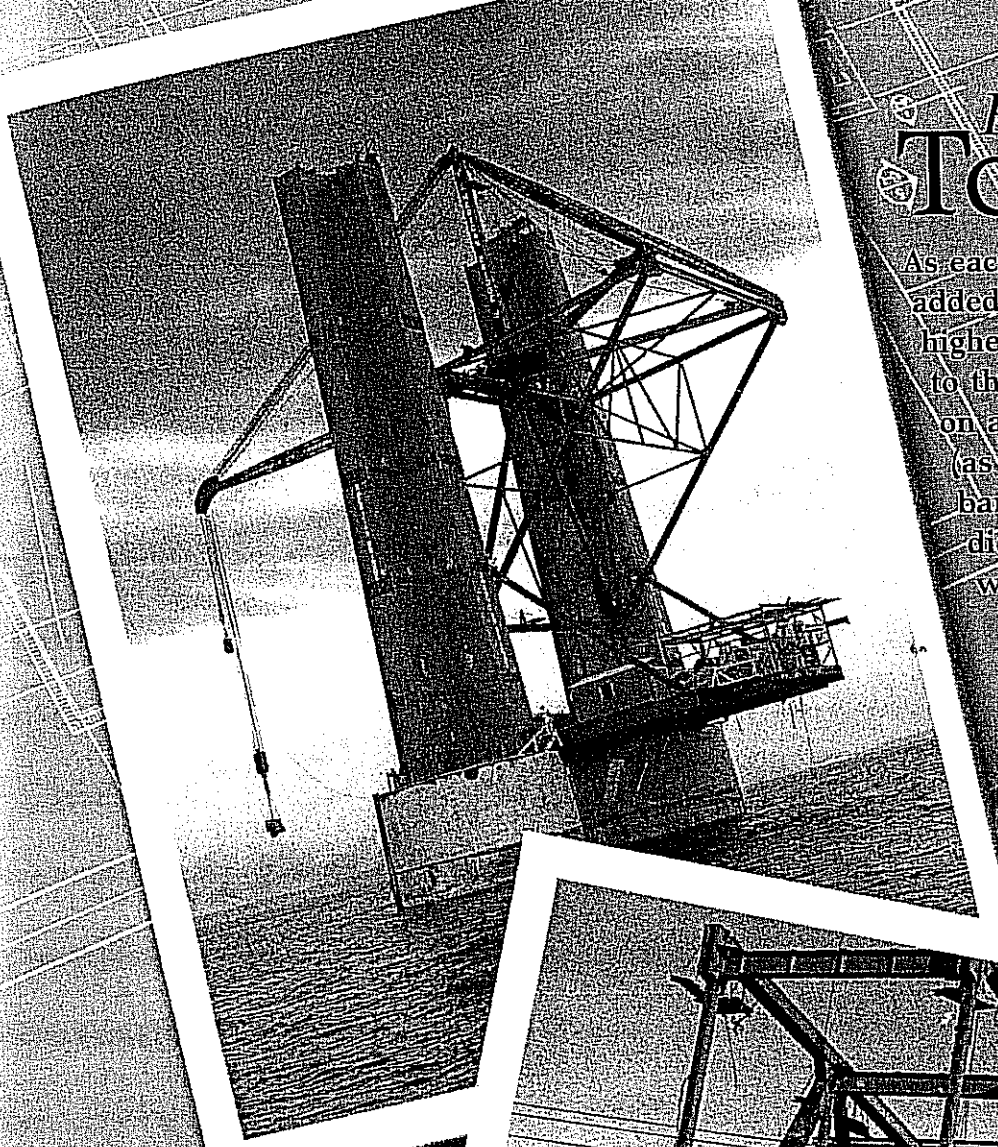
The steel towers were prefabricated, completely assembled and bolted together before being dismantled and shipped to St. Ignace. The entire steel framework of the bridge towers was assembled like a huge Erector set. The prefabricated sections were assembled in series of tiers, one set upon the next. Each tier consisted of four sections; when fully assembled they resembled a thick four-dimensional plus sign. Derrick barges worked well for lifting the first three tiers into place, up to 87 feet. Since the tiers weighed between 140 and 280 tons, and varied in height from 16 feet to just over 42 feet, lifting the massive remaining sections, safely, efficiently and to extreme heights would require another on-site invention. Thus, the Creeper was born.

A rather ugly triangular shaped device, the Creeper literally "creeped" up the cable towers. It could pick up a 100-ton section of tower, carry it 80 feet high and hold the section in place until the bridge crew secured it. Two diesel-lifting engines mounted on a stationary platform served as its power source.

The "creeping" mechanism was a three-legged "out-rigger-type" assembly with a triangular member that bolted to the tower shafts, giving stability while the mechanism was in operation. When an additional section was placed on the towers, the Creeper used its own lifting engines to hoist itself to a higher level. It was then rebolted to the tower.

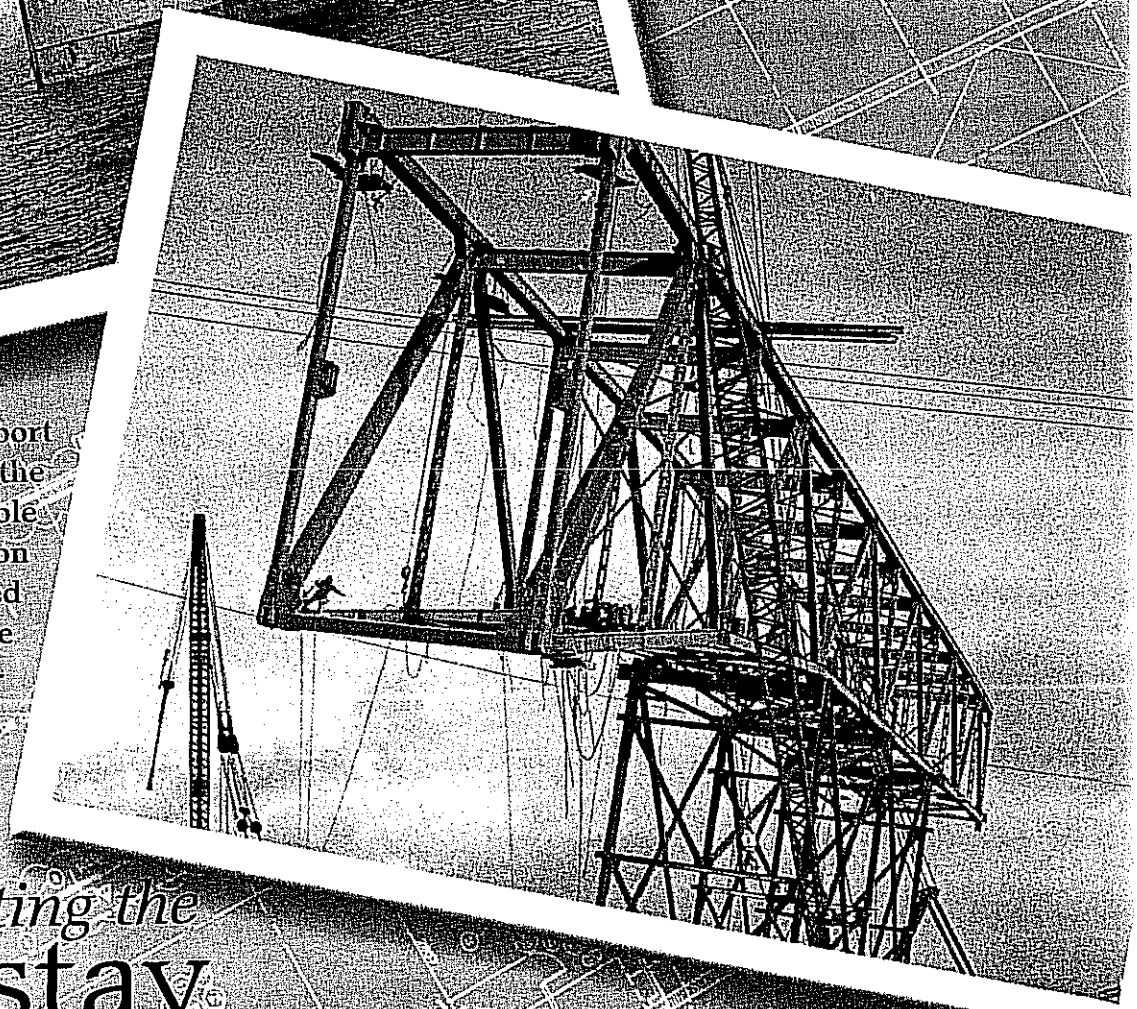
On the horizontal platform was a 90-foot boom that incorporated a 20-piece "block-and-tackle" arrangement. Using 3/4-inch wire rope, the system could lift up to 100 tons. The only restriction was

NUMBER OF WIRES IN EACH CABLE: 12,580



Raising the Towers

As each tower section was added, the Creeper moved to a higher level and was rebolted to the tower. Because it was on a non-moving structure (as opposed to a crane on a barge), Creeper operators did not have to contend with waves or current.



Side spans that support the road deck between the anchor blocks and the cable bents were mounted on two barges and lashed together. Because the structure was so top-heavy, contractors had to wait for calm weather before pulling them out into the Straits.

Connecting the Backstay

height—because of the angle of the boom and the distance between the upper and lower pulleys. Although limited, the Creeper could still lift tiered sections 70 to 80 feet above itself.

The Creeper was amazingly effective. Once it began to lift a 60-ton section there was little danger of dropping it. However, strong lake winds could cause the sections to bounce against already completed sections of the tower, damaging not only them but also the piece being lifted. Due to the enormous amount of weight being lifted, and the hazard poised by the fickle winds of the area, the Creeper was never used in rough weather. When the towers were completed—and the Creeper sat at the top of the tower—it had essentially lost its usefulness. It was unceremoniously disassembled and hauled away.

THE STORM OF '55

The most notorious adversary faced by the bridge builders was the temperamental Michigan weather. To stay on schedule, the team worked through grueling conditions. Summer temperatures soared well into the nineties, torrential rains swamped equipment, ice froze tools into place, gale force winds battered machines and men and Arctic cold froze fingers numb. Despite these conditions, a November storm in 1955 stands out in the memory of the builders.

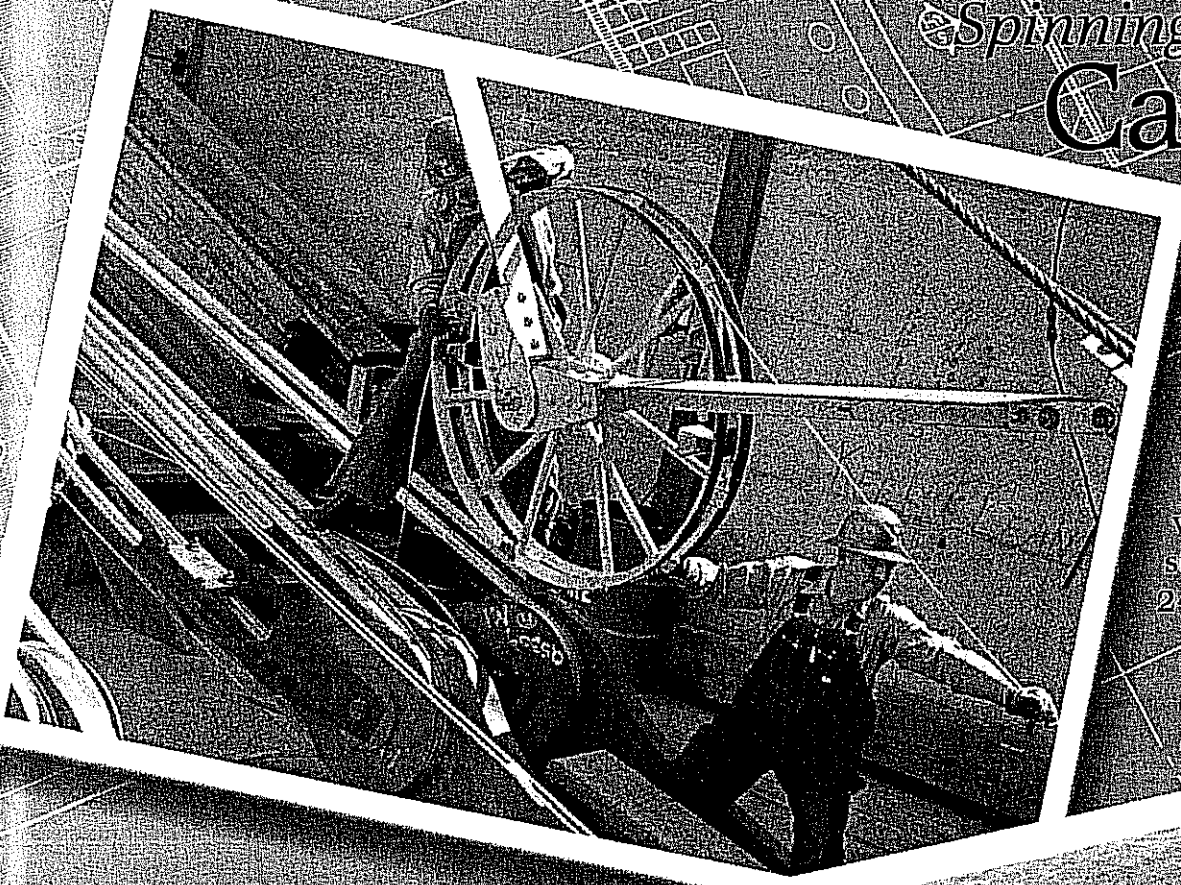
At this point in construction the bridge was ready to be fitted with its first truss span. Prefabricated off-site, the truss span would run between piers 17 and 18. When complete, it was 472 feet long and 38 feet tall and weighed 750 tons. The falsework or temporary framing needed to carry the truss span and to ensure it was elevated enough for workers to place it onto the two piers, was assembled aboard two transport scows. The massive truss span was perched on top. The gentle task of moving the truss span was now completely dependent on the weather. Any breeze alarmed the engineers and postponed the move. Their cautiousness was warranted.

Brisk 18-mile-per-hour breezes started the morning of November 16. During the next few hours, the wind whipped around from the southwest and raged at 75 miles per hour, near hurricane force. Working frantically in dangerous conditions, the work crews managed to bring most of the equipment into safe water, yet damage to the site was significant. The barge *Creole* broke anchor and was found several miles away with heavy damage; a second barge crashed against the rocks on Mackinac Island's west shore, its derrick boom toppled overboard.

The wind created whitecaps that poured over the piers; by nightfall, mountains of water were crashing across, against and over the uncompleted piers. The wind demolished the project's weather tower and downed electrical power lines throughout the region. The bridge towers, which were only half riveted together, took a brutal pounding. Trees on the surrounding islands were uprooted, roofs were blown from buildings, and two heavy welders were ripped from their platforms and dumped into the Straits. The winds destroyed bridge planking and temporary offices. Tarps covering newly poured grout were ripped to shreds, and three of the water-based survey towers were obliterated. But the two majestic bridge towers held, undamaged by the storm's fury. The biggest worry was whether the precariously balanced truss span would survive. Even over the deafening wind, workers could hear the groaning strains of the barges holding the truss span. Miraculously, the truss span, the falsework and the scows suffered no damage. In a tribute to the skill of the bridge's engineers, the incomplete towers had weathered the storm.

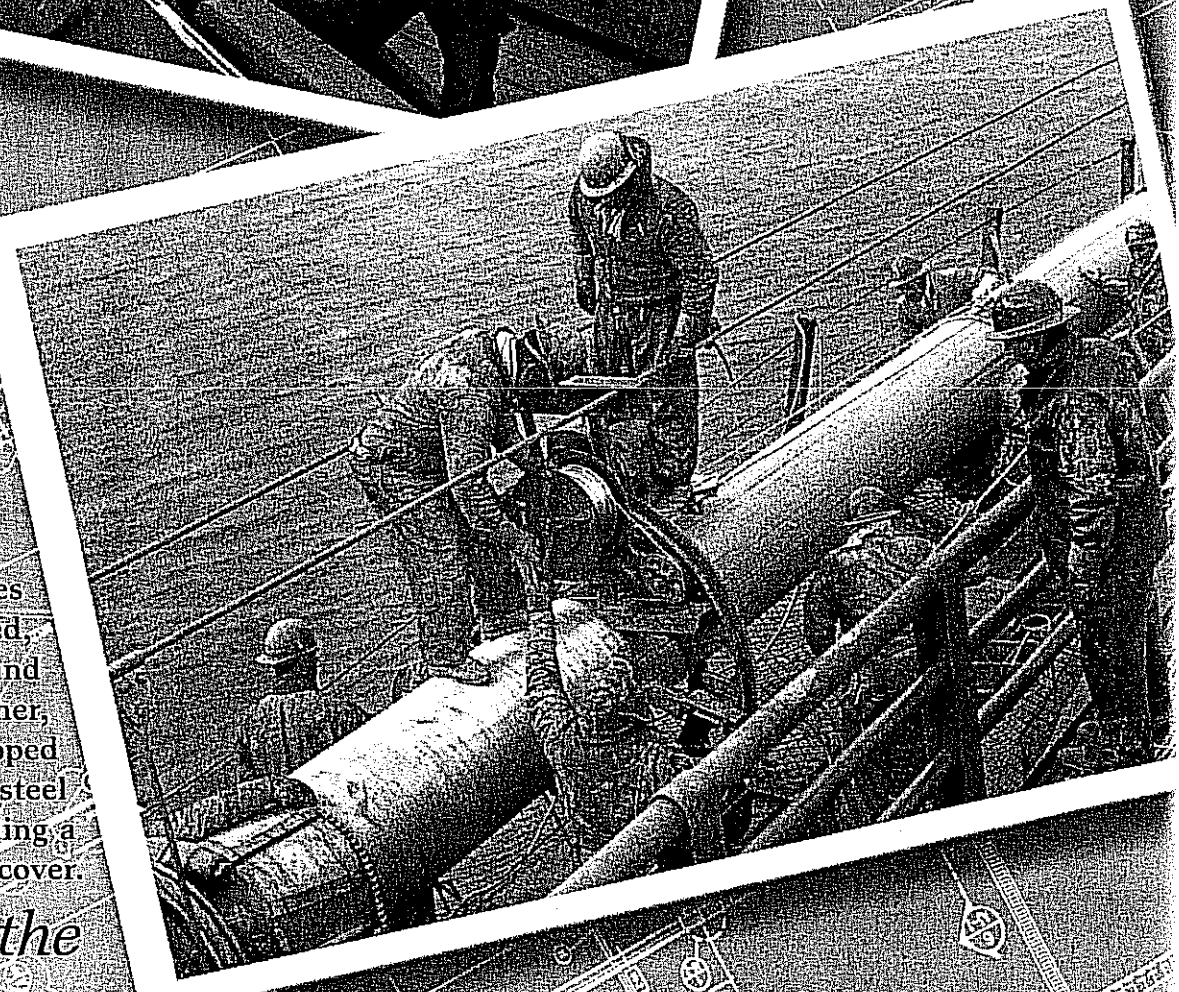
Three days later, the truss span was floated toward the bridge. The Coast Guard controlled shipping traffic and a small armada of tugs and other auxiliary craft led the two barges away from their dock and into the Straits.

TOTAL WEIGHT OF BRIDGE: 1,024,500 TONS



Spinning the Cables

Four cable spinning wheels carried wire across the span. Each wheel carried four wires to be included in a strand of 340 wires. Thirty-seven strands make up the 24-1/2 inch cable.



After the cables were measured, compacted and banded together, they were wrapped in pencil-thin steel wire, providing a watertight cover.

Wrapping the Cables

CABLE SPINNING

The sounds of cowbells echoed across the Straits in the summer and early fall of 1956. They were a whimsical safety reminder to the workers along the bridge's catwalks of the approaching danger from the spinning wheels. Spinning cable is an old, tried-and-true technique, first used in the construction of bridges 100 years ago by John A. Roebling, the father of modern bridge building. Although improved considerably through the years, it is essentially the same process. A spinning wheel carries wire across the bridge span, one loop after another, running it parallel to the previous loops until the desired number of loops of wire form one huge, round cable. The cable is not twisted, braided or woven. Historically referred to as "spinning cable," it is actually "strung" cable.

The 60,000 coils of wire for the Mackinac Bridge ran in lengths of 5,000 feet. The coils were spliced end-to-end to create the needed length of roughly 320,000 feet or 60 miles of continuous wire on each reel. Each spliced reel weighed in at over 19 tons.

Cable spinning on the Mackinac Bridge used four spinning wheels (two to a cable) with grooves resembling bicycle rims to carry loops of wire. Each loop held two wires—a moving or live wire that was drawn from a large reel mounted on an anchorage pier and a stationary or dead wire fastened to the same anchorage pier. The wire passed through a set of pulleys into a compensating tower atop the pier. By using a heavy chain counterweight, the compensating tower kept the correct tension on the cable.

Next, the wire traveled through another pulley to the spinning wheel. The wire was looped across the spinning wheel's top, fitting into one of two grooves on the wheel. This looped wire was carried to the strand shoes or anchoring points and temporarily bolted in place. The second wire drawn from a second reel was threaded identically across the bridge. Power was applied to the traveling rope, wire unreeled and workers with hooked poles reached up and pulled the wires into place, using the master wire as a guide. The winch operator completed the final adjusting, supervised by the surveyors.

Since this was in an era prior to cell phones, and satellite communication, men on the catwalk guided the winch operator's adjustments by the rings of a bell. The spinning wheels started in opposite directions and arrived at opposite anchorages. The process was repeated until the necessary size of cable wire was reached. The spinning wheels were four feet in diameter and could lay wire at about 700 feet per minute, about eight miles per hour. Both of the bridge's two-foot diameter cables have 37 strands of wire; each strand is made up of 340 wires. Each strand of each cable was designed to withstand a pulling load of 800,000 pounds. All 37 strands can withstand a pull of 15,000 tons.

THE ELEMENT OF DESIGN

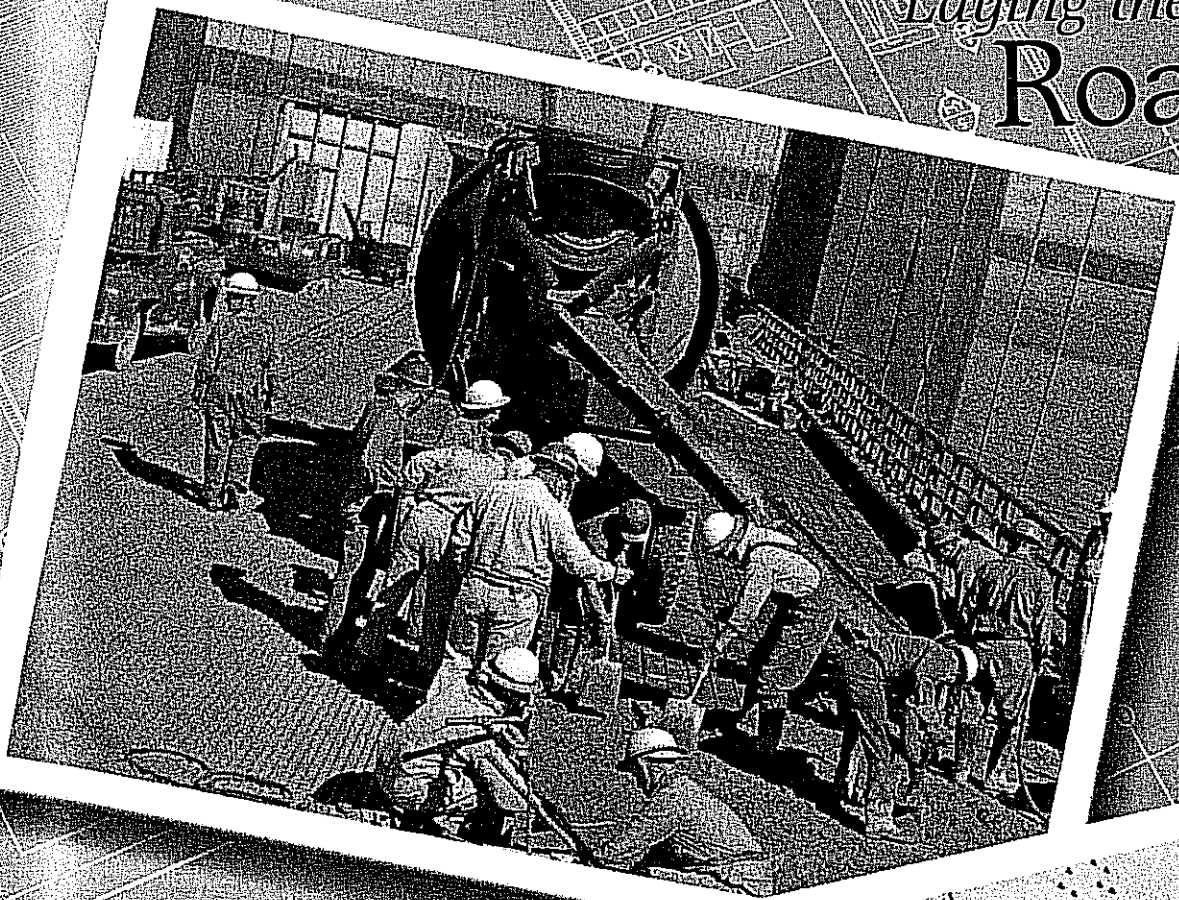
To appreciate the engineering, construction and mathematical genius involved in the bridge's creation, one must remember that the entire project was completed in an era before calculators, long before laser site surveying equipment existed and before computer-aided drafting was even a dream.

The Mackinac Bridge is a gentle ribbon of concrete and steel that seems to calm the ferocious soul of the beast lying within the waters of the Straits beneath it. Its massive, graceful towers inspire dramatic praise from all who see the bridge. The Mighty Mac has become the subject of poetic lyrics, photographic essays and artistic praise. Yet its purest art, its true artistic genius, lies hidden beneath its beautiful façade. It is the engineering brilliance of its creators that makes the Mackinac Bridge a true American legend. **mh**

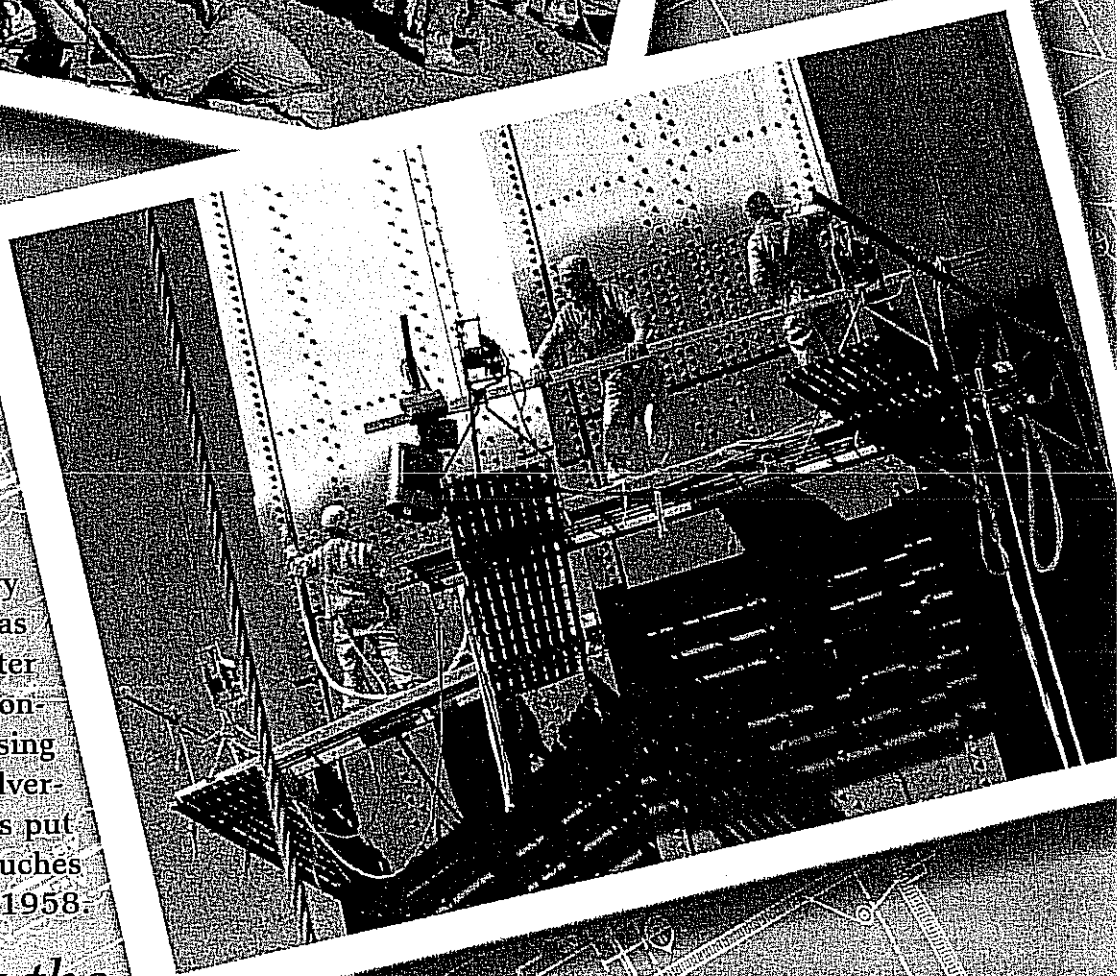
LINDA McMAKEN lives in Oregonia, Ohio. She wishes to thank Kim Nowack and Julie Neph, engineers of the Mackinac Bridge Authority, for reviewing this article. For more information on the building of the Mackinac Bridge, she suggests consulting David Steinman's *Miracle Bridge at Mackinac*.

TOTAL MEN EMPLOYED AT BRIDGE SITE: 2,500

Laying the Roadbed



Open grating on the two center lanes allows airflow, while the outer two lanes are made of lightweight concrete and covered in asphalt.



The green-and-ivory color scheme was decided upon after seeing an artist's concept of the bridge using these colors in an advertisement. Painters put the finishing touches on the bridge in 1958.

Painting the Bridge

Section 2

Dr. David B. Steinman

Steinman was responsible for the design and construction of over 400 bridges, including his most crowning achievement, the Mackinac Bridge. In addition to projecting himself as a world class structural engineer, Steinman is also a published author of eight books and poet. The following sources provide some background on Dr. Steinman and his many achievements.

1. Weingardt, Richard G. "David Barnard Steinman." Engineering Legends: Great American Civil Engineers. Reston: American Society of Civil Engineers, 2005. 66-72
2. Weingardt, Richard G. "George Dewey Clyde and David Barnard Steinman." Leadership and Management in Engineering. 4 no. 2. (April 2004.) 80-84.
3. David B. Steinman. (2009, July 9) In *Wikipedia, the free encyclopedia*. Retrieved Sept. 2009, fm http://en.wikipedia.org/wiki/David_B._Steinman.
4. Steinman, David B. "The Bridge at Mackinac." Miracle Bridge at Mackinac. Grand Rapids: Wm. B. Eerdmans, 1957.
5. Petroski, Henry. "Steinman." Engineer of Dreams: Great Bridge Buildings and the Spanning of America. New York: Alfred A Knopf, 1995. 320-374.

Prentiss M. Brown

Prentiss M. Brown, a Michigan native from St. Ignace, at the north end of the bridge, is often referred to as the "father" of the Mackinac Bridge due to his 20 year financial battle to construct the massive structure linking Michigan's two peninsulas. From humble beginnings as the Mackinac County prosecutor all the way up to the U.S. Senate and serving until his death as the Mackinac Bridge Authority chairman, Brown was devoted to public service. The Mackinac Bridge continues to serve commuters and tourists alike fulfilling Brown's dream of a unified State.

1. "Father of the Mackinac Bridge." *The Mackinac Bridge*. Michigan Department of Transportation. n.d. August, 2009. http://www.mackinacbridge.org
2. Prentiss M. Brown. (2009, April 25) In *Wikipedia, the free encyclopedia*. Retrieved Sept. 2009, fm http://en.wikipedia.org/wiki/Prentiss_M._Brown.
3. Brown, Prentiss M. The Mackinac Bridge Story. Detroit: Wayne University Press, 1956.

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Great American Civil Engineers

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Richard G. Weingardt, P.E.

Foreword by Henry Petroski, Ph.D., P.E.

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Engineering Legends

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ASCE PRESS

Library of Congress Cataloging-in-Publication Data

Weingardt, Richard.

Engineering legends : great America civil engineers : (32 profiles of inspiration and achievement) / Richard Weingardt.

p. cm.

Includes bibliographical references and index.

ISBN 0-7844-0801-7

1. Civil engineers—United States—Biography. I. Title: Great American civil engineers, 32 profiles of inspiration and achievement. II. Title: American civil engineers, 32 profiles of inspiration and achievement. III. Title: Civil engineers, 32 profiles of inspiration and achivement. IV. Title.

TA139W35 2005

624'.092'273—dc22 2005014120

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia 20191-4400
www.pubs.asce.org

ISBN 0-7844-0801-7
Manufactured in the United States of America.
15 14 13 12 11 10 09 08 07 2 3 4 5 6 7

Contents

Waddell was a role model and mentor to many budding engineering superstars, including the great David Steinman (of Mackinac Bridge fame). He conveyed to them that engineers have a moral obligation to share information to improve the profession and society. He wrote voluminously, using long hours on railroad and steamship journeys to record his investigations. His many important books on bridges—in addition to his first one on iron highway bridges—include *Bridge Engineering* (two volumes), *De Pontibus*, and *Economics of Bridge Work*.

> *"The science of bridge design lies mainly in the detailing."*
>
> JOHN WADDELL

As author of countless state-of-the-art engineering papers, John was awarded ASCE Norman Medals for three of his profession-altering writings in 1909, 1915, and 1918. His 1909 and 1915 award-winning papers delved into the advances in using high-strength steel alloys for bridge design, while his 1918 winner addressed the economics of steel arch bridges.

John's extensive writings dealt with more than engineering. A world-class big game hunter, fisherman, and sportsman, he held several world records and often wrote articles for fishing and hunting publications. Thrice, the Kansas City Whist Club elected him president.

In 1917, Waddell moved his company headquarters to New York City. It was renamed Waddell and Hardesty in 1927 when the brilliant Shortridge Hardesty—hand-picked by John from RPI's stellar class of 1908—became a partner. Currently, the company is called Hardesty and Hanover.

The flamboyant J. A. L. Waddell died in 1938. Six years earlier, at age 78, he had been awarded the Clausen Gold Medal by the American Association of Engineers for his distinguished career and his contributions around the world, and for his advancements to the social and economic well-being of the engineering profession.

David Barnard Steinman

In the middle of the twentieth century, from the mid-1920s to 1960, David B. Steinman was the nation's preeminent American-born designer of the long-span bridges, engineering more than 400 major bridges on five continents—a giant among his peers. He and his archrival, Swiss-born Othmar Ammann (1879–1965), dominated the American bridge-building scene. In their heyday, the two New York–based geniuses designed most of the suspension bridges that were built and had a hand in shaping the majority of the rest of them.

Of the two, Steinman designed a far greater number of major bridges than Ammann. His commissions came from every part of the world, and his designs were regularly hailed for their cutting-edge engineering and design innovations. He refined the use of exposed structural steel as art and pioneered the use of color and illumination on bridges. Over the years, doz-

ens of his structures were honored for being the most beautiful bridges in America and/or the world—many still are.

Although Ammann was responsible for two world record–holder suspension bridges (for longest span between towers), the George Washington Bridge (1931, 1,067 meters) and the Verrazano Narrows Bridge (1964, 1,298 meters), both of which are in New York, Steinman's masterpiece, the Mackinac Straits Bridge in Michigan (1957) held the title for being the world's longest suspension bridge (under-cable) at 2,626 meters. This record stood for more than 40 years, until 1998, when the Akashi Kaikyo Straits Bridge in Japan was completed.

David Steinman

Photo credit: NSPE

The record held by Ammann's George Washington Bridge lasted only six years. It was eclipsed by Joseph Strauss and Charles Ellis's Golden Gate Bridge (1,280 meters, San Francisco) in 1937. Twenty-seven years later, New York retook the title from California—by a mere 18 meters—at the completion of the Verrazano Narrows. The Verrazano (and the United States) lost its world title to the Humber Bridge (1,410 meters) in Britain 17 years later in 1981 (Weingardt 1998).

To Steinman, the Mackinac (the "Big Mack") would always be his crowning achievement. A commemorative U.S. postage stamp of the structure issued shortly after its completion recognized it as an American icon. When Postmaster General Arthur Summerfield personally presented him with a customized, first-issue album of the stamps in a formal ceremony on June 25, 1958, Steinman was in his element.

The unbelievable 1940 collapse of the Tacoma Narrows Bridge ("Galloping Gertie")—designed by Leon Moisseiff (1872–1943), a European-trained engineer who consulted with Strauss on the Golden Gate—sent chills through the U.S. engineering community. Designs of long-span suspension bridges went on hold, and Moisseiff's distinguished reputation was tarnished forever.

The disaster immediately prompted Steinman to study the aerodynamic stability of thin, narrow, long-span bridges. His research resulted in the publication of a series of authoritative articles on the subject and established him as the foremost expert on the aerodynamics of suspension bridges. This expertise, in the long run, is what allowed him to create his masterpiece—the elegant, streamlined, and perfectly aerodynamically stable Mackinac.

A genuine Horatio Alger success story, David Steinman figuratively rose from rags to riches. Born into poverty, he became a financial success beyond anyone's expectations and rose to the highest plateau in his field: one of the greatest bridge builders of all time.

David came into this world on June 11, 1887, a few months after the unveiling of the Statue of Liberty, whose framework was designed by the French engineer Gustave Eiffel. David was the seventh child of Eva Scollard

and Louis Steinman, an immigrant laborer family in a blighted tenement neighborhood on New York's East Side. A mathematics prodigy, he was the only family member to attend college. His five brothers and sister followed in their father's footsteps and became factory workers, constantly struggling to make a living.

It was from such abject poverty that the youngest Steinman vowed to escape and make his mark in the world. Early on, he was convinced that getting a comprehensive education, hard work, and thrift were the answers. While a youngster, he, like his siblings and many of his peers, worked at numerous odd jobs for pennies, including selling newspapers under the shadow of the majestic and awesome Brooklyn Bridge.

> *"I would gladly give up all my professional accomplishments to be able to create a single composition of exalting music. If I had my life to live over again, I would correct one omission—I would learn to play a musical instrument."*
>
> DAVID STEINMAN

Completed in 1883, the Brooklyn Bridge, with a clear span between towers of 833 meters, reigned as the world's longest suspension bridge. To young Steinman, it represented the outstanding engineering achievement of his day, and its builders the Roeblings—John, Washington, and Emily—became heroic figures in his eyes. As a feisty, ragged kid, he would mostly get chuckles when he pointed to the Brooklyn Bridge and told those around him, friends and adults alike, "Some day I'm going to build bridges like that!"

While still in high school, David started taking college classes at the City College of New York. There, he completed the first phase of his post–high school education, working at odd jobs to pay for his tuition and living expenses. He graduated summa cum laude with a bachelor of science degree in 1906 at the age of 20.

Immediately, he attended Columbia University and, by obtaining enough fellowships, scholarships, and nighttime jobs to stay the course, he earned three degrees. His education at Columbia culminated in 1911 with a Ph.D. in civil engineering. David's doctoral thesis "The Design of the Henry Hudson Memorial Bridge as a Steel Arch" foretold of an incredible project that would become a reality 25 years later.

In 1910, Steinman accepted a position at the University of Idaho, becoming the youngest civil engineering professor in the country. While there, he published *Suspension Bridges and Cantilevers: Their Economic Proportions and Limiting Spans*. He also translated two German books, *Theory of Arches and Suspension Bridges* and *Plain and Reinforced Concrete Arches*, establishing himself as a prolific academic with a practical bent.

After four years in Idaho, Steinman longed for New York and contacted Gustav Lindenthal, America's leading long-span bridge designer at the time, about working for him on the Hell Gate Bridge, which Lindenthal was in the midst of designing. David was hired on the spot and, on July 1, 1914, became Lindenthal's special assistant, second only to another young bridge-building star, Othmar Ammann. The experience of working

together on Hell Gate commenced a rivalry between the two that would last a lifetime.

The guns of war—World War I—started thundering across Europe shortly after David met his bride-to-be, Irene Hoffmann, on a trolley car ride on Long Island. Her father Dr. E. Franz Hoffmann, formerly on the faculty at the School of Medicine in Vienna, approved of Steinman, believing he had good prospects. Plus, he could intelligently discuss Kantian philosophy and world events with him.

Married on June 9, 1915, the young couple would have two sons and a daughter: John, Alberta, and David, Jr. John and David would become physicians specializing in psychiatry, and Alberta would become a renowned psychologist.

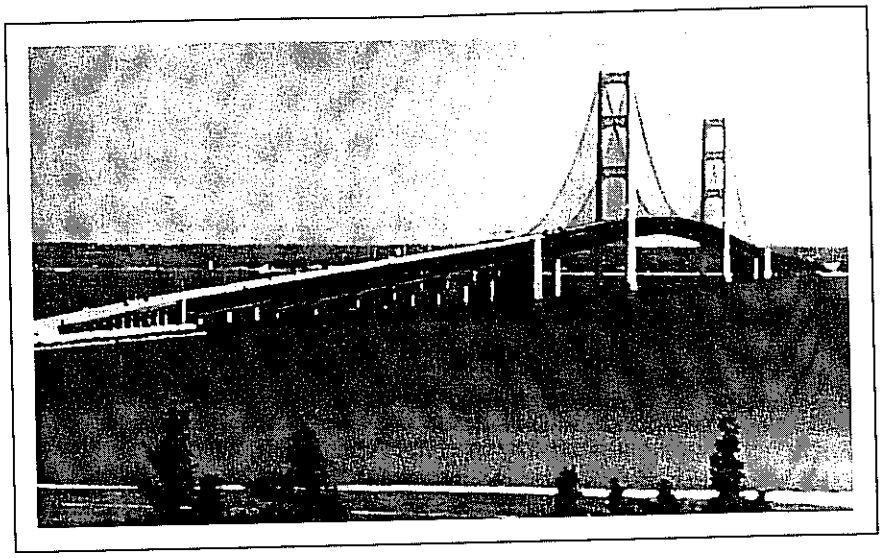
After his stint with Lindenthal, which, in addition to Hell Gate, included work on the important Sciotoville Bridge, another well-known U.S. bridge builder, John Waddell, employed Steinman. Waddell's main engineering office was located in Kansas City at the time; David was put in charge of his newly established New York office. While there, Steinman helped design the Marine Parkway Bridge.

From 1917 to 1920, Steinman was a part-time professor of civil and mechanical engineering at the newly formed engineering school at City College. In 1920, he opened his own consulting engineering office. His practice began slowly, and prospects looked quite bleak at the start. Recalled Steinman, "My first fee was $5, and for several months it was a difficult and discouraging struggle. Then Holton Robinson (1863–1945), who built the Manhattan and Williamsburg bridges, asked me to join him in a competition to build the Florianapolis Bridge in Brazil" (Ratigan 1959).

Their design proposal won and they were selected as the project's designers. Thus began a partnership—the firm of Robinson and Steinman—that would, over a 25-year period, design hundreds of impressive bridges around the world before Robinson's death in 1945. The Florianapolis, the largest-span bridge in South America when completed in 1926, was the largest eyebar-cable suspension bridge ever built and the first in the Americas to use rocker towers.

Next for Robinson and Steinman came the Carquinez Strait Bridge northeast of San Francisco, the fourth largest cantilever bridge in the world, and the Mount Hope Bridge over Narragansett Bay, Rhode Island. Commissions for the company quickly started flowing in from everywhere, several from overseas. Neither the 1929 stock market crash nor the Great Depression itself seemed to slow down the newly formed firm.

In late 1929, Steinman and Robinson designed the Grand Mere over the St. Maurice River in Quebec. The project introduced prestressed twisted wire rope-strand cables, a Steinman innovation that later debuted in the United States in 1931, with the simultaneous completion of the pair's St. John Bridge across the Willamette River in Portland, Oregon, and the Waldo-Hancock Bridge across the Penobscot near Bucksport, Maine. The Waldo-Hancock Bridge also featured the first-time use of Vierendeel trusses in bridge towers.



Mackinac Bridge

Stretching 17,913 feet across the Mackinac Straits in Michigan, the Mackinac Bridge was a 70-year dream come true when it was completed in 1957. The $100-million structure's two 24.5-inch-diameter main cables totaling 20,600 miles were spun in 78 days. The "Big Mack" held the title as the longest suspension bridge in the world until 1998.

Photo credit: Franklin Meyers and Gar Hoplamazian

Following those came many other noteworthy bridges such as the Henry Hudson (New York), Deer Isle (Maine), and Thousand Islands (linking Canada and the United States across the St. Lawrence River)—plus a wide assortment of significant structures outside the Western Hemisphere.

In 1947, Steinman was selected to do the reconstruction of the Brooklyn Bridge, the project that had first inspired him to become an engineer. He often said he considered it his supreme accolade to be chosen to modernize the Brooklyn Bridge.

In the late 1950s, Steinman was involved in designing the Messina Bridge, crossing the two-mile-wide Strait of Messina between Sicily and the Italian mainland. It would have been the world's longest suspension bridge by a huge margin. It still remained on the drawing board, however, when, on August 21, 1960, Steinman passed away in his beloved New York City at the age of 73.

A true believer in giving back to one's profession and helping advance it, Steinman served as president of a number of engineering groups, including the New York State Society of Professional Engineers, Society for the History of Technology, and American Association of Engineers (AAE).

As president of AAE, he began a national campaign for more professionalism and stringent educational and ethical standards within the engineering profession—and to get PE registration laws in every state in the union, as well as U.S. territories. He vigorously pushed the concept that engineering was a profession on a par with medicine, law, and science.

In 1934, he invited engineering leaders from four state professional engineering societies—Connecticut, New Jersey, New York, and Pennsylvania—to discuss forming a nationwide society of professional engineers. The result was the formation of the National Society of Professional Engineers (NSPE), for which he worked tirelessly to ensure its success (Robbins 1984).

Specifically, he was its first president (1934–1937, serving two terms), and, in his inaugural or keynote address, he emphasized a need to protect legitimate engineers against competition from the unqualified, from unethical practices, and from inadequate compensation. He sought to build public appreciation and recognition of the engineer.

An inspiring figure on the platform, Steinman made countless speeches on behalf of NSPE and the profession, giving depression-stricken engineers—many without jobs—renewed hope and faith in themselves and their profession. Every engineer could make the profession better than he or she found it by getting involved, he believed. What he promised the nation's engineers was pride in self, pride in profession, and pride in public service (AME 1960).

In addition to being a much-sought-after speaker, David was a prolific and accomplished author, writing both prose and poetry. He was the author of more than 600 professional papers and 20 books, among them *Bridges and Their Builders* (1941) with coauthor Sarah Watson; *The Builders of the Bridge* (1945), a best-selling biography of the Roeblings; and *I Built a Bridge and Other Poems* (1955). His 150-plus published poems included titles such as, "Brooklyn Bridge: Nightfall," "Blueprint," "The Harp," "The Song of the Bridge," and "The Challenge," in which he stated, "Nature said: 'You cannot,' Man replied: 'I can.'"

Over his illustrious career, Steinman received an unbelievable number of prestigious honors and tributes. In the period from 1952 to 1956 alone, he received more than 50 international awards, plaques, citations, and decorations, including the William Procter Prize (American Association for the Advancement of Science) and the 1954 Grand Croix de l'Etoile du Bien (French government). The only other recipient of this award in 1954 was Dr. Albert Schweitzer (Ratigan 1959).

In 1957, he was awarded five major medals:

1. The Kimbrough Gold Medal (American Institute of Steel Construction),
2. The George Goethals Medal (Society of American Military Engineers),
3. The Gzowski Medal (Engineering Institute of Canada),
4. The Louis Levy Medal (Franklin Institute), and
5. The Gold Medal of the Americas (Chamber of Commerce of Latin America).

The first of Steinman's 19 honorary degrees was a doctor of science from his alma mater, the City College, New York, in 1947. His doctor of engineering degree from Manhattan College in 1953 was conferred on him by the most eminent Cardinal Spellman on the occasion of the school's hundredth birthday. In 1957, he received a doctor of law degree from the University of Tampa; at the institution's graduation ceremony, he gave a commencement address titled "Moral Armor for the Atomic Age."

In his later years, Steinman became extremely philanthropic, especially in assisting needy and deserving students by establishing the David Stein-

man Foundation, the Irene Steinman Scholarship, and the Holton Robinson Scholarship. At City College, the school of engineering building—Steinman Hall—is named in his honor, as are numerous engineering awards programs around the world.

A man with many passions, Steinman was, for one, a skilled horseman, regularly riding his white stallion, Bill, at the head of the University of Idaho's Campus Day parades while a professor there. He shared a stamp-collecting hobby with his youngest son, David; he excelled at photography and loved classical music.

Said Steinman, "When I listen to a composition by Bach, Beethoven, Mozart or Schubert, I would gladly give up all my professional accomplishments to be able to create a single composition of exalting music. If I had my life to live over again, I would correct one omission—I would learn to play a musical instrument" (Raitgan 1959).

In its "turn of the millennium" special issue, *Engineering News-Record* honored Steinman as one of the greatest bridge engineers of all time. And his many outstanding bridges continue to be living monuments to that.

George Dewey Clyde and David Barnard Steinman

RICHARD G. WEINGARDT, P.E., HONORARY MEMBER, ASCE

GEORGE DEWEY CLYDE

A take-charge, no-nonsense two-term governor of the state of Utah (1957-1965), George Clyde was the only practicing civil engineer—a registered professional engineer (PE)—to hold such a lofty public position during the 20th century.

Prior to his election to Utah's highest office, Clyde was much sought after to fill public leadership roles in several areas, in large part, because of his expertise in water development and conservation— and because of his reputation as one of America's preeminent irrigation and hydraulic engineers. In 1945, for example, he was named chief of the Division of Irrigation Engineering and Water Conservation and Research for the U. S. Soil Conservation Service in Washington, D.C., and in 1953, as head of the Utah Water and Power Board.

While serving in those highly visible positions of power, Clyde was responsible for instigating the planning, design and construction of several notable water projects in the west. He was a major force behind the building of two crucial U.S. Bureau of Reclamation dams—the Flaming Gorge (Utah, 1964) and Glen Canyon (Arizona, 1963).

While governor, Clyde modernized Utah's state highway system and revamped its state road commission, creating a more efficient and professional department. He also broke ground for President Eisenhower's federal Interstate Highway System through Utah. During his reign, state highway construction increased by 500 percent.

In addition to road and bridge projects, Clyde secured funding for the design and construction of numerous other pressing public facilities. He built the University of Utah's world-renown Medical School and established Utah as the trendsetter among western states for public libraries, schools and park systems, including the creation of the Canyonlands National Park.

George Dewey Clyde was born in Mapleton, Utah, on July 21, 1898 to Elanora Jane Johnson and Hyrum Smith Clyde, a farmer. Active Mormons, Elanora and Hyrum instilled a strong work ethic and community spirit in their children, especially George who exhibited a passionate interest in scientific analysis early on.

After graduating from Springville High School, he attended Utah State University (then called Utah State Agricultural College) receiving a bachelor's degree in agricultural engineering. He then earned a master's degree in civil engineering from the University of California at Berkeley.

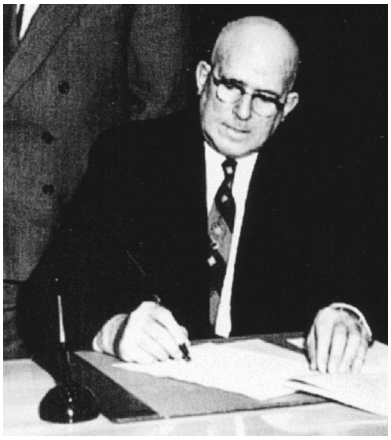
In 1919, he married Ora Packard. They would have five children, one of them, Ned, would later co-found Woodward-Clyde, which would develop into one of the world's largest and most respected geo-tech/environmental engineering firms, with numerous offices around the globe.

Armed with both a masters and bachelors degree in engineering, George immediately commenced his engineering career in 1923 by joining the Utah State engineering faculty in Logan, Utah. There he would teach continuously until he was called into full-time public service. After several years as a professor at the institution—specializing in agricultural, irrigation, hydraulic and water engineering—Clyde was named Dean of Engineering, a post he held until 1953. His advice was often sought by a wide-range of community leaders on matters dealing with his expertise.

In 1934, Utah Governor Henry Blood called on the 36-year-old civil engineer to fill the position of state water conservator to deal with Utah's worst drought in contemporary times. Even though the Great Plains states—Utah among them—were especially hard hit by the 1934 drought, its impact was nationwide. Along with the drought came a series of seemingly endless windstorms creating the terrible post-Depression Dust Bowl years.

The Dust Bowl era dramatically increased suffering among Americans nationwide, especially those already left destitute by the Great Depression. Banks closed everywhere and countless farmers lost hope, abandoned their lands and moved on, some to the west coast, others to beleaguered cities—all desperately in search of a better life.

In Utah itself, from June 1933 to May 1934, rainfall was barely 50 percent of normal. As state water conservator, Clyde's analysis of the state's water prospects in 1934 revealed that the



SPEC. COLLECT. ARCH., MERRILL LIBRARY, UTAH STATE.

George Dewey Clyde, 1957

state's lakes were at historic lows, and the supply of irrigation water only around a third of normal.

Clyde calculated that while, on average, around four million acre-feet of water ran through Utah's canals each year, less than one million acre-feet would be available in the future. He, further, revealed that few crops would be harvestable and only one cycle of alfalfa, a much-needed crop for the state's livestock industry, would likely mature. The state's sheep and cattle herds, so important to the area's economic well-being, faced an industry-threatening situation—and the state, as a whole, a strong likelihood a mass migration.

Clyde's report, along with his solutions on how to resolve the problems, were forwarded to Washington D.C. post haste by Blood and Robert Hinckley, Utah's director of the Federal Emergency Relief Administration (FERA). Within thirty-six hours, President Roosevelt approved an emergency grant of $600,000 for the state. The funds were quickly depleted and, following another appeal to FERA officials, the state received an additional $400,000.

In a little over three months, $1 million in federal assistance was distributed to a myriad of crucial projects identified by Clyde, Blood and Hinckly. Nearly 300 wells were sunk, 120 springs developed, 185 miles of irrigation ditches lined and 100 miles of pipeline laid. Plus, long-term solutions to drought—current and future—problems were initiated. They included the construction of dams and numerous reclamation projects statewide.

Soon after Utah's drought emergency was addressed, Clyde was appointed to the advisory board of the Utah Department of Industrial Development Water Resource Division. Shortly thereafter, he was elected director and vice-president of the Utah Water Users Association.

Even before construction of the massive, history-making Hoover Dam began in the early 1930s, Clyde was a strong supporter of controlling and utilizing the waters of the powerful Colorado River, especially the section running along the borders of Utah and Arizona. A key element in this grand plan was the proposed Upper Colorado River Storage Project. In an effort to finally get federal approval for the project, the powers to be in Utah decided that Clyde—with his national reputation for resolving important water issues—was needed as head of the Utah Water and Power Board.

After taking over the position in 1953, Clyde—with the help of U.S. Senator Arthur Watkins (R-Utah), a close friend of President Eisenhower— convinced the Administration and U.S. Congress of immense value of the Upper Colorado venture. Legislation to build it was officially signed into law on April 11, 1956, and final design and construction began immediately, on both Flaming Gorge and Glen Canyon.

As teacher, engineer and politician, Clyde authored a wide range of writings, including the oft-quoted article "History of Irrigation in Utah" (1959, *Utah Historical Quarterly*), and was the recipient of numerous public, industry and engineering honors.

In 1962, midway through his second term as governor, he was presented with an Honorary Doctor of Laws Degree from the University of Utah, an accolade he, as a pragmatic engineer, often took great pleasure in.

Clyde declined running for a third term in 1965, and calmly, without fanfare, left Utah's highest office and public life forever, to once again become a private citizen. He joined his son Ned's burgeoning engineering company and spent the rest of his career as an engineering consultant.

On April 2, 1972, the 74-year-old professor-governor-engineer quietly passed away at his home, after suffering a debilitating stroke one year earlier. The tremendous impact of his leadership, both within and beyond engineering, though, will last forever.

DAVID BARNARD STEINMAN

In the middle part of the 20th century, from the mid-1920s until 1960, David B. Steinman was the nation's preeminent American-born designer of the long-span bridges, engineering more than 400 major bridges on five continents — a giant among his peers. He and his archrival, Swiss-born Othmar Ammann (1879-1965), dominated the American bridge-building scene. In their heyday, the two New York-based geniuses designed most of the suspension bridges that were built and had a hand in shaping the majority of the rest of them.

Of the two, Steinman designed a far greater number of major bridges. His commissions came from every part of the world—and his designs were regularly hailed for their cutting-edge engineering and design innovations. He refined the use of exposed structural steel as art and pioneered the use of color and illumination on bridges. Over the years, dozens of his structures were honored for being the most beautiful bridges in America and/or the world—many still are.

Although Ammann was responsible for two world record-holder suspension bridges (for longest span between towers), the George Washington (1931, 1067 meters) and Verrazano Narrows (1964, 1298 meters), both in New York, Steinman's masterpiece, the Mackinac Straits Bridge in Michigan (1957) held the title for being what was the world's longest suspension bridge (under-cable) at 2626 meters. A record that stood for over 40 years, until 1998 when the Asashi Kaikyo Straits Bridge in Japan was completed.

The record held by Ammann's George Washington Bridge lasted only six years. It was eclipsed by Joseph Strauss' Golden Gate Bridge (1280 meters, San Francisco) in 1937. Twenty-seven years later, New York retook the title from California—by a mere 18 meters—upon the completion of the Verrazano Narrows. The Verrazano (and the USA) lost its world title to

NATIONAL SOCIETY OF PROFESSIONAL ENGINEERS

David B. Steinman 1953

the Humber Bridge (1410 meters) in Britain 17 years later in 1981.

To Steinman, the Mackinac (the "Big Mack") would always be his crowning achievement. A commemorative U.S. postage stamp of the structure issued shortly after its completion recognized it as an American icon. When Postmaster General Arthur Summerfield personally presented him with a customized, first-issue album of the stamps in a formal ceremony on June 25, 1958, Steinman was in his element.

The unbelievable 1940 collapse of the Tacoma Narrows Bridge ("Galloping Gertie") – designed by Leon Moisseiff (1872-1943), a European-trained engineer who was one of the main consultants to Strauss on the Golden Gate—sent chills through the U.S. engineering community. The future design of long-span suspension bridges went on hold—and Moisseiff's distinguished reputation was tarnished forever.

The disaster immediately prompted Steinman to intensely study the aerodynamic stability of thin, narrow long-span bridges. His research resulted in the publication of a series of authoritative articles on the subject and established him as the foremost expert on the aerodynamics of suspension bridges. This expertise, in the long run, is what allowed him to create his masterpiece— the elegant, streamlined and perfectly aerodynamically stable Mackinac.

A genuine Horatio Alger success story, David Steinman figuratively rose from rags to riches. Born into poverty, he became a financial success beyond anyone's expectations and rose to the highest plateau in his field: one of the greatest bridge builders of all time.

David came into this world on June 11, 1887—a few months after the unveiling of the Statue of Liberty, whose framework was designed by the great French engineer Gustav Eiffel. David was the seventh child of Eva Scollard and Louis Steinman, an immigrant laborer family in a blighted tenement neighborhood on New York's East Side. He was a mathematical prodigy and was the only family member to attend college. His five brothers and sister followed in their father's footsteps and became factory workers, constantly struggling to make a living.

It was from such abject poverty that the youngest Steinman vowed to escape and somehow make his mark in the world. Early on, he was convinced that getting a comprehensive education—and hard work and thrift—were the answers. While a youngster, he, like his siblings and many of his peers, worked at numerous odd jobs for pennies, including selling newspapers under the shadow of the majestic and awesome Brooklyn Bridge.

Completed in 1883, the Brooklyn, with a clear span between towers of 833 meters, reigned as the world's longest suspension bridge. To young Steinman, it represented the outstanding engineering achievement of his day, and its designers the Roeblings—John, Washington and Emily—became heroic figures to him. As a feisty, ragged kid, he would often get a chuckle when he would point to the Brooklyn and tell his friends and adults, "Some day I'm going to build bridges like that!"

While still in high school, David started taking college classes at the City College of New York. There he completed the first phase of his post-high school education, working at odd jobs to pay for his tuition and living expenses. He graduated summa cum laude with a Bachelor of Science degree in 1906 at the age of 20.

Immediately thereafter he attended Columbia University and after obtaining enough fellowships, scholarships and nighttime jobs to stay the course, he earned three degrees. His education at Columbia culminated in 1911 with a Ph.D. in civil engineering. David's doctorial thesis "The Design of the Henry Hudson Memorial Bridge" foretold of an incredible project that would become a reality 25 years later.

In 1910, Steinman accepted a position at the University of Idaho, the youngest civil engineering professor in the country. While there, he published *Suspension Bridges and Cantilevers: Their Economic Proportions and Limiting Spans*. He also translated two German books, *Theory of Arches and Suspension Bridges* and *Plain and Reinforced Concrete Arches*, establishing himself as a prolific academic with a practical bent.

After four years in Idaho, Steinman longed for New York and contacted Gustav Lindenthal (1850-1935), America's leading long-span bridge designer at the time, about working for him on the Hell's Gate Bridge, which Lindenthal was in the midst of designing. He was hired and, on July 1, 1914, he became Lindenthal's special assistant, second only to another young bridge building star, Othmar Ammann. The experience of working together on Hell's Gate commenced a rivalry between the two that would last a lifetime.

The guns of war—World War I—started thundering across Europe shortly after David met his bride-to-be, Irene Hoffmann, on a trolley car ride in Long Island. Her father Dr. E. Franz Hoffmann, formerly on the faculty at the School of Medicine in Vienna, approved of Steinman, believing he had good prospects. Plus, he could intelligently discuss Kantian philosophy and world events with him.

Married on June 9, 1915, The young

couple would have two sons and a daughter: John, Alberta and David, Jr. John and David would become M.D.s, specializing in psychiatry, and Alberta would become a renowned psychologist.

After his stint with Lindenthal, which in addition to Hells' Gate included work on the important Sciotoville Bridge, Steinman was employed by another well-known U.S. bridge builder, John Waddell. Waddell's main engineering office was located in Kansas City at the time and David was put in charge of his newly established New York office. While there, Steinman helped design the Marine Parkway Bridge.

From 1917 until 1920, Steinman was a part-time a professor of civil and mechanical engineering at the newly formed engineering school at City College. In 1920, he opened his own consulting engineering office. His practice began slowly—and things were quite bleak at the start. Recalled Steinman, "My first fee was $5 and for several months it was a difficult and discouraging struggle. Then Holton Robinson (1863-1945), who built the Manhattan and Williamsburg bridges, asked me to join him in a competition to build the Florianapolis Bridge in Brazil."

Their design proposal won and they were selected as the project's designers. Thus began a partnership—the firm of Robinson and Steinman—which would, over a 25 year period, design hundreds of noteworthy and impressive bridges around the globe before Robinson's death in 1945. The Florianapolis, the largest-span bridge in South America when completed in 1926, was the largest eyebar-cable suspension ever built and the first in the Americas to use rocker towers.

Next for Robinson/Steinman came the Carquinez Strait Bridge northeast of San Francisco, the fourth largest cantilever bridge in the world, and the Mount Hope Bridge over Narragansett Bay, Rhode Island. Commissions for the company quickly started flowing in from everywhere, several from overseas. Neither the 1929 Stock Market Crash nor the Great Depression itself seemed to slow down the newly formed firm.

In late 1929, Steinman/Robinson designed the Grand Mere, over the St. Maurice River in Quebec. The project introduced prestressed twisted wire rope-strand cables, a Steinman innovation that later debuted in the U.S. in 1931, with the simultaneous completion of the pair's St. John's Bridge across Willamette River in Portland, Oregon and the Waldo-Hancock Bridge across the Penobscot near Bucksport, Maine. The Waldo-Hancock additionally featured the first-time use of Vierendeel trusses in bridge towers.

Following those came many other noteworthy bridges like the Henry Hudson (New York), Deer Island (Maine) and Thousand Islands (linking Canada and the U.S. across the St. Lawrence River)—plus, a wide assortment of significant structures outside the western hemisphere.

In 1947, Steinman was selected to do the reconstruction of Brooklyn Bridge— the project that inspired him to become an engineer. He often said he considered it his supreme accolade to be chosen to modernize the Brooklyn.

In the late 1950s, Steinman was involved in designing the Messina Bridge, crossing the two-mile wide Strait of Messina between Sicily and the Italian mainland. It would have been the world's longest suspension bridge by a huge margin. It still remained on the drawing board, however, when on August 21, 1960 Steinman passed away in his beloved New York City, at the age of 73.

A true believer in giving back to and helping to advance one's profession, Steinman served as president of a number of engineering groups, including the New York State Society of Professional Engineers, Society for the History of Technology, and American Association of Engineers (AAE).

As president of AAE, he began a national campaign for more professionalism, and stringent educational and ethical standards within the engineering profession—and to get P.E. registration laws in every state in the Union, including U.S. Territories. He vigorously pushed the concept that engineering was a profession on par with medicine, law and science.

In 1934, he invited engineering leaders from four state professional engineering societies—Connecticut, New Jersey, New York and Pennsylvania—to discuss forming a nationwide society of professional engineers. The result was the formation of the National Society of Professional Engineers (NSPE), for which he worked tirelessly for years to ensure its success.

He was its first president (1934-1937, serving two terms) and, in his inaugural/keynote address, he emphasized the need to protect legitimate engineers against competition from the unqualified, from unethical practices and from inadequate compensation—and to build public appreciation and recognition of the engineer.

An inspiring figure on the platform, Steinman made countless speeches over much of the land on behalf of NSPE and the profession, giving depression-stricken engineers—many without jobs —renewed hope and faith in themselves and their profession. Every engineer could make the profession better than he or she found it if they would get involved. What he promised the nation's engineers was pride in self, pride in profession, and pride in public service.

In addition to being a much sought after speaker, David was a prolific and accomplished author, writing both prose and poetry, He authored some 600 professional papers and 20 books, among them *Bridges and Their Builders* (1941), co-authored with Sarah Watson, *The Builders of the Bridge* (1945), a best-selling biography of the Roeblings, and *I Built a Bridge and Other Poems* (1955). His 150-plus published poems included titles like, "Brooklyn Bridge: Nightfall," "Blueprint," "The Harp," "The Song of

the Bridge," and "The Challenge," in which he stated, "Nature said: 'You cannot,' Man replied: 'I can'."

Over his illustrious career, Steinman received an unbelievable number of prestigious honors and tributes. In the period from 1952-56, alone, he received more then 50 international awards, plaques, citations and decorations, including the William Procter Prize (American Association for the Advancement of Science) and the 1954 Grand Croix de l'Etoile du Bien (French Government)—the only other recipient of the award in 1954 was Dr. Albert Schweitzer.

In 1957, he was awarded five major medals: 1. The Kimbrough Gold Medal (American Institute of Steel Construction), 2. The George Goethals Medal (Society of American Military Engineers), 3. The Gzowski Medal (Engineering Institute of Canada), 4. The Louis Levy Medal (Franklin Institute), and 5. The Gold Medal of the Americas (Chamber of Commerce of Latin America).

The first of Steinman's 19 honorary degrees was a Doctor of Science, from his alma mater, the City College, New York in 1947. His Doctor of Engineering degree from Manhattan College in 1953 was conferred on him by the most imminent Cardinal Spellman, on occasion of the school's 100th birthday. In 1957, he received a Doctor of Laws degree from the University of Tampa; at the institution's graduation ceremony, he gave the commencement address titled "Moral Armor for the Atomic Age."

In his later years, Steinman became extremely philanthropic, especially with regard to assisting needy and deserving students, and established the David Steinman Foundation, the Irene Steinman Scholarship and the Holton Robinson Scholarship. The school of engineering building – Steinman Hall – at City College, is named in his honor, as are numerous engineering awards programs around the country and the world.

A man with many passions, David was, for one, a skilled horseman, regularly riding his white stallion "Bill" at the head of the University of Idaho's Campus Day parades, while a professor there. He shared a stamp-collecting hobby with his youngest son David, excelled at photography and loved classical music.

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Richard G. Weingardt, P.E., Hon.M.ASCE, is the chairman and chief executive officer of Richard Weingardt Consultants, Inc., Denver. He can be reached by e-mail at Reingardt@aol.com. LME

David B. Steinman

From Wikipedia, the free encyclopedia

You may also be looking for David Steinman, American environmentalist.

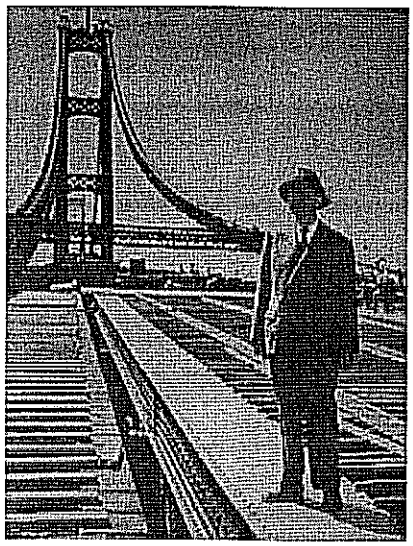
David Bernard Steinman (June 11, 1886[1] - August 21, 1960) was an American structural engineer. He was the designer of the Mackinac Bridge and many other notable bridges, and a published author. He grew up in New York City's lower Manhattan, and lived with the ambition of making his mark on the Brooklyn Bridge that he lived under. In 1909 he received a Master of Arts from Columbia University and a Doctorate in 1911.

Contents

David Steinman built bridges in the United States, Thailand, England, Italy, Haiti, Puerto Rico, Canada, Korea, and Iraq. He had a literary bent, and was a published author with several books, articles in advancement of his craft, and even had children's books and poetry to his credit.

"A bridge is a poem stretched across a river, a symphony of stone and steel"
-- a line from his poem[2]
Brooklyn Bridge - Nightfall[3]

Early life

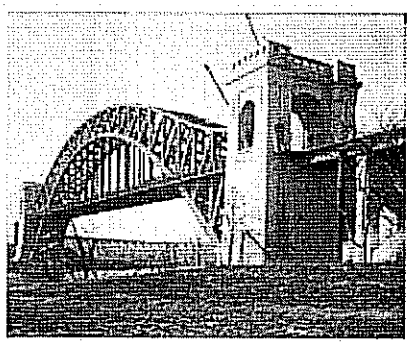

Steinman on the Mackinac Bridge

Steinman was the child of immigrant workers. Little is known of his family and early childhood other than that he had 6 siblings. There is some controversy about where and when he was born. Some sources[4] have him born in Khomsk, Brest, Belarus in 1886, and emigrating to the United States with his family in 1890. However other sources, including Ratigan,[5] and Steinman himself[6] have him born in New York in 1887.

In any case, regardless of where he was actually born, he grew up in New York City, New York, and was raised in the shadows of the Brooklyn Bridge. The Williamsburg Bridge was constructed as he grew up. The late Nineteenth and early Twentieth centuries were a time of significant bridge construction in the area, and he later said this is where he got his first interest in bridges.

Because his family had little money, he worked to put himself through both the City College of New York, graduating Summa Cum Laude in 1906 and then Columbia University, where he completed 3 additional degrees culminating in a PhD in Civil Engineering. His PhD thesis was on a steel truss arch design for the Henry Hudson Bridge. While he was attending Columbia he did fellowships as well as taught nighttime classes at the City College and Stuyvesant Evening High School. He accepted a teaching position at the University of Idaho in Moscow, Idaho (1910-1914) but longed to return to New York.

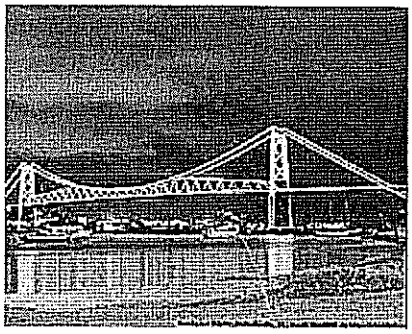
Start at bridge building


Hell Gate, NYC, NY, cantilever arch suspension, as it looked in 1917

After contacting Gustav Lindenthal about working on the Hell Gate Bridge, he returned to New York City to become a special assistant to Lindenthal, along with Othmar Ammann of Switzerland, another young bridge builder. It was said this experience of working together led to their 40 year professional rivalry. Pay was typical for the era, 200-225 USD/month. Lindethal gave his proteges advice about engineering such as, "Steinman, bridge engineering is easy. It is the financial engineering that is hard" (Petroski 327). While working with Lindenthal, Steinman also worked on the Sciotoville Bridge, a crossing of the Ohio River. After this work Steinman sought other employment, working as assistant engineer on the Rondout Creek Bridge, and as an assistant engineer for the New York Central Railroad.

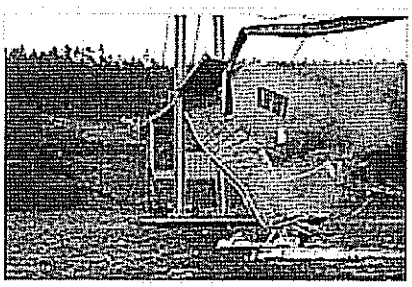
Robinson & Steinman

In May 1920, Holton D. Robinson (b. 1863, Massena, NY, d. 1945, engineer of the Williamsburg Bridge) contacted Steinman and requested that they join forces to create a design for the Florianópolis Bridge (or Hercilio Luz Bridge, 1926) in Florianópolis, Brazil. After getting advice from Charles Fowler, Steinman agreed and they formed the firm of Robinson & Steinman (http://en.structurae.de/firms/data/index.cfm?ID=f000173) in 1921, a partnership that lasted until the 1940s. They did not win the contract immediately but continued to collaborate on it and other projects. The early 1920s were considered a tough time for bridge construction, so Steinman tried to design his bridges to be economically pleasing rather than artistic, without sacrificing the structural integrity of the bridge. For example, Robinson and Steinman changed the original plans for the Florianopolis bridge, using eyebar chains as the upper chord of the stiffening truss instead of the conventional wire-cable. The new design produced a very stiff bridge with much less material than the original plan. Other bridge engineers would also have to take this new economical design into account when competing with Steinman. Steinman was well regarded in the profession and had a reputation for good presentations and for being politically astute.


Hercilio Luz, Florianópolis Brazil, suspended truss

The 1920s and 1930s were a relatively busy period for Steinman. His firm was involved in many significant projects including the Hercilio Luz Bridge (or Florianópolis Bridge, 1926), the Carquinez Strait Bridge (1927, at the time the second largest cantilever bridge in the US), the Mount Hope Bridge and Grand Mère Suspension Bridge (both 1929), the St. John's Bridge and Waldo-Hancock Bridge (both 1931), the Sky Ride (1933 passenger transporter bridge at the Chicago Century of Progress exposition), the Henry Hudson Bridge (1936, particularly gratifying as this bridge realised his PhD thesis proposal), the Wellesley and Hill Islands Bridge, Wellesley Island Suspension Bridge and Georgina Island Bridge (all 1938) and Deer Isle Bridge and the Sullivan-Hutsonville Bridge (both 1939) (many of these are part of the Thousand Islands Bridge System).

In addition to the many bridges that Steinman designed, he was consulted on several projects that his firm did not win. Perhaps the most famous of these bridges is "Galloping Gertie", the original Tacoma Narrows Bridge. Steinman consulted extensively with the boosters of the bridge during the 1920s, but his design was not selected. He wrote of his frustration with the design that was chosen, and predicted a failure. He presented his findings at the 1938 meeting of the structural division of the American Society of Civil Engineers. In the audience was the designer of the Tacoma Narrows Bridge, which was under construction at the time. The failure did occur and he wrote that it had a profound impact on his design principles; he became even more conservative. It is said that he designed the Mackinac Bridge considered by many to be his most significant work, to withstand winds of 365 mph.

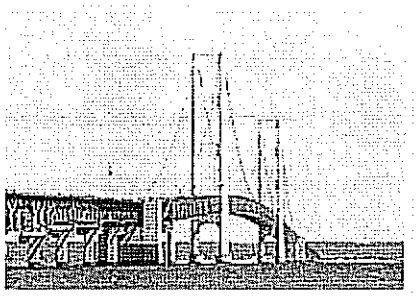

The Tacoma Narrows Bridge in mid collapse

During this period Steinman became president of the American Association of Engineers and campaigned for more stringent educational and ethical standards within the profession. He also founded the National Society of Professional Engineers in 1934 serving as its first president. By the mid 1930s Steinman had a professional reputation as one of the pre-eminent bridge engineers of the US, especially for long span suspension bridges, but his bridges were eclipsed in the public eye by his old rival Ammann's George Washington Bridge (1931) and by Joseph Strauss's Golden Gate Bridge (1937) among others. His plans for

a NYC cross harbor bridge (the "Liberty Bridge") came to naught with the 1940 collapse of Tacoma Narrows which cast all long suspension span proposals in doubt.

Postwar work

Steinman and his firm were also in charge of the major rehabilitation of the Brooklyn Bridge commencing 1948. Structurae.de has an image (http://en.structurae.de/files/photos/r0000012/steinman1.jpg) (from Petrovsky's text) of Steinman jauntily perched in mid air in the cables of the bridge, perhaps one of the best known images of him extant.



Steinman's crowning achievement, the "Mighty Mac" or Mackinac Bridge

But there were still long span suspension bridges to be built. Steinman was responsible for the Kingston-Rhinecliff Bridge (1957). More importantly, development and planning of the Mackinac Bridge had been contemplated for some time, and Steinman was appointed to the board of engineers based on Michigan State Legislature legislation of 1950, stating "the board of engineers retained by the Mackinac Bridge Authority was to be selected and nominated by the Dean of Engineering at the University of Michigan", and was soon the spokesman for the board. But his health was failing and he suffered heart attacks in 1952, the same year the legistlature approved funding. He was nevertheless heavily involved in all aspects of the construction of the bridge from start to finish.

Although he proposed a grandiose 1524 meter center span crossing of the Sicilian Straits of Messina, the "Mighty Mac", completed in 1957, and at the time the longest suspended span between anchors, was his last major achievement. Steinman died in 1960. At the time of his death, he was president of the Society for the History of Technology.

The Steinman engineering firm is now part of the Parsons Transportation Group (company site (http://www.parsons.com/)) as of 1988.

Personal Life and Hobbies

At the age of 63, Steinman took interest in poetry. Many people wrote to him saying his bridges represented poems. This inspired him to start writing. His love for bridge building was reflected in his writing, which can be seen in the titles of two of his poems, "The Bridge" and "I Built a Bridge". He received much recognition for his poetry; many poems were published in various newspapers and magazines. Continuing his natural ability to lead, Steinman became involved in leadership roles in many poetry groups including the president of the Wisconsin Poetry Foundation and director of the Poetry Institute in New York.

Notes

1. ^ most probable date
2. ^ as cited here: poem (http://www.endex.com/gf/buildings/bbridge/bbpoetry/bbpoemsteinman.htm)
3. ^ chosen by the ASCE as his tag line on their flash presentation (http://www.asce.org/history/bio_steinman.html) of his entry in the 50 most notable civil engineers of the US.
4. ^ For example, his biography (http://en.structurae.de/persons/data/index.cfm?id=d000035) at Structurae

5. ^ Ratigan, W. (1959). "Highways Over Broad Waters." Grand Rapids: Wm. B. Eerdmans Publishing. ASIN B0007IY0OC, page 11; "a boy born under the shadow of the Brooklyn Bridge"
6. ^ The back flap biography of Steinman's children's book, "Famous Bridges of the World" also references NYC

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External links

- David Bernard Steinman (http://en.structurae.de/persons/data/index.cfm?ID=d000035) information at Structurae (accessed 15 March 2005 and again 29 January 2006)
- Bio (http://www.asce.org/history/bio_steinman.html) at American Society of Civil Engineers site

Categories: American civil engineers | Bridge engineers | Structural engineers | 1886 births | 1960 deaths | City University of New York people | Columbia University alumni | University of Idaho faculty

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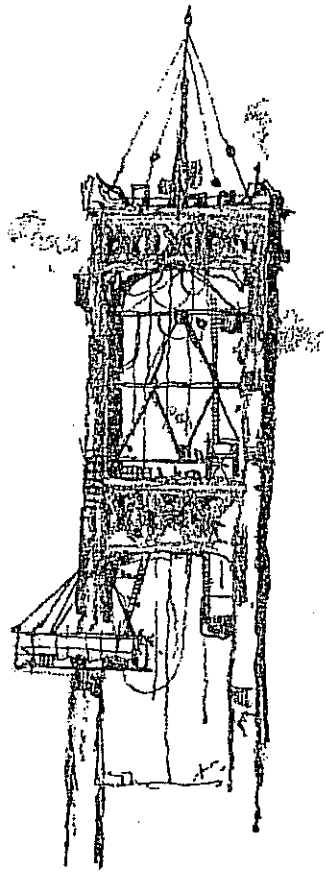

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JOHN T. NEVIL

Charcoal Drawings a

REYNOLD H. WEID

Wm. B. Eerdmans Publ

BRIDGE MACKINAC

by

DAVID B. STEINMAN

in collaboration with

JOHN T. NEVILL

Charcoal Drawings and Mezzotints by

REYNOLD H. WEIDENAAR

Wm. B. Eerdmans Publishing Co., Grand Rapids, Michigan

Library of Congress catalog number: 57:13037.

Printed in the United States of America.
First printing, September 1957
Second Printing, November 1957
Third printing, April 1958
Fourth printing, December, 1958

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New York

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To

PRENTISS M. BROWN

A Distinguished American

. . . and the Mackinac Bridge Authority, without whose vision, wisdom, tact, perseverance, and influence the Mackinac Bridge might not have been built in our time, this book is gratefully dedicated

D B Steinman

New York, New York

John T. O'Neill

De Tour, Michigan

THE BRIDGE AT MACKINAC *

In the land of Hiawatha,
Where the white man gazed with awe
At a paradise divided
By the straits of Mackinac —

Men are dredging, drilling, blasting,
Battling tides around the clock,
Through the depths of icy water,
Driving caissons down to rock.

Fleets of freighters bring their cargoes
From the forges and the kilns;
Stone and steel — ten thousand barge-loads —
From the quarries, mines, and mills.

Now the towers, mounting skyward,
Reach the heights of airy space.
Hear the rivet-hammers ringing,
Joining steel in strength and grace.

High above the swirling currents,
Parabolic strands are strung;
From the cables, packed with power,
Wonder-spans of steel are hung.

Generations dreamed the crossing;
Doubters shook their heads in scorn.
Brave men vowed that they would build it —
From their faith a bridge was born.

There it spans the miles of water,
Speeding millions on their way —
Bridge of vision, hope, and courage,
Portal to a brighter day.

— D. B. Steinman

* Pronounced "Mackinaw." This poem and all other poems in this book are from the published poems of D. B. Steinman, and are reprinted by permission.

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ENGINEERS of DREAMS

GREAT BRIDGE BUILDERS
AND THE SPANNING
OF AMERICA

HENRY PETROSKI

ALFRED A. KNOPF NEW YORK 1995

THIS IS A BORZOI BOOK
PUBLISHED BY ALFRED A. KNOPF, INC.

 Published in the United States by Alfred A. Knopf, Inc., New York, and simultaneously in Canada by Random House of Canada Limited, Toronto. Distributed by Random House, Inc., New York.

Library of Congress Cataloging-in-Publication Data
Petroski, Henry.
Engineers of dreams: great bridge builders and the spanning of America. / Henry Petroski. — 1st ed.
p. cm.
Includes bibliographical references (p.) and index.
ISBN 0-679-43939-0 (hardcover)
1. Bridges—United States—History—19th century.
2. Bridges—United States—History—20th century.
3. Civil engineers—United States—Biography. I. Title.
TG23.P47 1995
624'.2'0973—dc20 94-48893
CIP

MANUFACTURED IN THE UNITED STATES OF AMERICA
FIRST EDITION

to Catherine

CONTENTS

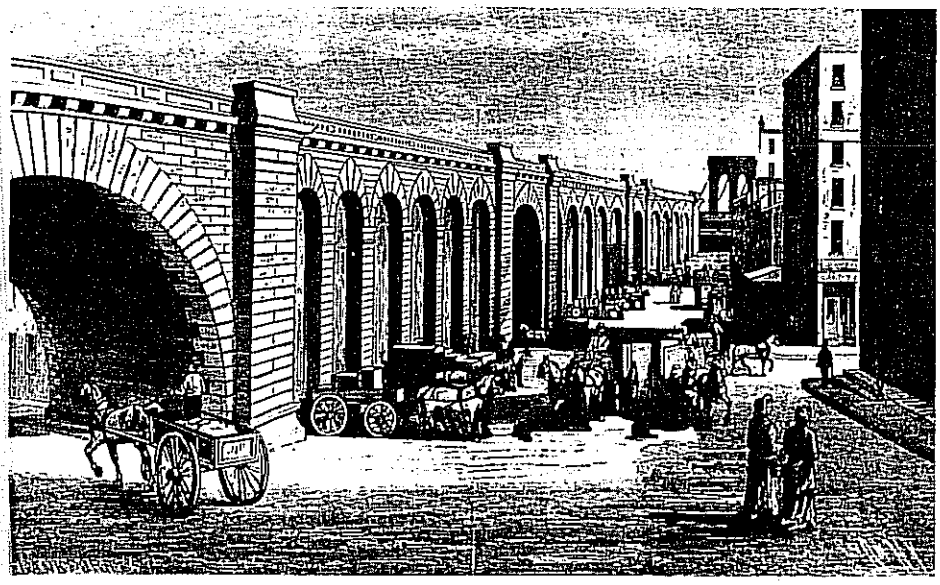
VI

STEINMAN

Many children have grown up in the shadow of a bridge, especially in a city like New York. In the late nineteenth century, the Lower East Side of that city was crowded with small children and one large bridge—that leading to Brooklyn—and life among the ever-present but ever-changing shadows cast by its approaches, abutments, decks, and towers was hard and squalid. Escape via the automobile to the suburbs was for many not yet even a realistic dream, and one did what one could do with what one had.

The stone towers of the Brooklyn Bridge had risen ever so slowly during the first half of the 1870s, and its cables had been spun equally slowly during the second half of the decade. As the bridge deck was hung in the early 1880s—piece by piece, like laundry from a line—the shadows cast by the structure lengthened and thickened over the tenements of New York City. There was a bright day of celebration and a still brighter evening of fireworks when the bridge opened in May 1883, and the central promenade that John Roebling had so thoughtfully designed above the traffic provided a welcome escape route from the heat and closeness of the tenements, if only for the hour or so it took to walk to Brooklyn and back, perhaps stopping midway to look out at New York Harbor.

Perhaps some found the bridge or its shadows oppressive, but the great structure provided an alternative to the ferries that so many people had daily to take back and forth across the East River. Others discovered in the bridge a new prosperity, with the uniting of the formally separate cities of



The New York approach to the Brooklyn Bridge, near where David Steinman spent his childhood

New York and Brooklyn providing new opportunities for commercial growth and real-estate development. On the other hand, some residents of the Lower East Side may not have thought much about the bridge at all, especially if they were busy raising large families in small apartments, as so many of the immigrant factory-worker families in the neighborhood were. However, at least one child growing up in those apartments became obsessed with bridges of all kinds.

David Barnard Steinman was born on June 11, 1886, and his childhood might have seemed unremarkable even to himself had he not lived in the shadow of the Brooklyn Bridge, which was to him not cold but warm. He grew up with the dominating bridge, whose towers looked over the city day and night, and whose arms of traffic reached far into the city, bringing and taking people and goods in unprecedented volume and with unprecedented speed. Not only was the Brooklyn Bridge there and functioning as a great communicator between what young David knew and what he could discover, but as he grew so did another bridge—the Williamsburg—under construction a mere mile or so away. For him, the Brooklyn and Williamsburg bridges became almost surrogate parents.

Eve and Louis Steinman were the real parents of David and his six siblings, but his hagiolatrous biographer, William Ratigan, no doubt acceded to Steinman's wishes in keeping them as much out of his later life as possi-

ble. Ratigan's 350-page biography has young David recalling only that his immigrant parents were lonesome, that "his father lashed him with a cat-o'-nine tails for wearing out his shoe leather" exploring Manhattan, and that "his mother wept." Among Steinman's few recorded recollections of his mother was of her "softly weeping" for the "cottage and the fields, the streams and meadows, of her native land," which remained nameless. Neither Steinman's mother nor father appears in the index to the biography, and there are no pictures of them or of his nameless siblings, from whom he learned the alphabet and the numbers. His first alluring taste of school was at five years old, when he was taken by his older sister to her teacher and principal so that he could show them his prowess in mathematics: "He could rattle off the powers of two: 2, 4, 8, 16, 32, up to a million." He was tested with mental multiplication problems, like 17 times 19 and 27 times 43, and he was rewarded with candy and visits to teachers' homes, which "were a glimpse of another world." A boxed charlotte russe brought home from one of those visits was such a treasure that it was nursed for nearly three weeks, being kept fresh on the fire escape because the Steinman apartment had no ice box. There is a mythic quality to Steinman's childhood, to his finding solace mainly in the cradle of the Brooklyn Bridge's cables and stays, and in the promise and reward of education.

Talk about building a new bridge across the East River to Williamsburg had, of course, begun even before the Brooklyn Bridge was opened, but a debate ensued as to whether the next crossing should be farther north instead, at Blackwell's Island. Before young David Steinman had reached his tenth birthday, Theodore Cooper had prepared plans and specifications for a "steel wire suspension bridge, stiffened by a longitudinal girder," between 59th and 60th streets, and Leffert Buck had had his plans approved for a new suspension bridge with four cables, each three inches larger in diameter than those of the Brooklyn Bridge, so that the elevated railway could be extended from the Williamsburg section of Brooklyn into New York. By the time David was twelve years old, the controversy had died down over the bare steel towers and the stepped-truss design of Buck's bridge, and work on the foundations and anchorages had begun. The precocious and studious youngster took a keen interest in the construction project and began to seek opportunities for further education.

Like many a child of immigrants, without money or access to established private colleges, Steinman began attending the City College of New York. In fact, because of his precocity, he began taking college classes even while he was still in high school. Eventually, the ambitious and conscientious young student, with the help of one of his teachers, was able to obtain a pass to enter the Williamsburg Bridge construction site. He climbed upon

the steelwork and proceeded across the catwalks set up for the cable-spinning operation, thus seeming to follow an inexorable pull toward a life of, on, and about bridges. Steinman had to work to put himself through college, but he graduated *summa cum laude* in 1906 with a bachelor-of-science degree. Since he wanted a degree in engineering, he applied to Columbia University, whose School of Mines had been established in 1864, just two years after the Morrill Land Grant Act had promoted an expansion of engineering schools around the country.

Steinman's application was read by Professor William H. Burr, who endorsed it with a personal note: "The most deserving case I have known in all my years at Columbia." The aggressive and assiduous young man was eventually able to piece together enough scholarships, fellowships, and nighttime teaching jobs at City College and Stuyvesant Evening High School to complete three degrees at Columbia. In 1909, he was awarded the A.M. and C.E. degrees, having written for the latter an engineering thesis entitled "The Design of the Henry Hudson Memorial Bridge as a Steel Arch." Twenty-five years later, the Henry Hudson Bridge, connecting the uppermost tip of Manhattan and the Bronx, would be built by Steinman's firm, substantially as he had designed it in his thesis.

Even while still a student, Steinman engaged in miscellaneous engineering work, including projects involving subways, elevated railways, and aqueducts for New York City, and in 1910 he accepted an offer to become the youngest professor of civil engineering in the country—at the University of Idaho. Although he was far from the Brooklyn Bridge, Steinman's thoughts were not far from bridges. The following year, while continuing to teach in Moscow, Idaho, Steinman received his Ph.D. degree from Columbia. His dissertation, a comparative study of cantilever and suspension bridges, was of less urgency in the wake of the collapse of the Quebec cantilever, but nevertheless did treat a topic of keen interest to engineers. The work, *Suspension Bridges and Cantilevers: Their Economic Proportions and Limiting Spans*, was soon published under the same title as a textbook in the Van Nostrand Science Series, and a second edition appeared two years later. Steinman had an instinct for writing and publishing, especially on new, significant, and controversial topics, and he exploited it to the hilt. While teaching in Idaho, he also translated two books from the German: the highly mathematical *Theory of Arches and Suspension Bridges*, in which Josef Melan expounded the deflection theory that Moisseiff had introduced in the design of the Manhattan Bridge, and Melan's *Plain and Reinforced Concrete Arches*. Such a prolific output was fast establishing Steinman as a successful academic, but he by no means neglected practical engineering—or practical self-promotion. It is difficult to imagine how otherwise

Professor William H. Burr, who strongly endorsed David Steinman's application to Columbia University

Engineering News in 1913 carried an article on a timber cantilever bridge "built by a troop of Boy Scouts over the Potlatch River, Idaho, after a sketch made by Prof. D. B. Steinman." The magazine could hardly have been expected to send a reporter to Idaho to cover the story, collect a sketch of the design, and take a photograph of the Boy Scouts flanking their engineer leader.

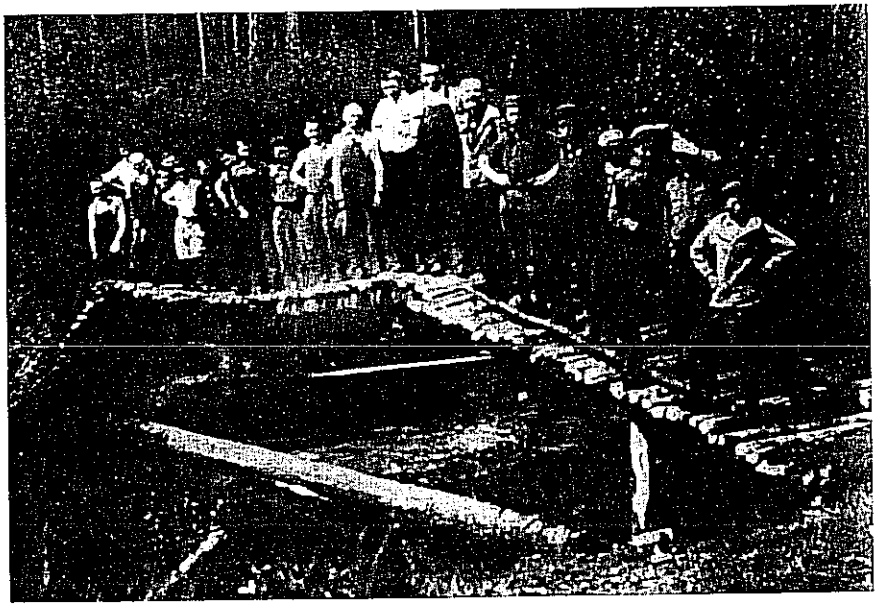
I

David Steinman was not satisfied with building timber bridges with Boy Scouts, and he wrote to Gustav Lindenthal about the possibility of working with him on the Hell Gate Bridge, whose construction was then beginning in New York. Preceded by the credentials of his translation of Melan's books on arches and suspension bridges, which had been published in 1913, the young engineer began working in New York as special assistant to Lindenthal, second only to Ammann, on July 1, 1914. Steinman personally calculated the internal loads, including those due to temperature changes, and visible deflections associated with the erection of the Hell Gate arch, and he supervised teams of engineers who measured the actual strains and displacements at key points on the structure. The design and construction of the great arch was based on theoretical calculations; the measurements on

the actual bridge confirmed not only the validity of the specific calculations for that structure but also the basic validity of the theory itself, thus advancing the confidence of engineers to apply it to still larger structures, such as the Bayonne arch, in the future.

Steinman reported the results of his calculations, and their comparison with the measured values, in a paper presented at the same meeting of the American Society of Civil Engineers at which Ammann presented his paper on the design and construction of the Hell Gate Bridge. Next to Ammann's global paper, which put the great project in historical perspective, Steinman's appeared to be that of an engineer with his nose pressed to the drawing board, looking so closely at the details and how to calculate and check them with measurements as to lose sight of the bigger picture. There was, however, in Steinman's paper a brief outline of the "growing movement" to supplement and check theoretical calculations with experimental measurements. Lindenthal and Steinman, at least, knew that the bigger picture was in jeopardy, as it had been in Quebec, without close and personal attention to details that rested solely on theory. At the end of his synopsis of his paper, Steinman gave "special acknowledgement" to Lindenthal, "who undertook to make these measurements in furtherance of engineering science." Lindenthal, in his discussion of this "able paper," explained that he

David Steinman (seventh from right) *and Boy Scouts on the wooden cantilever bridge they built across a stream in Idaho*



had "wanted to ascertain what, if any, bending stresses remained in the trusses after erection," recalling that such stresses had been significant enough to cause one of the steel tubes in the Eads Bridge to need replacing after it broke when the arch was closed. Lindenthal concluded his remarks with the confident assertion that, thanks to Steinman, "there are no unknown stresses in the Hell Gate Arch structure" to cause any cracking or breaking.

At the end of his paper, where acknowledgments were more traditionally made, Steinman mentioned those who had helped him with the new extensometer, or "strain gauge," that was employed, and those who had helped with some of the calculations. Finally, he also thanked Ammann for unspecified "suggestions." Ammann apparently could not graciously leave his involvement at that, however, and in a written discussion he expressed caveats about the generality of Steinman's work: "The analysis of the painstakingly recorded stress measurements, made by Mr. Steinman, may lead the uninitiated reader to overlook the important fact that he has to do with an extremely special case, which may not repeat itself in the history of bridge construction." Ammann also pointed out that "one important object" had not been accomplished by Steinman—namely, that the "actual stresses," as opposed to the secondary and erection stresses referred to by Lindenthal, remained indeterminate. But, so as not to appear to be contradicting Lindenthal, Ammann added that "the expense for such further investigation is too heavy for an individual engineer"—an allusion to Lindenthal, who himself had assumed the costs of the study. Ammann suggested that a government agency or an engineering society in cooperation with the railroads should sponsor such a project.

In his closure to the discussions of his paper, Steinman pointed out that, contrary to Ammann's suggestion that he was claiming more generality than his work allowed, there was "but one paragraph" in the entire paper that was "not a rigorous deduction from the results of the investigation," and it was a simple statement of considered judgment as to how other structures might behave. With undertones somewhat at odds with the usual gentlemanly exchanges among members of a professional society discussing one another's papers, Steinman wrote that he "would like to ask Mr. Ammann to point out anything in the summary of conclusions which can possibly be regarded as too far-reaching a deduction from the results of the investigation." That there was a tension and competition between the two engineers was thus evident in the discussion of this early paper, and perhaps one aspect of it was highlighted in Steinman's closure, in which he appears to have deliberately introduced titles before the names of the discussants, referring to Mr. Ammann and Dr. Lindenthal. Although Lindenthal's doctor-

ate from Dresden was honorary and Steinman's from Columbia was earned, they shared a title of which he no doubt wished to remind Ammann.

Acknowledging Ammann at all may have been somewhat begrudging on Steinman's part, because were it not for Ammann, Steinman might have been in charge of the entire project and thus the logical person to write the more comprehensive paper. When the war called Ammann back to Switzerland, Steinman had assumed responsibilities for the connecting-railroad project for which the Hell Gate Bridge was the engineering centerpiece. However, despite his increased responsibilities, Steinman continued to be paid his initial salary of $200 per month. It was only as a "wedding present," when Steinman married Irene Hoffmann on June 9, 1915, that his salary was raised to the $225 which Ammann had been receiving. After Ammann returned from his stint in the Swiss army, Steinman was no longer to be second in command to Lindenthal: he seems clearly to have preferred the European-trained Ammann to the American Steinman, who seemed to want to forget his European roots.

David Steinman had also played an important role in the design and analysis of the Sciotoville Bridge, Lindenthal's other technologically significant project of the period. As a result of the new methods Steinman had developed in the course of this work, *Engineering Record* "commissioned him to write a series of articles presenting his new design methods." According to Steinman's biographer Ratigan—a World War II correspondent and a writer of "stories and adventure serials"—when Ammann returned from Switzerland he reportedly persuaded Lindenthal to curtail his rival's articles, although the impending consolidation of the journal with *Engineering News* may have been a less insidious factor. In any case, there was clearly a lot more than technical know-how to being a successful engineer—and to letting the world know about it.

Lindenthal reportedly called the younger engineer into his office one day and told him, "Steinman, bridge engineering is easy. It is the *financial* engineering that is hard." A major part of Lindenthal's complaint, which no doubt centered on his continuing frustrations in finding backers for his Hudson River Bridge proposal, was that bankers added millions of dollars in financing costs to bridges after "engineers had sweated and strained to secure the most economical design." These words were evidently taken to heart by Steinman, an inveterate student who seemed to measure his life by his documented degrees, honors, and achievements, and almost to lust after any recognition or achievement that he did not yet have. Not that Steinman did not work for what he got. Upon recognizing that he had no formal training in the important aspect of engineering that Lindenthal had discussed, Steinman enrolled in a correspondence course in business ad-

ministration, which he found invaluable in his later career. Even if this aspect of the engineering endeavor seemed subsequently not to have been Steinman's favorite, he learned to talk the language of and to work with not only bankers and investors but also public officials and other nontechnical people essential to getting a large engineering project off the drawing board, and also off the ground. Lindenthal, on the other hand, for all his understanding of the importance of financing, saw no room for compromise in his plans. When the war put a stop to engineering projects, especially of the kind that he had dreamed about, Ammann may at least have given the impression of being more sympathetic to the elder engineer's technical resolve. In any case, it was Ammann who was kept on Lindenthal's payroll, however indirectly, and Steinman who was let go.

Years hence, when the two rivals would approve, if not compose, their own curricula vitae for *Who's Who in Engineering*, Ammann would list his service under Lindenthal as extending from 1912 to 1923, not mentioning that some of those years were spent in exile at the New Jersey clay mine in which Lindenthal had an interest. Steinman's record of service under the master extended only from 1914 to 1917. Their respective entries in the 1959 edition of this biographical dictionary tell a good deal more than factual details, however; they also tell a lot about the personalities of the engineers.

Ammann's entry occupies only one column, though this could reflect either his relative shyness and modesty or his sense of security in his significant accomplishments. After the standard identification of his origins, education, and marital status, there is a chronological listing of his principal engineering projects, giving in parentheses the dollar value of the most significant ones. The entry concludes with a list of memberships in professional and other organizations.

Steinman's *Who's Who* entry offers a sharp contrast. Following a long list of engineering projects, but without any mention of their dollar value, there is a much longer list of honors, awards, and memberships, seemingly citing every organization from which he had ever received a certificate of membership or a statement of dues. More curious than what is included is what is omitted from the very beginning of Steinman's entry. In a biographical dictionary whose entries customarily begin with a description of a person's origins, Steinman's contribution omits entirely any mention of his parents, as if he had maintained a firm resolve to suggest that his beginnings were in the stone and steel of a mythic bridge rather than in the flesh of immigrants. After his place and date of birth, the entry goes immediately to his education—including the number of medals, scholarships, and fellowships he won as a student pursuing his various degrees—as if to record that he did it all himself.

He was not merely keeping personal matters out of a professional biography, for his marriage is recorded, as are the names of his three children. It is hard to escape the conclusion that Steinman wished to obscure if not forget his origins, which were, according to a 1958 *New York Times Magazine* profile, "in the slums, in the shadow of the Brooklyn Bridge," giving a different twist to the bridge's inspiration for his career. On the other hand, he was immensely proud of his marriage to Irene Hoffmann, daughter of a former member of the Faculty of Medicine at Vienna, who not only approved of his daughter's marrying a young man with a Ph.D. but also encouraged her to do so, that he might have a son-in-law with whom he could discuss Kantian philosophy. Such dichotomies would naturally lead to tensions in Steinman's later life, at which the biographical dictionary could only hint. In the mid-1950s, for example, he would be identified as one of many significant personalities who had begun life as a Jew and had made things happen. Yet, during the same period, Steinman himself was turning away from those roots, telling reporters that he was "active in Presbyterian affairs."

In spite of whatever unresolved personal tensions he experienced, Steinman accomplished a great deal in his life and career. And in spite of the niggardly professional recognition Ammann gave him in discussions and reviews of his work, Steinman's reputation became established through his books. In 1917, he accepted an appointment as professor of civil and mechanical engineering at his alma mater, City College of New York, which then was organizing a school of engineering. One day, in the spring of 1920, while Steinman was still head of the engineering school, he received a telephone call from "a man who modestly introduced himself as H. D. Robinson." The two met, and Holton Robinson described to Steinman an international design competition for a bridge at Florianópolis, to connect that capital city of the off-coast island state of Santa Catarina with the Brazilian mainland, and proposed that they join in an effort to produce an entry.

2

Steinman had dreamed of actually building bridges of his own, but until that time, with the exception of directing the Boy Scout troop in building a modest cantilever, he had worked exclusively on others'. Now Robinson made it possible for him to participate as an equal partner in a major bridge project. It was a rare opportunity, for there was little work for bridge engineers in the early 1920s, and Steinman jumped at the chance. He went into private practice as a consulting engineer, renting a desk in the office of a

friend for ten dollars a month and working on jobs for fees as small as five dollars. He soon got larger jobs, such as writing a survey for $250 and inspecting forty railroad bridges for a fee of ten dollars each. With business picking up, he was able in 1921 to move into his own office and hire assistants and draftsmen. Steinman invited Robinson to share this office, and the older engineer thus moved from "a drafting table in his home, where he did all computing and drafting himself," including solving "difficult three-span catenary problems by suspending a fine chain against the wall and measuring the ordinates." With Robinson's practical experience and Steinman's theoretical talents, technical traits that complemented each other as nicely as did the engineers' different personalities, the partnership of Robinson & Steinman would be able to compete successfully for major bridge projects for many years to come.

Holton Duncan Robinson was a generation older than Steinman, having been born in 1863 at Massena, New York, near the Canadian border. He was the son of Ichabod Harvey and Isabelle McLeod Robinson, and his Scots-English ancestry included Sir Alexander Mackenzie, the Canadian explorer after whom the river is named. Robinson grew up on the family farm beside Robinson Bay, which is located on the St. Lawrence River, and from childhood he was "outstandingly shy, modest, and retiring." He attended a local college, St. Lawrence, in nearby Canton, New York, and studied liberal arts and sciences, receiving a bachelor-of-science degree in 1886.

Young Robinson entered the engineering field through his uncle, the bridge builder George W. McNulty, who was associated with Leffert Buck. Buck and McNulty in turn had begun in engineering under Washington Roebling on the construction of the Brooklyn Bridge, and had started their own firm after that project was completed. Robinson began working on survey crews for Buck and McNulty and studying engineering at home. He slowly gained a variety of experience, being sent to the sites of various bridge projects, including one in the small town of Suspension Bridge, New York, where he took charge of repairs on the stiffening truss of John Roebling's aging Niagara Gorge Bridge. After a few years as draftsman and assistant engineer in the chief engineer's office of the New York Central & Hudson River Railroad Company, Robinson accepted an offer to return, as chief draftsman, to work under Buck, who was then chief engineer planning the Williamsburg Bridge. Robinson eventually became assistant engineer in charge of cable construction on the bridge, remaining so when Lindenthal became bridge commissioner. (Perhaps Holton Robinson and young David Steinman may actually have passed each other on the catwalks.) In 1904, after the Williamsburg Bridge had opened, Robinson was transferred to the Manhattan Bridge project and placed in charge of design

Holton Robinson, when he was engineer in charge of construction of the Williamsburg Bridge

and construction—again under Buck, who was consulting engineer to Othniel Foster Nichols, an 1868 graduate of Rensselaer Polytechnic Institute who was chief engineer of New York's Department of Bridges from 1904 to 1906, in which position he oversaw the redesign of the Manhattan Bridge after Lindenthal's departure from the position of commissioner.

Robinson left the employ of the city in 1907 to join the Glyndon Contracting Company, fabricator of the cables for the Manhattan Bridge. Besides designing the machinery to effect the spinning of the twenty-one-inch cables, then the largest ever, during his tenure with Glyndon he produced an unsuccessful design for a suspension bridge to cross the St. Lawrence River at Quebec, where the great cantilever had failed. He left Glyndon in 1910 to build, as an independent contractor, a suspension bridge near his hometown; this structure was completed in about six months at a cost of $40,000, 50 percent lower than the lowest bid that had been received by the town of Massena. Over the next several years, Robinson worked on a variety of bridge, tunnel, and navy war projects; his experience was broad and deep by the time Steinman met the "modest, distinguished-looking man" in 1920.

In 1922, Robinson was appointed consulting engineer for cable construction on the Delaware River Bridge between Philadelphia and Camden,

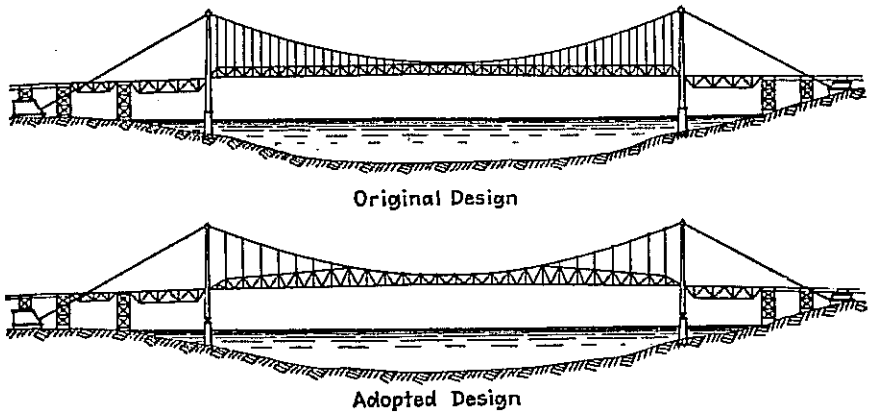
New Jersey. He assured the joint commission that, instead of four smaller ones, two cables of thirty-inch diameter could be spun, thus simplifying construction, and he supervised their design before resigning as consulting engineer to work for the contractor, the Keystone State Construction Company, which was to make the cables. The office of Robinson & Steinman, in turn, was given responsibility for designing the temporary work and machinery needed to accomplish the task. In 1926, at a joint meeting of the Franklin Institute and the Philadelphia section of the American Society of Civil Engineers, Robinson, then in his early sixties, presented his first technical paper, "Construction of the Cables of the Delaware River Bridge." For all his accomplishments, his boyhood shyness had not left him; "he suffered excruciatingly from stage fright and the experience so unnerved him that he vowed he would never repeat it."

He may have eschewed public speaking, but Robinson did not shy away from the physical challenges bridge engineers had constantly to face. According to Steinman,

> Even in his last years, Mr. Robinson was active, agile, and fearless in his outdoor work on bridges. He would climb on high steelwork or walk the cables of a suspension bridge with greater ease than most younger engineers. In 1941, during the investigations that followed the Tacoma Narrows . . . disaster, he was retained by the insurance companies, and made a personal examination of the cables of the wrecked structure. Although seventy-eight years old at the time, he calmly walked out over the 17½-in. cables, each 5,900 ft long and 450 ft high at each tower, to examine the condition of the wires and to cut out samples of the wire at midspan. His feat was rendered more difficult and hazardous by the fact that the hand ropes in the main span had been wrecked.

Thus, in spite of his social reticence, Robinson suffered no fear in the face of technical or physical challenges. Steinman, on the other hand, was, ostensibly at least, as comfortable before large audiences as he was on tall bridges. The partnership of Robinson & Steinman, extremely complementary and compatible, would last for a quarter-century without a written contract between the men.

The project that brought them together, the Florianópolis Bridge, was a success, thanks in large part to an unusual and distinguishing structural design by Steinman that had the eyebar chains doubling as the curved upper chord of the stiffening trusses, which resulted in a very economical structure. When it was completed in 1926, the Florianópolis Bridge, with a main span of over eleven hundred feet, was the largest in South America, and the



The Florianópolis Bridge, as originally designed by Robinson & Steinman, and as altered to suit the client

largest eyebar suspension bridge in the world. Steinman's article on the design of the bridge appeared in *Engineering News-Record* late in 1924, and he explained how the bridge was originally "designed along conventional lines," which meant a wire-cable structure that looked very much like the Williamsburg Bridge, with which Robinson was so familiar. When a decision based on economy was made to use eyebars rather than cables, however, this led to a reconsideration of the truss, into which the eyebars then became incorporated. According to Steinman, first sketches showed a "most pleasing outline" for the truss, which curved as it did at the towers, but straight chords were employed in the final design, "in deference to the preference expressed by our client." Such compromises might not be made by an engineer like Lindenthal, but Robinson and Steinman were more interested in establishing their firm's reputation for economical and reliable work than in making an engineering or artistic statement.

The new truss-eyebar arrangement produced a very stiff bridge with less material, and such an economical solution was something which other suspension bridge engineers would now have to take into account. It presented a realistic alternative to the stiffened cables or stiffened eyebars, such as the kind Lindenthal had proposed for his North River Bridge, which were not integrated with a deck truss. An immediate response to Steinman's article came in the form of a letter to the editor from Leon Moisseiff, who took exception to Steinman's claim that his structure was the first to incorporate a bridge's chain or cable into a stiffening truss that continued for the entire length of the main span. Moisseiff included a drawing of his 1907 design for a bridge over the Kill von Kull, which, "for better appearance," continued the line of the truss through the towers. But a drawing is not a bridge.

Moisseiff was, in a sense, echoing Ammann's review, two years earlier, of Steinman's book, *A Practical Treatise on Suspension Bridges: Their Design, Construction and Erection*. Since Ammann had written little for publication on suspension bridges up to that time, Lindenthal would actually have been the much more logical reviewer for *Engineering News-Record* to have chosen, and it seems very possible that he may indeed have passed the book on to his assistant chief engineer at the North River Bridge Company, as Ammann's affiliation was identified over the review. The review itself might best be described as mixed, with Ammann finding parts done with "fair completeness" and thus providing a "useful manual, especially for the student or young engineer," but also criticizing the book for not discussing matters of aesthetics. According to Ammann, Steinman also discriminated "against the eyebar chain" on technical grounds, but he was in fact ever flexible in his thinking, as the Florianópolis Bridge was to demonstrate.

Steinman, both with Robinson and independently, began to get more and more significant commissions, and the younger partner wrote about them with facility. The Carquinez Strait Bridge, located about twenty-five miles northeast of San Francisco, was one such project. Consisting of two main spans of eleven hundred feet, it became the second-largest cantilever in the United States and the fourth-largest in the world when it was completed in 1927. The chief engineer of the bridge project was Charles Derleth, Jr., with William H. Burr as consulting engineer and Steinman as design engineer.

But Steinman's real ambition was to build world-class suspension bridges that would also be recognized as things of beauty. Though the Florianópolis Bridge was a major structure, its oddness of type and compromised lines, not to mention its location, put it in a category almost by itself. A new opportunity arose, albeit still off the beaten track, with the Mount Hope Bridge, which Steinman designed, and whose construction the firm of Robinson & Steinman supervised "to take the Island out of Rhode Island." The total length of this bridge was over a mile, and its twelve-hundred-foot main span put it almost in a class with the major suspension bridges of the day. Its cross-braced towers suggested a Gothic arch above the roadway, and the bracing was topped by a crown of smaller crosses, this latter feature echoing somewhat the tower tops of several contemporary suspension bridges, including Modjeski's Delaware River Bridge, whose towers Pennell so disliked. Steinman's Mount Hope towers have a balanced look, however, and are in good proportion to the uniformly deep truss of the roadway. The bridge received the 1929 Award of the American Institute of Steel Construction as the most artistic new long-span bridge in America.

At the same time, the firm of Robinson & Steinman was designing the St. Johns Bridge over the Willamette River at Portland, Oregon. With a

twelve-hundred-foot main span supported from rope-strand cables, which for such a distance were found to be somewhat more economical than parallel-wire cables spun in place, this bridge was then the longest suspension type west of Detroit. According to Steinman, perhaps responding to Ammann's criticism, "the desire to secure a beautiful public structure was a governing consideration" in the design, and the towers were the result of "extensive architectural studies," although he identified no particular architect or style. The unique towers have battered (i.e., slightly inclined) sides, spires, and, in a more extreme fashion than the Mount Hope Bridge, Gothic arches above and below the roadway. The stiffening truss, however, is undistinguished, and there does not seem to be a successful integration of towers and deck. Although the bridge was described in the Robinson & Steinman firm's brochure, *Bridges Lasting and Beautiful*, as "a poem stretched across the river" and "a symphony in stone and steel," the aesthetic success of the towers and the overall bridge can be debated. The towers were designed to echo and harmonize with the dramatic scenery of evergreens, mountains, and clouds, visible through the four-hundred-foot-tall structures, but they seem too unintegrated into the natural setting. In something of a departure from tradition, the bridge was painted a pale green. In 1931, "on a gusty, rainy day," Robinson and Steinman, whose firm had complete charge of design and construction, gave the newly completed crossing its final inspection from the open cockpit of a stunt plane which Tex Rankin, "northwest flying ace," flew around the towers and over and under the roadway. Both engineers were thrilled by the experience, and with the bridge.

In his memoir of Robinson, who died in 1945, Steinman described him as being "professionally connected with the construction of almost every notable suspension bridge built during his lifetime," a fact that "was his chief pride." Without detracting from Steinman's eulogy of Robinson, this could be said of a number of the great bridge engineers; indeed, it almost naturally followed, because great engineers wanted to be associated with great bridges, whose designs in turn relied on a variety of engineers who had a variety of experience with the unique and specialized design and construction problems that were faced. Sometimes, of course, as in the case of the Tacoma Narrows Bridge, the greatness of the engineers has come to seem more important than the design itself.

In any event, who would consult on what bridge had a lot to do with who was the chief engineer, of course, and who had the dominant reputation or the most correct politics at the time. When plans for the George Washington Bridge were being finalized in the mid-1920s, for example, Lindenthal, because of his relationship with Ammann, was a problematic choice as a

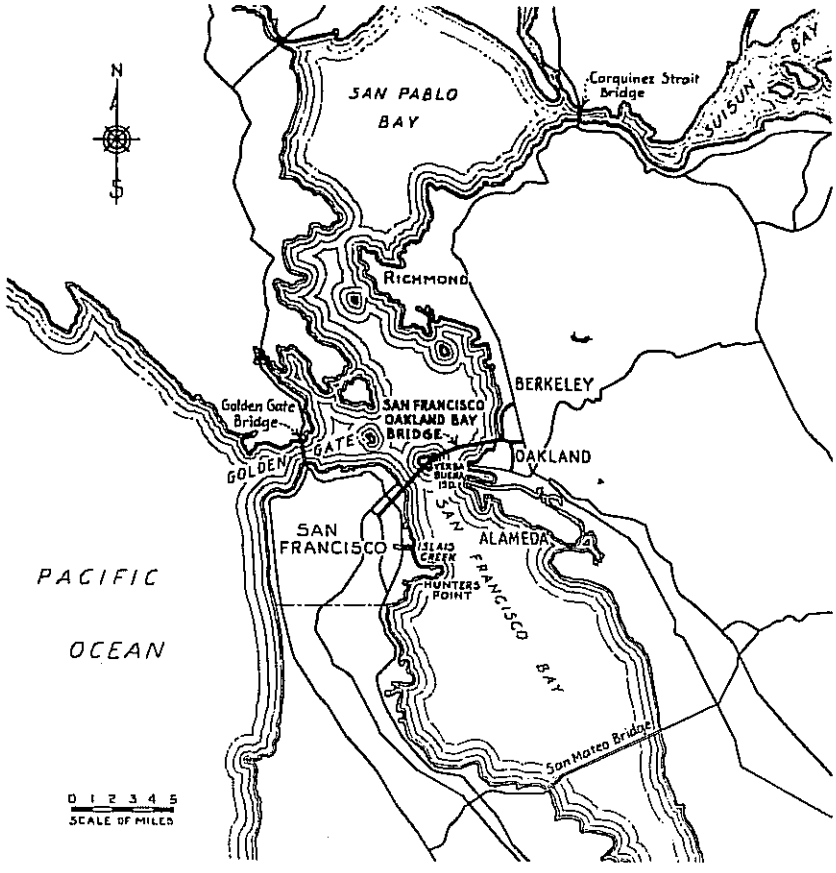
consulting engineer. On the one hand, he was the engineer who had been most visibly associated with such a Hudson River project; on the other, his inflexibility and prior relationship to Ammann put him in a special category. Robinson, because of his extensive experience, was a natural choice, but his then recent association with Steinman may have presented problems for Ammann. As for Steinman himself, for all his writing about bridges, he was only just beginning to gain his first experience with their design and construction. In some accounts, however, Robinson and Steinman, in particular, "helped to design" the bridge, as consultants on the erection of the steel superstructure, even though they are not listed among the consulting engineers in the dedication program.

3

The 1930s were a heyday of large-bridge construction, with the George Washington opening in 1931 and the two great bridges connecting San Francisco with Marin County and with Oakland under construction simultaneously. Of these, the bridge to Oakland was actually completed first, in 1936, but it was to be permanently overshadowed by the Golden Gate, completed six months later, in 1937, with its world-record span of forty-two hundred feet between towers. The beginning of construction of the lesser-known structure took place in mid-1933, with President Franklin Roosevelt setting off a blast by remote control from Washington, and the first earth being turned up with a golden spade. At this ceremony, Herbert Hoover called the San Francisco–Oakland Bay Bridge "the greatest bridge yet erected by the human race," yet until the 1989 earthquake it remained largely unknown outside the Bay Area, where it serves such an important transportation role. Among the reasons for its relative obscurity must also be counted the fact that this bridge had no single prominent and dominant dreamer like a Roebling, Lindenthal, Ammann, or Strauss serving as executive director and providing a visible personality to the project. Even its official name—San Francisco–Oakland Bay Bridge—is impersonal and awkward; it has often been abbreviated to the Transbay, or simply the Bay Bridge, the name by which it is best known locally.

In spite of these differences, the Bay Bridge, like all great engineering projects, did encompass a long history of dreams and dreamers. Talk of having a bridge between San Francisco and Oakland began shortly after the Gold Rush and continued throughout the latter part of the nineteenth century. The 1906 earthquake distracted attention from a bridge, since the city had to be rebuilt, and in the meantime a ferry system carrying four million

vehicles and fifty million passengers a year developed. Agitation for a bridge again arose, only to be suppressed by the world war. In the decade after the war, numerous applications for bridge-building franchises were filed, only to meet continuing opposition by the War Department, especially for a bridge north of Hunters Point, across the bay from Alameda. By the end of

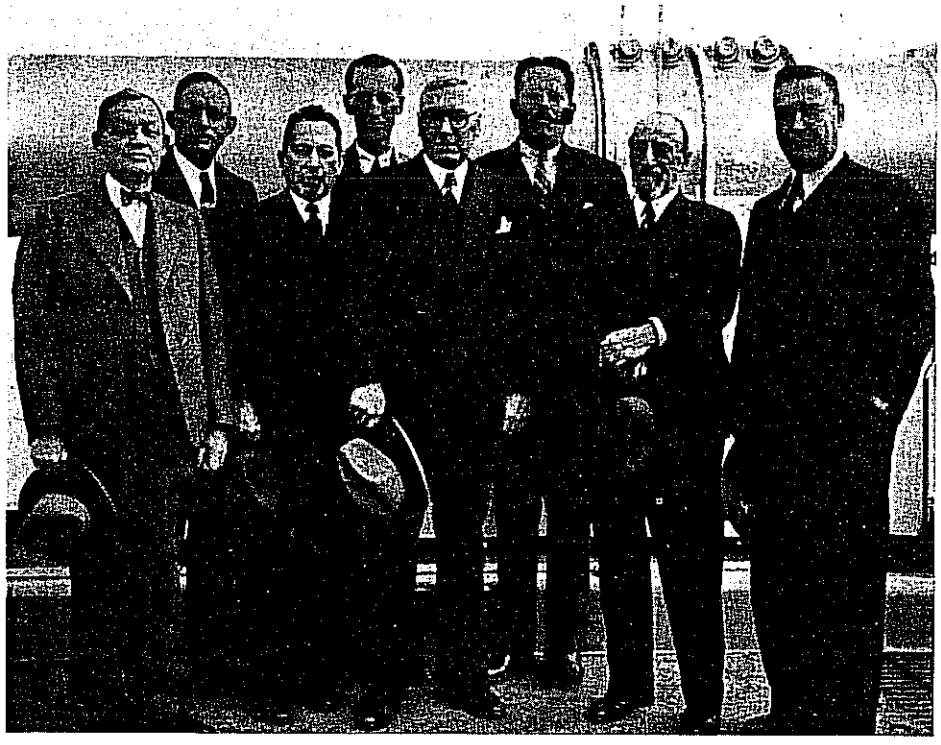


The San Francisco Bay area, showing the locations of the Carquinez Strait, Golden Gate, and San Francisco–Oakland Bay bridges

that decade, the progress of the Port of New York Authority in financing and constructing the 179th Street bridge across the Hudson had led to calls for a West Coast bridge supported by revenue bonds. A San Francisco Bay Bridge Commission was appointed by President Hoover, which seems ultimately to have made the objections of the War Department less absolute; the state highway engineer Charles H. Purcell was appointed as secretary.

Purcell was born in 1883 in North Bend, Nebraska, and attended Stanford and the University of Nebraska, where in 1906 he received his B.S. in civil engineering. He began working for the Union Pacific Railroad in Wyoming, then held positions in Nevada, New York, and Peru, with smelting, refining, and mining companies, before returning to construction and railroad work in the Pacific Northwest. In 1913, he joined the Oregon State Highway Department, which was then just forming, and became its first state bridge engineer. He accepted an appointment in 1917 as bridge engineer for the United States Bureau of Roads, and two years later became district engineer for the bureau, serving in Portland. He moved to California in 1927, to become state highway engineer there. Among the notable structures for which he was responsible is the Bixby Creek Bridge, located in the dramatic setting of the coast highway south of Carmel. This 330-foot reinforced-concrete arch, designed in conjuntion with F. W. Panhorst, has been described as being "among the lightest and most graceful structures of this type in the United States." But Purcell's greatest achievement certainly has to be the San Francisco–Oakland Bay Bridge. His involvement with the project began when he and Charles E. Andrew, bridge engineer with the California State Highway Department, were placed in charge of "studies and investigations of engineering, location, and traffic" for a bay crossing.

In the meantime, the state legislature had created a California Toll Bridge Authority, which provided the means for financing the project. Sound technical considerations regarding such important matters as foundations led Purcell and Andrew to recommend a bridge route from Rincon Hill in San Francisco to Yerba Buena Island, also known as Goat Island, which was occupied jointly by the U.S. Army, Navy, and Lighthouse services, and then on to Oakland. (The adjacent Treasure Island was to be created as the site of the 1939 exposition to commemorate the completion of both the Golden Gate and the San Francisco–Oakland Bay Bridge.) Including approaches, the total length of such a bridge would exceed eight miles, half of which was over the bay; to cross each of the two stretches of water, engineers would have to devise independent structural solutions as great as any single major bridge then extant or under construction. After preliminary designs and underwater borings were made in 1930 and 1931, a San Francisco–Oakland Bay Bridge Division of the Department of Public Works was set up, with Purcell as chief engineer, Andrew as bridge engineer, and Glenn B. Woodruff as engineer of design. The board of consulting engineers comprised Ralph Modjeski, the chairman, who with J. Vipond Davies had made a preliminary survey for such a project a decade earlier;



Engineers making final inspection of San Francisco–Oakland Bay Bridge (left to right): *Charles Derleth, Jr., Glenn B. Woodruff, Leon S. Moisseiff, Henry J. Brunnier, Charles H. Purcell, Carlton S. Proctor, Ralph Modjeski, and Charles E. Andrew*

the partners Daniel E. Moran and Carlton S. Proctor; Leon Moisseiff; Charles Derleth, Jr.; and Henry J. Brunnier.

In an article in *Engineering News-Record*, subtitled "A Review of Preliminaries," Purcell, Andrew, and Woodruff described some of the site and design alternatives they had considered. Though they confessed that it would be impossible for them, in this paper, to "consider the large number of tentative designs that were made," they did discuss several, which included cantilevers longer than the Quebec Bridge and suspension bridges almost the equal of the Golden Gate. They admitted that the forty-one-hundred-foot suspension design "presented strong temptations" for its acceptance: "It required fewer departures from past practice than any alternate layout, reduced the number of piers to be constructed and was a more monumental structure." However, it did present some drawbacks: it would have required a large amount of material to construct the San Francisco anchorage and to

stiffen the truss against the wind. Furthermore, the longer span would have provided inferior clearance for shipping, required the destruction of some piers, and cost about $3 million more than the adopted design.

Detailed considerations of the many alternative design possibilities led the group of engineers to recommend that the "bridge," which was really two distinct bridges separated by a tunnel through an island, would consist of: (1) a unique pair of double-deck suspension bridges, each with a main span of 2,310 feet, arranged in tandem and sharing a common central anchorage in the middle of the water; (2) a 540-foot tunnel through Yerba Buena Island, with a bore larger than any other tunnel in the world; and (3) a great truss bridge laid out in a sweeping curve, with a cantilever section fourteen hundred feet long, which made it the longest and heaviest cantilever span in the U.S. and the third-longest in the world, flanked by a number of other spans exceeding five hundred feet. (It was on this latter portion of the bridge that a section of the upper deck fell during the 1989 Loma Prieta Earthquake, and the traffic disruption during the months when the bridge was closed for repairs provided many opportunities to reflect on the importance of the communications link that the bridge provided, including carrying Bay Area Rapid Transit trains on its lower deck.) In June 1933, the start of construction was marked on the island by a ceremony that included the explosion set off from Washington by President Roosevelt, and the symbolic beginning of excavation with the use of the golden spade. Chief engineer Purcell expressed the hope that traffic would be using the bridge by January 1937.

The opening of the San Francisco–Oakland Bay Bridge actually took place late in 1936, ahead of Purcell's public hopes as well as of the completion of the Golden Gate. Like all such events, the opening provided an opportunity to look both backward and forward. Among the episodes in San Francisco Bay history that was recalled on the occasion was the story of "a shrewd and likable fellow" named Joshua A. Norton, who had come to California during the 1849 Gold Rush, "attained considerable importance and amassed a fortune," only to lose it and his mind. Returning to the area after years of absence, he declared himself "Emperor of the United States, Protector of Mexico and Sole Owner of the Guano Islands," and issued paper money, which was honored by the locals, who humored him. Among the many imperial proclamations issued by Emperor Norton was one ordering the Coast Guard to blockade Carquinez Strait, long before Steinman's cantilever crossed it, and one inviting Abraham Lincoln and Jefferson Davis to meet and arbitrate an end to the Civil War, an invitation they did not accept. But the document most on the minds of those celebrating the completion of the Bay Bridge was the following:

PROCLAMATION

We, Norton I, Emperor of the United States and Protector of Mexico, do order and direct . . . that a suspension bridge be constructed from the improvements lately ordered by our royal decree at Oakland Point to Yerba Buena, from thence to the mountain range of Saucilleto. . . . Whereof fail not under pain of death.

Given under our hand this 18th day of August, A.D. 1869, and in the 17th year of our reign, in our present Capitol [*sic*], the city of Oakland.

(signed)
Norton I.—Emperor

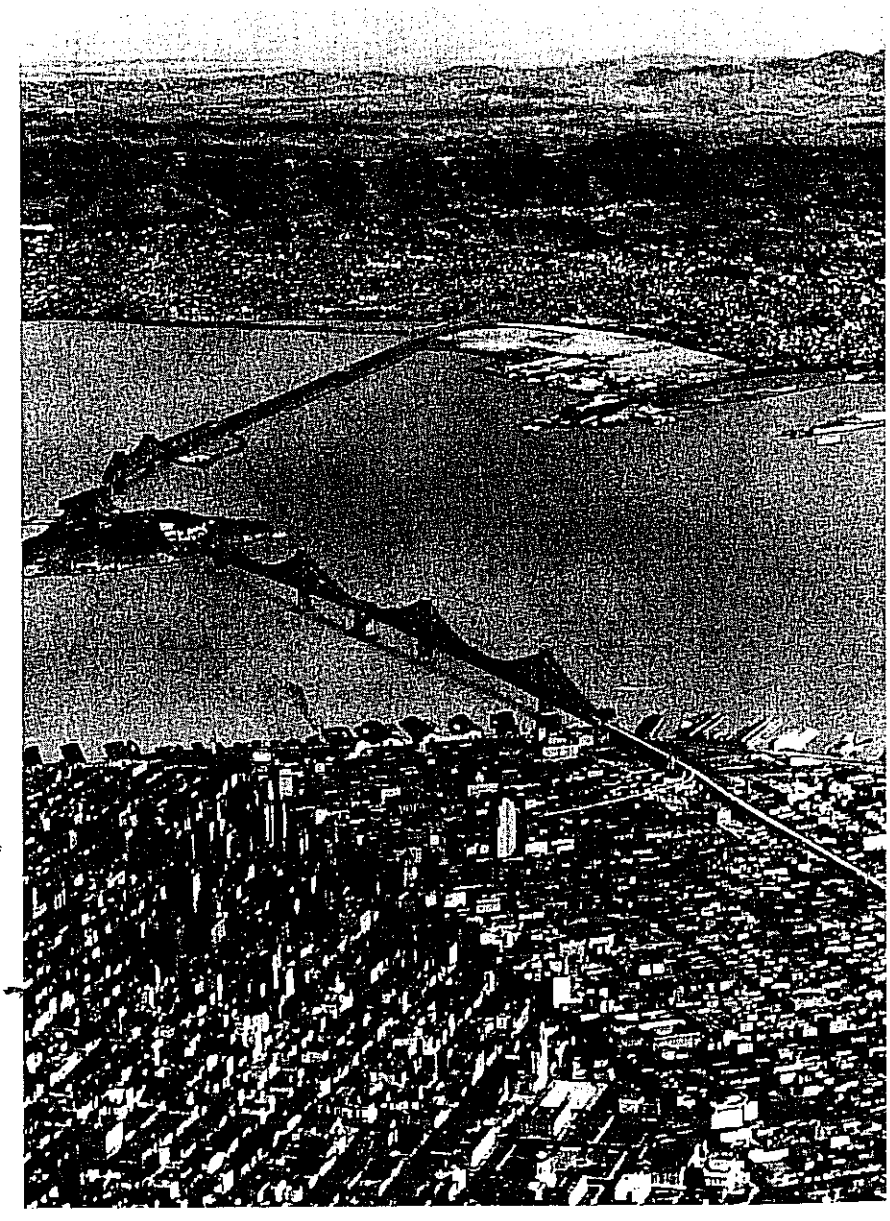
Though Norton's bridge might have been an even grander span than the one built, at the same time snubbing San Francisco and making the Golden Gate Bridge unnecessary for getting to Marin County, at least from Oakland, the order certainly leaves no doubt that dreams of bridges were grand during the emperor's reign. In 1936, the builders of the Bay Bridge saw the historical anomaly not as just an amusing footnote to the story of their own bridge, but as a testament to dreams of all kinds: "Who is bold enough to say that they will not some day be fulfilled?" Many decades after Norton flourished, the actual bridge inspired the Spanish-language poet Jorge Carrera Andrade to write *Canto al Puente de Oakland*, one verse of which reads, in translation:

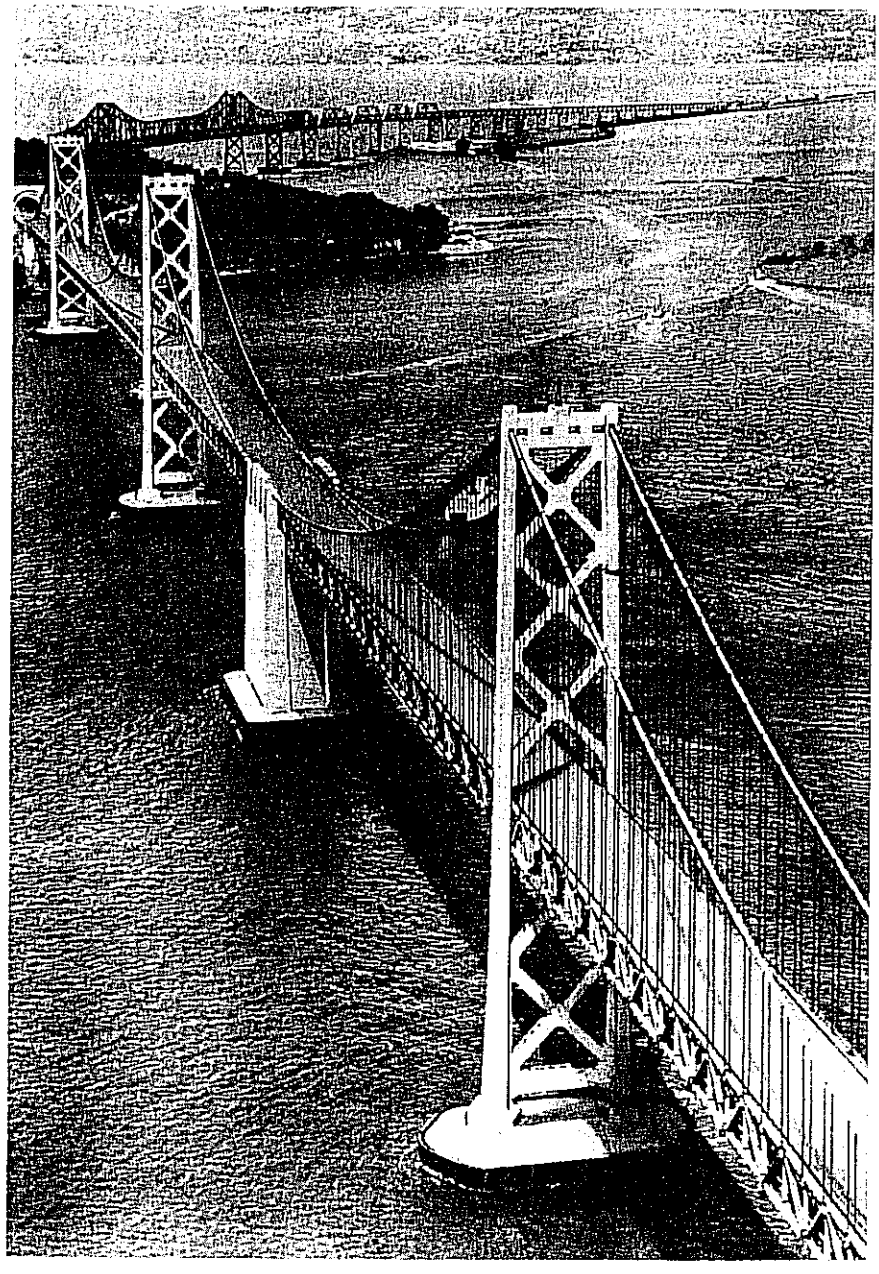
Your length like a river or like buoyant hope
—miles of iron and of sky interwoven—
can only be measured with the music
or the metres of dream.

Just as so many New York City bridges owe their existence and appearance to a group of engineers who worked for government bodies of one form or another, so did the San Francisco–Oakland Bay Bridge owe its final form to the talents and abilities of California state engineers like Purcell and Andrew. Consulting engineers play a crucial role whenever it comes to particular questions of detail, experience, and precedent, but the creative and political sympathy and savvy of career government employees around the nation have also played significant roles in shaping the built environment. Among such engineers was Conde McCullough.

Conde Balcom McCullough was born to a physician and his wife in 1887 in Redfield, South Dakota. As a young man, he attended Iowa State College, from which he received his bachelor's degree in civil engineering in

Artist's conception of how the San Francisco–Oakland Bay Bridge would look when completed





The completed San Francisco–Oakland Bay Bridge, showing its tandem suspension bridges, tunnel, and cantilever sections

1910. After a first engineering job in Des Moines, he joined the Iowa State Highway Department, beginning as a designing engineer in 1911 and rising to assistant state highway engineer by the time he left, in 1916, to join the Civil Engineering Department at Oregon State College. Within two years, he had risen to the rank of professor and was head of the department, but he left the college the following year to become state bridge engineer for the State Highway Department. In order better to understand and deal with the legal constraints on his job, McCullough also went to law school, at Willamette University, receiving the bachelor of laws degree and being admitted to the Oregon State Bar in 1928. He wrote a considerable number of articles and books on bridges, economics, and law, including—with his attorney son, John McCullough—a two-volume work, *The Engineer at Law*.

Conde McCullough's creations in steel and reinforced concrete are even more responsible for Oregon's overall reputation for beautiful bridges than are Lindenthal's and Steinman's efforts in the state. McCullough's Bridge of the Gods and his Caveman and Rogue River bridges, this last incorporating the innovative prestressing techniques developed by the French engineer Eugène Freyssinet, are as graceful and whimsical as their names. The Coos Bay cantilever, which in 1936 completed one of the last major links in the Oregon Coast Highway, was designed by McCullough and was dedicated to him after his death in 1946. The Conde B. McCullough Memorial Bridge thus joined the exclusive group that includes the Eads Bridge at St. Louis and the Roebling Bridge at Cincinnati in being named for its engineer.

Not every engineer who works for the government or a government-related agency gets an opportunity to be as broadly based in his work as McCullough did in the course of a career, but some certainly have and do. The shy Ammann, for example, who may have appeared on the surface to be apolitical and uninterested in law or public affairs, did engage in politics of a private nature. After all, it was he who wooed the future governor of New Jersey with plans for a Hudson River Bridge, which he in turn could advocate in his inaugural address, and for which he also could recommend Ammann himself as the project engineer. The independent Steinman, on the other hand, engaged more in a politics of a quite open and different kind—namely, the politics of his profession, for which he had begun to emerge, in the 1920s, as the most energetic and articulate spokesman.

4

In 1925, David Steinman, then president of the American Association of Engineers, wrote an article on "Outstanding Practice Problems of the Pro-

The Conde B. McCullough Memorial Bridge over Coos Bay on the Oregon coast, one of the few bridges in America named for their engineers

fession," which appeared in *Engineering News-Record*. The article reported on the results of a survey that asked "representative engineers of national reputation for their views on ethical conduct in negotiations for professional services." Steinman had not, of course, discovered this issue, which involved "how far the engineer may solicit an engagement without invitation; whether he should decline to do so competitively; whether a warning against competition should be included in the code of engineering ethics; and what can be done by the profession to combat the evil of inadequate fees." However, though Steinman had no doubt heard a lot relating to such topics in Lindenthal's office a decade earlier, the issues had become much more openly articulated in the meantime, going well beyond the pages of trade journals.

The American Society of Civil Engineers, begun in 1852 as the American Society of Civil Engineers and Architects, joined in 1916 the so-called founder societies, which then included the American Institute of Mining Engineers, dating from 1871; the American Society of Mechanical Engineers, from 1880; and the American Institute of Electrical Engineers, from 1884 and now known as the Institute of Electrical and Electronics Engineers. The proliferation of engineering societies in America followed only shortly after the same phenomenon in Britain, where the Institution of Civil Engineers, originally intended to encompass all of engineering that was not military, became only one among a plethora of specialized institutions, such as the Institution of Mechanical Engineers and the Institution of Electrical

Engineers. These were formed in large part because proponents of new areas of developing technology were not so easily integrated into the existing societies by their more traditional counterparts. By the early years of the twentieth century, there was such a diversity of engineering societies, differentiated largely by the technical specialty of their members, that engineers felt that there was no single voice for the profession itself.

Among the organizations formed "to address the social and economic interests of the engineer regardless of technical discipline," was the American Association of Engineers, founded in 1914. There were two schools of thought among its founders, one of which "favored establishing a labor union affiliated with the American Federation of Labor," and the other of which "visualized a professional society, avoiding the coercion normally inherent in labor organizations." The latter philosophy prevailed, and the American Association of Engineers was about twenty-five thousand strong when Steinman assumed its presidency. At the time, the question of professional ethics was a lively topic of debate, even though the technical societies had been talking about such matters for fifty years. In 1912, the American Institute of Electrical Engineers and the American Society of Mechanical Engineers had finally adopted codes of ethics, and so, in 1914, did the American Society of Civil Engineers. The codes of these founder societies, as well as those of the American Association of Engineers, were thought to be too general and too subject to interpretation by some of its members, however, and in 1923 a number of "practice cases," or case studies, had been issued to remove some of the ambiguities.

This did not solve everything, of course, and when Steinman's article on outstanding practice problems appeared in *Engineering News-Record*, it occasioned an editorial on the subject. According to the editors, it had to be admitted that the profession's ethics were "neither satisfactorily formulated nor universally followed," and existing codes were "made up of fine words which no one can controvert but of such embracing vagueness that interpretation is a matter of individual desire." The editorial continued: "Certain things are permissible, certain other things lie beyond the pale. In between is territory where the engineer may roam at will. There is no Supreme Court which interprets the law and publicly enforces it." Steinman's undertaking for the American Association of Engineers was held out as a step toward "disciplinary control." The "question of competition for business" was seen to be central to the problem, and engineers were thought to need "something comparable in solemnity to the doctor's Hippocratic oath." Unfortunately, it was a difficult time to be discussing such ideals, since business for engineers was no better than it was for the rest of the economy:

> In plain words there are more practising engineers, acting as principals, than there are jobs. There is the constant struggle for the majority of those principals to get enough of the existing work to maintain themselves as principals and to keep from falling back into the ranks of the employed, ranks that are apparently not so crowded as are the upper strata of the employing class. Work, too, must be sought to a large extent not from old clients, as is the case with the doctor and the lawyer, but from new interests who too frequently know nothing about engineers or engineering. Competition becomes a dominant factor in independent engineering, and the selfish motive strong in those who are trying to practice it.
>
> The problem of the code, therefore, is to set up an altruistic motive that will reinforce and justify the selfish one. It is not enough merely to assume that everybody agrees that certain things are not to be done; reasons must be given why they are not to be done. Because such reasons generally go back to the underlying necessities for truth and justice and honor, they lack force, for generalities on ethical conduct are always subject to individual interpretation. They must, therefore, be put on the more practical ground that self advancement lies also in the advancement of the profession one practices.

These were tough times in which to aspire to such ideals, but discussions of the kind initiated by Steinman were seen as the way to proceed to raise simultaneously the general status of the profession and the level of its practice. In the meantime, another engineering organization, the Federated American Engineering Societies, was formed, with Herbert Hoover as its first president. This organization of societies, not of individuals, was created "to further the public welfare whenever technical knowledge and engineering experience are involved." A third organization, the Engineers' Council for Professional Development, was formed in 1932 "primarily to increase the input of the practicing profession into the educational process." The issues remain to this day, having outlasted the organizations, which have been transformed several times since.

Another development in the 1920s and into the 1930s was the increasing number of states that had instituted registration laws, thus placing "engineering on a par with law and medicine as legally restricted and recognized learned professions," according to Steinman, who was among the most outspoken proponents of such registration laws. Between 1907, when Wyoming enacted the first such statute, and 1935, engineering registration was established in thirty-two states containing over 85 percent of the engineers in the country. Among the arguments he put forth in his many talks and articles on the subject were the following:

> The public needs to be protected against the quack, the incompetent, the unscrupulous, and the impostor, who do not belong in our profession but nevertheless practice in its name. . . .
>
> The public judges a profession by the examples it meets. When the public sees men who are unlettered and untrained holding themselves out as "engineers," respect for the engineering profession is weakened or destroyed. When the public sees the word "engineer" on the shop window of a plumber, an electrician, a radio dealer, or an automobile mechanic, a wrong picture of the engineering profession is implanted.
>
> For years, the engineering profession talked about this problem—the abuse and misuse of the term "engineer"—but nothing was done about it. Finally with the aid of registration laws, means for successfully protecting our designation became available.
>
> At first, public officials were slow to co-operate. They declared that we could not "copyright the dictionary." We pointed to the precedents of the other legally established professions which had successfully "copyrighted large chunks of the dictionary." Any unlicensed man hanging out his shingle as a "lawyer," a "physician," a "dentist," or an "architect" will be promptly arrested and subjected to the penalties of the law.

Steinman believed so strongly in registration that he thought it should be a requirement for membership in engineering societies, but established groups like the American Society of Civil Engineers were not receptive to such an idea. Indeed, as with college degrees and other non-society designations they would not include the letters "P.E.," indicating registration as a professional engineer, after the names of engineers appearing in society publications. Thus, in 1934, Steinman invited representatives of four relatively young state societies of professional engineers to join him at the Columbia University Club in New York for an organizational meeting of a new group, the National Society of Professional Engineers, whose membership would be restricted to registered professional engineers and whose activities would be limited to the "nontechnical concerns of all engineers." Not surprisingly, Steinman became the society's first president.

With the establishment of registration laws and the growing proliferation of engineering schools, entry into the profession via the self-taught route of an Eads, or even the semiformal educational route of a Lindenthal, became less and less common. Though state licensure regulations included grandfather clauses so established practitioners were not excluded no matter what their route to their practice, and allowed for responsible experience as a substitute for formal education, earning an engineering degree was increasingly the way to become an engineer.

As president of a national group, Steinman spoke and wrote frequently on matters relating to the profession, including engineering education. Whereas so many in his profession less than a century earlier had little if any formal education, Steinman expected the engineer of the twentieth century to be a lettered individual. Then, when identifying himself to strangers as an engineer, he would not hear "an involuntary exclamation," as Herbert Hoover once did from a woman he had met while traveling, followed by her admission, "Why, I thought you were a gentleman!" Hence, among the ways Steinman saw to advance the status of the profession was the manner in which engineers were educated. This had changed to a considerable degree since the nineteenth century, but he saw reasons for it to change further still:

> The four-year course may have been adequate two generations ago, but the increasing content of essential engineering knowledge and the growing recognition of the desirability of a background of liberal and cultural studies for a professional man have altered the picture. Those of us who took a complete college course before entering an engineering school have never regretted it. . . . Personally, I favor a pre-engineering college course of two years, ultimately of four. This is in line with the best standards achieved in other professions.

Although Steinman might have changed "men" to "men and women" if he were writing today, he would have to change little else, for the issue of what form an engineering education should take, and whether it should follow a general college degree, is still a matter of some discussion. A strong argument can also be made that engineering, which is "essentially a mode of thought based on a mastery of the laws of nature," should be a component of all liberal education in an age that must deal with problems not only of bridging ever-wider chasms, both literally and figuratively, but also of undoing some of the inherited neglect and environmental legacies of earlier times.

In addition to advocating the liberal education and registration of engineers, Steinman pushed for use of the professional title "Engineer" or "Engr." with personal names, which he likened to physicians' use of "Dr." Adopting the practice for himself, Steinman began to sign his letters "Engr. D. B. Steinman." On this issue, however, not even *Engineering News-Record* was in his corner. In an editorial commenting on Steinman's introduction of the proposal at the first annual meeting of his National Society of Professional Engineers, the magazine retorted: "Engineers above all are supposed to be logical; do they propose to follow the present plan to its

logical conclusion with Physician Jones, Dentist Smith, Chiropractor Brown—or Barber Cavello, for that matter, for barbers too are licensed in the interest of public safety?"

Among the letters to the editor on the subject was one from Ing. Robert B. Brooks, Jr., who pointed out that the "Mexican engineer is a titled individual." Indeed, in many Spanish-speaking countries, the earned title "Ingeniero" is a mark of distinction, as is the title "Ingenieur" in Germany. But such traditions were not easily introduced in America, "where titles have been looked upon with disfavor." No matter the inconsistency of *Engineering News-Record* in forgetting that the young country did confer the titles of doctor, senator, general, captain, professor, and the like; the time was not propitious for Steinman to be suggesting the adoption of the title of engineer. Though his commitment to the issue never fully disappeared, it seems to have flagged a bit after he completed his two terms as president of the National Society of Professional Engineers. Among the things that competed for his time and attention were the new opportunities that had arisen for engineers generally to undertake bridge projects following such eminently successful and prominent models as the George Washington Bridge, in which the structure was paid for by the tolls levied on the traffic using it.

5

All the great bridge designers seemed to want to hold the record for the longest span, but there were only so many locations that needed or could justify a bridge of record size. Among the last of the great unbridged crossings in the United States that remained unspoken for in the mid-1930s was the entrance to New York Harbor known as the Narrows. Ammann was only one engineer working clandestinely at the time on plans for a bridge at that location. Steinman also saw the crossing not only as the opportunity to regain the span record for the East Coast, but also as the opportunity of a lifetime for an engineer who wished to be memorialized in his work. Though perhaps not quite so obsessive about what Steinman would call his "Liberty Bridge" as Lindenthal was with his North River Bridge, Steinman nevertheless worked on and off on the design for twenty-five years, possibly having an idea for the structure as early as 1926. It was planned to have a main span of 4,620 feet, "a thousand feet longer than the George Washington span" and over four hundred greater than the Golden Gate. Steinman would also point out that it would have a clearance of 235 feet above high water, "100 feet higher than the East River Bridge," of his great hero Roebling, and towers eight hundred feet high, "higher than the Woolworth Building."

David Steinman's unrealized Liberty Bridge

After the death of Holton Robinson, Steinman practiced under his own name for fifteen years. The cover of a brochure issued by D. B. Steinman in the late 1940s was dominated by a sketch of Liberty Bridge. A smaller reproduction of this same sketch had appeared without identification or comment on the inside title page of a Robinson & Steinman brochure dating from the early 1930s, but now a description of the cover declared that Steinman's dream would be "the world's greatest engineering achievement. Furthermore, spanning the gateway to America, it will be a symbol of our free, vital civilization, a portal of hope and courage—an inspiring symbol of the spirit of America." These postwar words may have been intended to rouse support for his dream bridge, and they may indeed have done that among his friends and associates, but Steinman apparently did not have the ear of Robert Moses, the person who, perhaps more than any other single individual, controlled whether a bridge would be built across the Narrows and, if it would, who would build it. Ironically, Steinman, the supreme politician of his profession, seems to have been much more naïve in the local politics of bridge building than Ammann or Strauss in their quests to erect a great bridge in a great municipality. Nevertheless, as late as 1948, in an interview that appeared in *The New York Times*, Steinman said, "I expect Liberty

Bridge to be built and hope to be identified with it." After that achievement, he would be ready to retire, he allowed, but an aging engineer had to do more than hope to win the competition for a great bridge.

Steinman continued to promote his Liberty Bridge, and himself, in his own way. The back cover of the same brochure that carried a sketch of the span contained a photograph of "the hands of Dr. Steinman at work on plans for the great span over the Narrows," taken by the photographer Frank H. Bauer for a book of studies of "the hands of outstanding representatives of the various arts and professions."

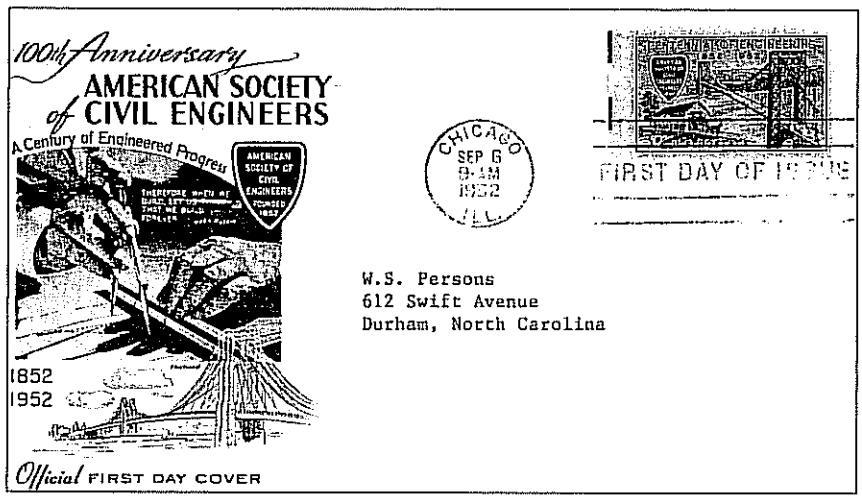
To accompany his hands using dividers and scale, Steinman took a quote from John Ruskin about building not for "present delight" but "forever" with stones that "will be held sacred because our hands have touched them," by descendants who will say, "See, this our fathers did for us." Steinman, who never showed any such admiration for his own father, evidently thought so much of the portrait of his hands that it formed the larger-than-life focus, surrounded by images of many of his already realized bridges, in a mural in an engineering-faculty lounge that he would donate to the University of Florida. Before he did that, however, Steinman thought there might be an opportunity for greater exposure of his engineer's hands immortalized with dividers and scale over drawings of his dream bridge. In fact, he thought the image would form the perfect basis for the design of a postage stamp that was to be issued to commemorate the centennial of the American Society of Civil Engineers, in 1952. As late as 1957, a biographical sketch of Steinman described such a stamp as having been issued, but the stamp that was actually released in 1952 showed not an engineer's hands but two bridges—a covered wooden bridge and a steel suspension bridge, which represented the century of engineering progress. Steinman must have been greatly disappointed that his stamp design was displaced in the final decision, but he may have been even more disappointed that it was Ammann's George Washington Bridge that represented the century of progress. That the hands did appear as part of the design of an official first-day cover envelope may have been but small consolation.

Though it could be said that the George Washington Bridge was indeed the most significant structure to mark the century of progress since the founding of the American Society of Civil Engineers, an equally strong argument might have been made for not including it, or for employing the image of any one of several other bridges. After all, the George Washington was over twenty years old in 1952, making it more a symbol of eight decades, rather than a century, of progress. Had nothing of significance happened in bridge engineering, if that was indeed to be the metaphor for progress, since 1931? The light suspension bridges with sleek girder-stiffened decks

that culminated in the Tacoma Narrows Bridge were not suitable candidates, for obvious reasons, but it could also be argued that the George Washington itself made engineers do what they did to those bridges. And what of the Golden Gate Bridge? Did it not represent progress beyond the George Washington? In short, the George Washington was a curious choice for the stamp. To understand why such a choice was made, however, requires a detour onto some routes of engineering progress that remain incompletely mapped to this day.

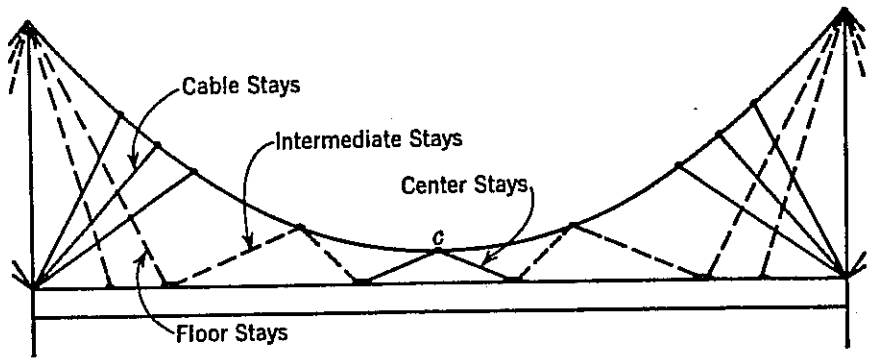
After the George Washington demonstrated that a stiffening truss was not absolutely necessary for the success of a suspension bridge, roadways supported by shallow stiffening girders were a natural development. As we have seen, the thin, ribbonlike profile provided by such designs was in keeping with the aesthetic goals of the time, and so Ammann, Steinman, Moisseiff, and their contemporaries were designing bridges with more and more slender profiles. Problems had begun to appear in bridges built as early as 1937. The Fykesesund Bridge in Norway, which had a 750-foot span suspended by rolled I-beams, and the Golden Gate Bridge, which had a conventional truss, oscillated in the wind, but it was the eight-hundred-foot span of Steinman's own Thousand Islands Bridge over the St. Lawrence River, completed in 1938, and the 1,080-foot span of his Deer Isle Bridge in Maine, opened in 1939, along with Ammann's Bronx-Whitestone Bridge, finished that same year, that drew the greatest attention to the problem, es-

Official first-day cover and U.S. postage stamp commemorating the centennial of engineering in America, incorporating, respectively, David Steinman's hands working on plans for his not-to-be-realized Liberty Bridge and Othmar Ammann's George Washington Bridge



pecially with the collapse of the Tacoma Narrows, which had essentially the same plate-girder construction as these.

Even before that disaster, Steinman and Ammann disagreed as to how best to retrofit their wavy bridges. Both of Steinman's spans had been fitted with cable stays that were stretched between points on the tower near the roadway and the suspension cables. Thus installed, they were designed to stay, or steady, the main cables, and thereby check oscillations of them and the suspended roadway to an acceptable level. Ammann's Bronx-Whitestone Bridge, on the other hand, had cables stretched between the tops of the towers and the roadway, which proponents believed would check the motion of the roadway directly. Within a month of the collapse of the Tacoma Narrows Bridge, which had been fitted with cable stays of yet another kind, *Engineering News-Record* published separate articles on the alternatives endorsed by



Terminology used for various means of attempting to suppress or reduce oscillations of suspension-bridge decks

Steinman and Ammann. Some time after these pieces appeared, Steinman brought the issue out in the open with a letter to the editor in which he challenged the implication that Ammann's solution was found to be preferable to his own after "elaborate tests on a model conducted at Princeton University." In fact, Steinman contended, his system of cable stays was not included in the tests, which were carried out for the Triborough Bridge Authority.

Steinman concluded with nine reasons why he believed that the system adopted to steady the Bronx-Whitestone was "less efficient and effective than the system previously successfully applied on the Thousand Islands and Deer Isle bridges." Among his reasons were factors relating to temperature changes, tower flexibility, side-span motion, torsional oscillations, and various technical details having to do with the nature of harmonic motion. The letter was followed, in the same issue, by a response from

Ammann, who labeled as "valueless" Steinman's "general unqualified assertions" that were "unsubstantiated" by analysis or experiment, and speculated that his criticism of the Bronx-Whitestone solution was motivated by Steinman's "unsuccessful attempts to sell to the Triborough Bridge Authority his services and the use of his patented stay ropes which he endeavors to advertise as being superior to anything else." In an attempt to refute some of the more technical of Steinman's points relating to the dynamic behavior of bridges, Ammann revealed some of his own prejudices: "They involve such a complex problem that no one, not even the most learned physicist, could make a reliable analysis without experimental investigation. Dr. Steinman's medley of arguments is pure guesswork expressed in impressive sounding scientific words." Extensive studies involving models were required to resolve the matter, according to Ammann, and all installations called for "constant watching" to be sure they did not slip the way those on the Tacoma Narrows Bridge had done. The report of the committee of Ammann, von Kármán, and Woodruff on the collapse of that bridge gave no acknowledgment of the disagreement with Steinman over the form that stays should take. Steinman would later tell *Engineering News-Record* that the committee was composed of his "competitors" and that he was left out.

Politics and personalities can most easily enter where there are no incontrovertible solutions to technical problems, for the analytical difficulties can be horrendous and may rest upon assumptions that can always be called into question. Model tests, including the computer-based ones that are possible today, are also subject to criticism for their assumptions, and even when these are agreed upon, there can never be an exhaustive study of all possible conditions under which the bridge and its cable systems can operate. As for the "most learned physicist" that Ammann referred to, the analysis of such an individual, who might be a onetime academic like Steinman, remains a sore point among engineers to this day, for physicists tend to deal with such idealized systems that many bridge engineers fail to see the analyses as representing real bridges in real winds. Indeed, the problem epitomized by the Tacoma Narrows Bridge continues to stir controversy and debate among theoreticial engineers, practical engineers, and physicists alike. Whatever explanations of that collapse may be claimed or proposed remain open to the accusation that they are pure theory, for the simple reason that the very phenomenon they are intended to explain—namely, the actual oscillation and collapse of a full-scale suspension bridge across the Tacoma Narrows—is not available for verifying the theory. As for the retrofitted bridges of Steinman and Ammann, they have been made even more difficult to analyze with

the added complications of their stays and stiffening systems. Though Steinman's cable-stay solution was never admitted to be superior to Ammann's, the latter's Bronx-Whitestone Bridge was finally retrofitted with the stiffening trusses that essentially made the question of cable stays moot, and incidentally destroyed the bridge's sleek lines.

Thus, when it came time to decide what bridge to put on a stamp commemorating a century of engineering, the choice between an Ammann reality and a Steinman dream also became a choice between the two camps of engineering approaches and responses to the Tacoma Narrows collapse. Furthermore, since the centennial of the American Society of Civil Engineers was being viewed as an occasion to define the centennial of the profession of engineering itself in America, that organization no doubt had desired to have a say in whose bridge should be pictured on "their" stamp. They would naturally turn to the work of Ammann, who after his break with Lindenthal had become the consummate organization man. He was more identified with bridges than anyone in New York, where the headquarters of the American Society of Civil Engineers was located, and his George Washington Bridge was the topic of an entire volume of the society's *Transactions*. This must certainly have made a portrayal of that bridge preferable to a photograph of the hands of Steinman, who in his promotion of professional-engineering registration could actually have been seen as a threat to the oldest professional-engineering group in America. In 1953, the year after the stamp was issued, Ammann was made an Honorary Member of the society, thus achieving its coveted "Eminence Grade" of membership. Steinman, on the other hand, continued as an ordinary Member and was never recognized by the ASCE as having achieved "eminence in engineering."

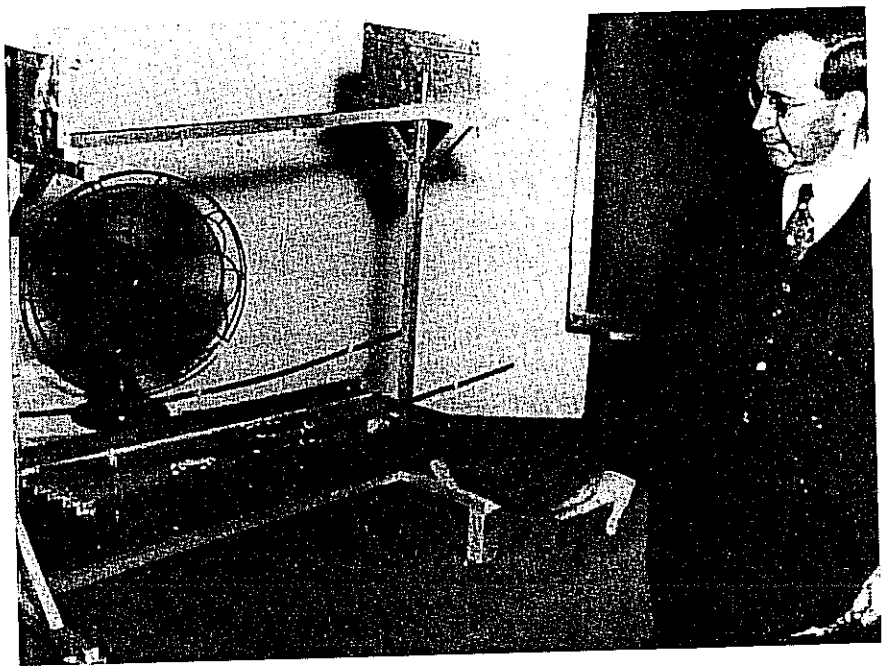
Among the reasons for Steinman's lack of recognition by some segments of the engineering establishment must certainly have been his insistence on keeping the embarrassment of the Tacoma Narrows collapse more in the forefront of discussion than many engineers, such as Ammann, would have liked. The more it was talked about, the more attention it might call to the underlying influence of the George Washington Bridge, and to other spans built in the design climate of the 1930s. In the early-to-mid-1940s, Steinman's desire to understand and articulate theories on the stability of suspension bridges, not to mention to build still larger ones, had brought plenty of attention to the most ignominious event in engineering history. But his interest in bridges became nicely complemented by his desire to pursue literary endeavors.

The book that Steinman wrote with Sara Ruth Watson, *Bridges and Their Builders*, had its origins when Steinman, the very visible engineer and pro-

moter of his profession, was approached by the publisher G. P. Putnam's Sons to write a book for the general reader on the history of bridges. After entering into a contract to do so, he had not been finding time to complete the ambitious project when, early in 1941, in Tampa, Florida, he met Watson, who taught at Fenn College in Cleveland, at a meeting of the American Toll Bridge Association, an organization Steinman had founded about a decade earlier. He was at the meeting to give his classic demonstration of bridge-deck instability, using (like von Kármán) a crude model and an electric fan, in his lecture, "Bridges and Aerodynamics," and Watson was there to lecture on "Bridges in Poetry and Legend."

When Steinman checked in at the meeting and met Watson, she "struck him as so charming" that he offered on the spot to turn the book contract over to her, according to his biographer Ratigan. However, Steinman and Watson agreed to write the book jointly, and it was immensely successful. The chapter on the Roeblings and the Brooklyn Bridge so captivated Irene Steinman that she suggested it be made into a movie. To his response, "I can't write a movie," Irene retorted, "David, you can do *anything*." Since this was no doubt what the egoist Steinman wanted to hear, he set out first to

David Steinman, with simple model and electric fan, giving one of his many lectures on the aerodynamics of suspension bridges



write an entire book on the Roeblings and their bridge, seeing this as a necessary first step toward writing a screenplay. This new book project was to take five years to complete, during which time the movie notion seems to have been forgotten, but not other ones.

In his early sixties, Steinman began to write poetry, some of it bordering on the devotional but much of it about bridges and bridge building, and the verse was eventually collected in several volumes, including *I Built a Bridge* and *Songs of a Bridgebuilder*. His poetry, like almost everything else he did, brought him recognition and awards, and he must have relished the attention that poetry societies gave an engineer who advocated the liberal education of his colleagues so that they might be more readily perceived also, as a group, to be citizens of culture and stature. In one of his poems, Steinman praised the life of the mind, as nurtured in college, where eager young students go

> *To spark the things of spirit that transcend*
> *The shibboleths of ancestry and creed.*

Such ideas must have consoled Steinman, who had repudiated his ethnic origins, even before he committed the thoughts to verse. His major prose-writing project of the time gave him, in addition, a surrogate family to research—the Roeblings and their Brooklyn Bridge. In the preface to his finished work, Steinman perpetuated the myth of his own life story, making himself a child of the bridge rather than of an immigrant family that lived in the squalor and hunger that surrounded it:

> A boy grew up in the shadows of the Bridge. He loved to walk over the span and to explore its marvels. He was awed by its vastness, by the majesty of the towers and by the power of the cables; and he was fascinated by all the details of the construction—the anchorages and the cables, the trussing and the beams, the slip-joint at mid-span, the machinery of the cable railway, the stone work of the towers, and the magic of the radiating stays. When he returned from these pilgrimages he would recount to his playmates and to his elders the wonders he had seen. To him it was truly a "miracle bridge"; and, as he wondered how so marvelous a work could have been created, he was fired with the ambition to become a builder of suspension bridges. In a background of poverty, this far-flung ambition seemed beyond the boy's reach; but the spirit of the Bridge, and later the story of its builders, had entered his heart—and the dream came true.

It was, Steinman continued, "in partial discharge of that debt of inspiration" that he undertook to write his book on the Roeblings, perhaps imagin-

ing them to be his professional progenitors. Gleaning information from "thousands of sources—original manuscripts, family letters, diaries, memoirs, notes, reports, periodicals, newspaper files, biographical works, scrapbooks, technical literature, records of historical societies, and correspondence," Steinman cobbled together a gripping story, if in a ponderous book. The first edition of *The Builders of the Bridge* appeared in 1945, the same year that his longtime partner, Holton Robinson, died. Soon afterward, as if released from some constraint by the event, Steinman dropped his elder's name from the firm's, as he had omitted his parents from his biography. In 1948, the firm of D. B. Steinman received a contract for modernizing the Brooklyn Bridge by eliminating the trolley tracks so that it could carry six lanes of vehicular traffic. Steinman assumed, as a further labor of love, this responsibility to modify yet preserve the bridge that had inspired him as a youth.

A second edition of Steinman's story of the Roeblings appeared in 1950, and it differed from the first mainly in its acknowledgment of a woman's contribution to the Brooklyn Bridge enterprise. When Colonel Washington Roebling was struck with caisson disease in 1872, at the age of thirty-five, and became bedridden in a room overlooking the construction site of the Brooklyn Bridge, where three years earlier his father had suffered the accident that was to claim his life, control of the bridge project might have passed on to another engineer had it not been for Washington's wife, Emily Warren Roebling. According to Steinman, writing elsewhere,

> She grasped her husband's ideas and she learned to speak the language of the engineers. She made daily visits to the bridge to inspect the work for the Colonel and to carry his instructions to the staff. She became his coworker and his principal assistant—his inspector, messenger, ambassador, and spokesman—his sole contact with the outside world.

Emily Roebling in fact functioned as assistant to the chief engineer. In a speech on the occasion of unveiling a tablet memorializing her, Steinman related how, upon the day the bridge was dedicated in 1883, Washington Roebling turned to Emily and told her, as a more generous Lindenthal might have told his assistant Ammann or Steinman upon the completion of the Hell Gate Bridge, "I want the world to know that you, too, are one of the Builders of the Bridge." In an epilogue added to the second edition of his book, Steinman claimed as one of its accomplishments the attention that the book had directed "to the heroic contribution of a woman in the building of the Bridge." He was, in part, atoning for the fact that he had forgotten her in giving his story of the builders of the bridge

the subtitle *The Story of John Roebling and His Son*, and that he had seemed to dedicate it to the great men alone. Perhaps Steinman was coming to realize, no matter how subliminally, the debt he owed his own father and mother.

6

Steinman was able to devote time to literary pursuits in the 1940s in part because it had been a slow decade for new bridge building. This was caused not so much by the collapse of the Tacoma Narrows—that should only have affected the genre of suspension bridges, the way the fall of the Quebec had adversely affected only cantilever bridges a few decades earlier—as by World War II, which had focused so much attention on the destruction of existing bridges rather than on the erection of new ones, both literally and metaphorically. Writing after the war, Steinman noted that, "compared to the 1930s, when nearly every year witnessed a new bridge triumph, this slowing down of an accelerated tempo is an unusual situation." This article in *Engineering News-Record* presented a series of tables giving such information as the world's longest spans in various categories and recording "progress in bridge building as recorded in successive record span lengths." Suspension bridges had dominated that progress for the previous century, with only rare anomalies, such as the Firth of Forth and Quebec steel cantilevers or the Hell Gate and Bayonne arches. Steinman, and others who had dreamed of designing and constructing even greater suspension bridges, must have worried, especially when they looked at the historic record, that in the wake of the Tacoma Narrows disaster their bridges of choice might become as unpopular as cantilevers had earlier in the century.

Steinman still wanted to build the record-setting Liberty Bridge, which was on his drawing board, on the cover of his firm's brochure, and in the frontispiece of his book with Sara Watson. When *Bridges and Their Builders* was issued in a revised edition by Dover Publications in the mid-1950s, however, Liberty Bridge no longer occupied a position of honor; by then it was clear that his dream bridge was not to be in Steinman's trophy case. In the meantime, he had begun to dream of other great spans, such as those crossing the straits of Mackinac, in Michigan, and Messina, in Italy, which awaited the design of exceptional bridges. Yet, if suspension structures were to make credible bridge proposals for such crossings, the matter of aerodynamic stability would have to be addressed. One approach was to test bridge models in wind tunnels, the way airplane-wing designs had then been studied for some years. Such an approach was, however, open to the

limitations of experimental work generally, which meant that it gave only specific information on a specific test of a specific model of a specific design. A cleverly selected array of experiments could provide rather conclusive evidence about the phenomena and design under consideration, but there would always remain uncertainty as to whether the critical conditions had been tested or whether the model gave a true representation of the behavior of the full-scale bridge.

Theoretical studies, on the other hand, could encompass general conditions and thereby deal, in principle, with every conceivable combination of wind and resistance, for example. Whereas Ammann was able to dismiss Steinman's "guesswork expressed in impressive sounding scientific words" during their letter exchange on cable stays, a more mathematically based description of the rigidity and aerodynamic stability of suspension bridges was more difficult to refute. Steinman, with his theoretical background and experience translating the mathematical Melan, was recognized to be capable of producing such a description, and he published it in the November 1943 issue of the *Transactions of the American Society of Civil Engineers*, exactly three years after the Tacoma Narrows collapse. He modeled with mathematical formulas of considerable generality the cables and stiffening girders of a suspension bridge, and proceeded to pursue their mathematical and physical implications for the engineering of such bridges. He was able to conclude from his formulas that by "increasing weight, depth, rigidity, and bracing," or adding stays and devices of various kinds, much as John Roebling had written about and done in the previous century, engineers could make suspension bridges stable in the wind. However, Steinman also pointed out that "these methods resist or check the effects, but do not eliminate the cause." He was also able to conclude from his theoretical analysis that modifications to the cross section of a bridge, such as "using open spaces in the floor or by adding horizontal fins or other wind-deflecting elements" could eliminate the cause of instability. He found it "more scientific to eliminate the cause than to build up the structure to resist the effect," a point of view with which von Kármán would no doubt have concurred. The idea of cutting slots in a bridge deck to obviate its oscillation was, in fact, one of the recommendations that emanated from the board of engineers appointed to investigate the Tacoma Narrows collapse, and the rebuilt bridge across the Narrows did incorporate the idea.

Finally, Steinman concluded his *Transactions* article with a more personal request, that readers "share with him his faith and conviction that suspension bridges of all span lengths can be designed economically to any desired degree of rigidity and with assured aerodynamic stability." Not surprisingly, given the interest in the subject in the wake of the Tacoma Narrows col-

lapse, Steinman's work attracted discussions that occupied more pages than did his paper, as did his responses to these discussions. In general, however, the reactions of readers, especially to his conclusions, were favorable.

In the 1950s, after a decade in which literary and historical pursuits competed for his time as a theoretician and a designer, Steinman rededicated himself with rejuvenated interest to promoting bold new suspension bridges. In part because of theoretical work like his on aerodynamic stability—which provided guidance to wind-tunnel tests of new deck designs, which in turn confirmed theoretical predictions—there was renewed interest and confidence worldwide in building long-span suspension bridges. One project that had been shelved during the 1940s was the crossing of the Straits of Mackinac, which had so separated the Upper from the Lower Peninsula of Michigan that the Upper Peninsula was for all practical and economic purposes more a part of Wisconsin than of Michigan. Thousands of cars would wait sometimes almost a full day to get ferry service across the straits during summer-vacation time. At least as far back as 1888, when Cornelius Vanderbilt was attending a directors' meeting at the Grand Hotel on Mackinac Island and said, "What this area needs is a bridge across the Straits," an obvious advantage had been seen in such a structure. In one of his later poems, "The Bridge at Mackinac," Steinman would not only set the scene but also use rhyme to clarify the pronunciation of the place name. Whereas the island's name is pronounced as it is spelled, this is not so for the waters in which it stands:

In the land of Hiawatha,
Where the white man gazed with awe
At a paradise divided
By the straits of Mackinac—

Regardless, however, of how the place names were pronounced, it had not been until the 1930s that legislation encouraged the serious consideration of a bridge across the straits. Even then, although the technological climate was right, the financial promise of a self-supporting toll bridge for seasonal traffic in the upper Midwest was not so bright as it was in the traffic-growth areas on the East and West Coasts.

By 1950, the sight of thousands of cars waiting for ferries had renewed interest in a bridge. An Inter-Peninsula Communications Commission appointed by Governor G. Mennen Williams promoted a resurrection, with an influential membership, of the Bridge Authority that had been abolished during the war. Though there was some question as to whether the Authority could actually finance or build a bridge, they could certainly gather

technical and financial information. The engineering questions were to be addressed first by a board of three consulting engineers, to be recommended by Dean Ivan C. Crawford of the University of Michigan.

A major suspension span would likely be among the bridges of choice for the Mackinac crossing, and so the appointment of a credible consulting board was saddled with the decade-old legacy of the Tacoma Narrows disaster. Whereas Ammann had been a member of the expert committee that reported on that accident, Steinman had subsequently been a much more visible theorist as to how such an event could have happened and be prevented in future bridge designs. The naming of consulting engineers was further complicated by the debate that had ensued between Ammann and Steinman as to how to deal with their own flexible bridges. In the end, Dean Crawford extricated himself from the dilemma by recommending *both* Ammann and Steinman for appointment as consulting engineers for the project, along with Glenn Woodruff, the San Francisco engineer who had sat on the Tacoma Narrows investigatory panel with Ammann and with the aerodynamicist von Kármán.

The board of engineers reported in January 1951, after six months of study, that a "perfectly safe suspension bridge" could be built across the straits, for a cost of approximately $75 million. An independent report on traffic and financing matters supported the economic feasibility of such a project. A final decision was delayed for various reasons, including: questions of steel availability during the Korean War; suggestions that there were unsuitable foundation conditions beneath the straits; and a stipulation that none of the preliminary consulting engineers could be picked for the actual construction project. This last was a frustrating obstacle, for Ammann and Steinman were the two most logical builders. In the end, the Michigan Legislature granted the Bridge Authority the right to engage the engineer of its choice.

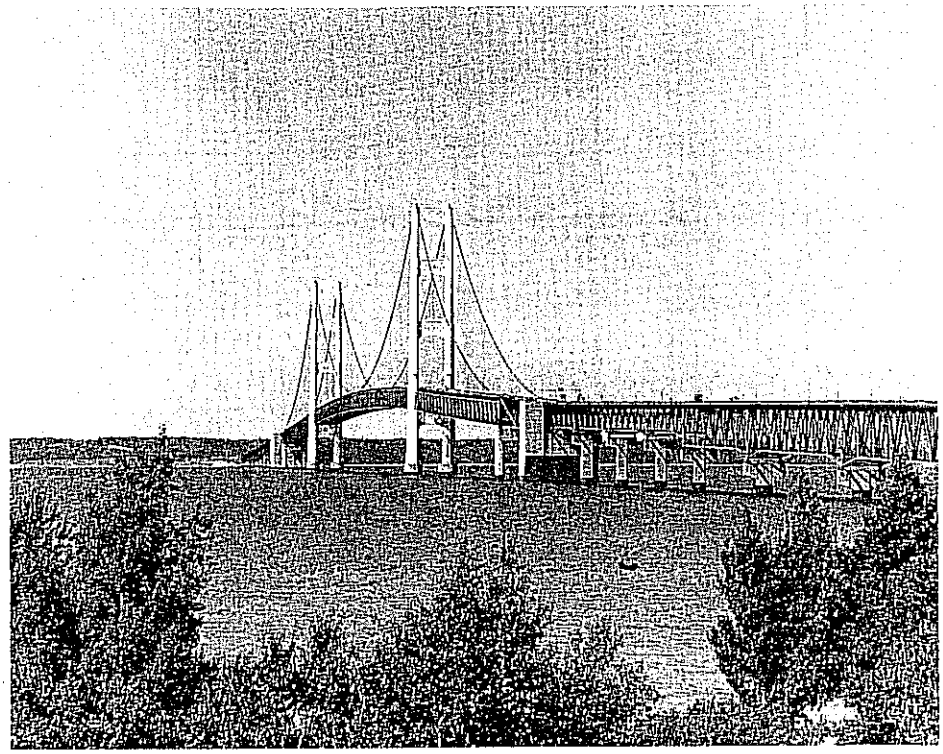
In the meantime, the federal Advisory Board on the Investigation of Suspension Bridges, which had been appointed by the commissioner of public roads in 1942 to coordinate research relevant to suspension-bridge design, especially with regard to aerodynamic stability, had issued its preliminary report of tentative findings, which was published in 1952 by the American Society of Civil Engineers. The authors of the 1941 failure report—Ammann, von Kármán, and Woodruff—were members of the Advisory Board, but the "competitor" Steinman was not. Steinman's articles were, however, prominently referenced in the new report. The behavior of some particular bridges, including the Bronx-Whitestone, was discussed, and an unpublished report by Ammann to the Triborough Bridge Authority was quoted as admitting that the effect of the stay cables had "not been sufficient to prevent nor apparently reduce the exceptional oscillations of larger amplitude."

Such disappointing behavior had led to the addition of the present stiffening truss to the bridge, and it gave Steinman a victory of sorts.

Bankers evidently let it be known that financing would be difficult for the Michigan Bridge Authority if it did not involve Steinman actively in the design and construction of a bridge between the peninsulas. Finally, in January 1953, he was selected as designing engineer of the Mackinac Bridge; Woodruff was later named as his associate. Preliminary plans and estimates were ready within two months, and construction contracts were negotiated, as required, before the bonds could be issued. Steinman's design incorporated features endorsed by the Advisory Board, including space between the deep stiffening trusses and the outer edge of the roadway. This was to raise the critical wind velocity, at which oscillations of the deck could start, from the forty-two miles per hour that had become associated with the failed Tacoma Narrows Bridge to a calculated value of 642 miles per hour. An additional feature—namely, an open-grid roadway under the two center traffic lanes—raised the critical wind velocity to "infinity."

Steinman's design, when drawn to scale, showed the Mackinac Straits Bridge to be larger than the Golden Gate. Though the older structure still retained the record for the longest suspended span between towers, the Mackinac Bridge was actually longer in total suspended span, by almost a thousand feet. When measured from the end of one anchorage to the end of the other, the suspension bridge itself was over eighty-six hundred feet long, and thus surpassed by over two thousand feet the overall length of any suspension bridge extant. Steinman had, in a way, gotten to build the largest suspension bridge on earth. When he wrote, in collaboration with Michigan newspaperman John T. Nevill, the story of the design and construction of the enormous structure, the book was entitled *Miracle Bridge at Mackinac*. At least in his own mind, Steinman was no doubt likening his crowning achievement to the now dwarfed Brooklyn Bridge of his youth. In another work, the "official picture history" of the new bridge, Steinman wrote of the structure and himself:

> The Mackinac Bridge is my crowning achievement—the consummation of a lifetime dedicated to my chosen profession of bridge engineering. As far back as 1893, when I was a newsboy selling papers near the Brooklyn Bridge, I told the other newsboys that someday I was going to build bridges like the famous structure that towered majestically above us. They laughed at me. Now I can point to 400 bridges I have built around the world, and to my masterwork—the Mackinac Bridge—the greatest of all. The realization, one after another, of dreams that seemed hopeless leaves me reverent and humble.



The Mackinac Bridge

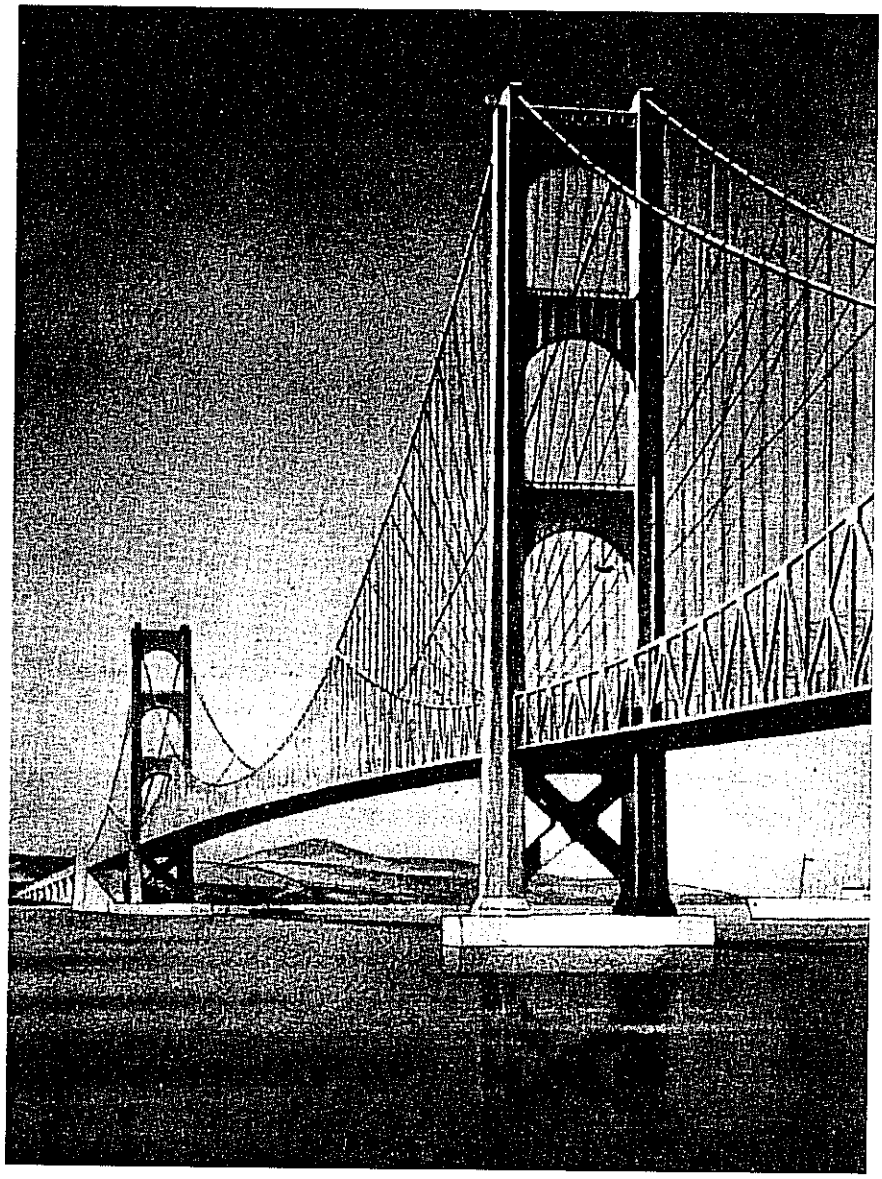
Though Steinman may have had a curious way of expressing his humility, he was no doubt humbled at this time, for it was also clear that the Mackinac Bridge would have to be his "Liberty Bridge," because the New York Narrows project had in the meantime been given to Ammann by Robert Moses, who was in effect his own banker.

There were still other bridge prizes to be pursued, of course, and Steinman had been pursuing them. Yet, even if he had not been growing old, and even if he had not always acknowledged the essential role of assistants in helping him reach his goals, including lesser ones than his "crowning achievement," Steinman the chief engineer knew that he could not have succeeded in his quests without a talented and broad-based staff. As Ammann had acknowledged his dependence upon his assistants, so did Steinman at the conclusion of the Mackinac project. Among those who were central to the success of the enterprise were R. M. Boynton, C. H. Gronquist, and J. London. Boynton, a 1920 civil-engineering graduate of the University of Maine, had been with Steinman since 1928 and was responsible for the substructure of the bridge. Carl Gronquist, who received B.S., M.S.,

and C.E. degrees from Rutgers University, joined Steinman after receiving the master's degree in 1927, and was in charge of the superstructure. London, who received both his B.S. and his C.E. degree from the City College of New York in the early 1920s, had joined Steinman in 1922 and had responsibility for the approaches, lighting, and equipment associated with the Mackinac Bridge. Together, they represented a new generation of engineer, one that came out of the many newer American public schools of engineering that in the early twentieth century overshadowed the once dominant position of the European tradition and private schools like Rensselaer Polytechnic Institute.

In 1960, Steinman added the names of three partners to his firm's name. Whereas he had practiced as D. B. Steinman since the death of Holton Robinson, now the consulting firm would be known as Steinman, Boynton, Gronquist & London. The new firm needed a new brochure, of course, and in it a brief background on the organization, with no false modesty, stated its credentials: "Since 1921, the members of the firm have been designers or consultants on over 400 bridges on five continents, many of them being among the most renowned bridges in the world." The "record cost" of the Mackinac Bridge, almost $100 million, was described as more than that of the George Washington and Golden Gate bridges combined. This "artistically and scientifically . . . outstanding" structure, the "longest suspension bridge in the world," was further described in more personal terms: "Here is Dr. Steinman's and his firm's crowning achievement. It represents the attainment of a new goal of perfect aerodynamic stability, never before attained or even approximated in any prior suspension bridge design."

Not only past achievements were pictured in the consulting firm's brochure. In a foreword signed by Steinman, he wrote of "the great spans of tomorrow," and it was one of these especially that had recaptured his imagination. As early as 1950, the Italian Steel Institute had retained Steinman to prepare plans for a crossing of the two-mile-wide Strait of Messina, between Sicily and the Italian mainland. The legendary passage through which Ulysses had to sail between Scylla and Charybdis, the strait is the site of the occasional mirage known as the *fata morgana*. How the poet Steinman must have longed for the commission, and the occasion to commemorate its achievement in verse. There was no time for poetry when courting engineering commissions, however, and the bridge sketched in the brochure was described as having a record five-thousand-foot main span, stiffened against railroad traffic, aerodynamic forces, and earthquakes. According to the consulting firm's brochure, commencement of construction awaited only the financing of the $150 million cost.



The Strait of Messina bridge design proposed by David Steinman

Perhaps it was the adrenaline that the Mackinac commission released that caused Steinman to produce a new outpouring of articles on bridges and aerodynamics in the early-to-mid-1950s, but it was the bridge across the Strait of Messina that became his new sought-after achievement. Steinman knew that, no matter how much he spoke of the total suspended span or the eighty-three hundred feet between abutments or the five-mile overall

length of the roadway of the Mackinac Bridge, the main suspended span was the technological achievement by which records were really kept, and the Mackinac's was only thirty-eight hundred feet long, a full four hundred feet less than that of the Golden Gate, and less still than that of Ammann's Verrazano-Narrows Bridge would be. If Steinman really wanted to hold the record, he had to be identified with a bridge like the one he had proposed across the Strait of Messina.

Among the articles Steinman had written, more than incidentally promoting his new dream bridge, was one entitled "Suspension Bridges: The Aerodynamic Problem and Its Solution." This appeared in 1954 in *American Scientist*, the journal of Sigma Xi, the research honor society that had been founded early in the century as a scientific counterpart to Phi Beta Kappa. In this comprehensive piece, renderings of the Mackinac and Strait of Messina bridges, drawn from the same perspective, appear on facing pages. There is a strong physical resemblance between the two bridges' towers, and the clear implication had to be, if the one, why not the other. There were certainly no technical impediments in Steinman's mind, as his article clearly argued. He showed how he had physically checked with stays the aerodynamic motion of his Deer Isle Bridge, without having to resort to a retrofitted truss, and he pointed out how he had solved the mathematical problem of understanding what it took to control aerodynamic motion in bridges on the drawing board. Forty years after its appearance, the paper is remembered by engineers and scientists alike as having been a definitive resolution of the problem of suspension-bridge oscillations, both practically and theoretically, in spite of a renewed interest in 1990 in revisiting and reanalyzing the Tacoma Narrows collapse on the occasion of its fiftieth anniversary. Another article by Steinman, a historical perspective on bridges generally but with a special emphasis on suspension bridges and the aerodynamic problem, had appeared in *Scientific American*. It concluded with a discussion of bridges of the future, of which the Strait of Messina span was the clear successor to the one across the Straits of Mackinac.

7

Perhaps those whose dreams of bridges go to the lengths that Steinman's did cannot ever stop dreaming of bettering themselves. The Messina bridge project was to be left on Steinman's drawing board, however, when he died in 1960. He had become ill barely six months after establishing the partnership that would associate his name with projects well beyond his death. His obituary in *The New York Times* remembered him as the designer of the

Henry Hudson Bridge, the work he had effectively completed as a student at Columbia, as well as of "more than 400 others spanning rivers and harbors in many parts of the world." An editorial in that paper called his "greatest success" the bridge in Michigan that had come to be recognized as the "world's longest suspension bridge" and to be called affectionately "Big Mack." Ironically, the hometown paper incorrectly spoke of Steinman as having been "born on the Lower East Side four years before Brooklyn Bridge was opened on May 24, 1883," which would have made his year of birth the same as Ammann's. The paper did not misspeak, however, when it referred to Steinman's belief that a bridge could be "a poem stretched across a river" and that "bridges are an index to civilization." Though the editorial recognized Steinman to have been a poet who wrote in steel, it by no means remembered him only as a dreamer: "He helped in the negotiations and the rivalries that must proceed—sometimes it seems endlessly—before a great bridge is built." It should not diminish Steinman's accomplishments to say that this prosaic praise might also have been written of any of his few significant rivals and peers.

But if the popular press remembered Steinman affectionately, only allowing that "rivalries" were a part of bridge building, the engineering press did not recall him so warmly. *Civil Engineering*, the magazine of the American Society of Civil Engineers, treated his death as but another bit of society news, albeit with a picture of an aged Steinman holding a drawing of his last dream, the Messina Strait bridge. He was acknowledged to be "regarded as [*sic*] one of the great engineers of the twentieth century," but the reserved tone of the notice of the death of the "famous bridge builder," who had been a member of the society for half a century, only hinted at the legacy Steinman had left behind in the profession he so loved. Unlike Ammann, who had received the society's highest formal recognition, Steinman seems to have been thought of as just another dues-paying member, albeit one of some notable accomplishment who had been active for fifty years. In fact, he had been the promoter of what was seen as a competing organization, the National Society of Professional Engineers. Given his aspirations toward honors and awards, he may have been disappointed at not being made an honorary member, or at least a fellow, of the civil-engineering society. He would be further shunned by having not so much as an abstract of a memoir of him published in the society's *Transactions*. But such mean-spiritedness had been foreshadowed.

A year before he died, *Engineering News-Record* had profiled Steinman in the same "Men and Jobs" series in which its editors had profiled Ammann a year earlier. The contrast of the two treatments is striking. Ammann's was titled "An Artist in Steel Design," and it portrayed the

"unobtrusive looking man" as one who disliked attention and preferred to stay at home rather than go to parties that served "no particular purpose." Instead of being a loner, however, he was a firm "believer in the conference table and in amalgamation of talents to do a job." When asked by the interviewer to describe the "typical" engineer's personality, Ammann replied:

> We may lack glamor and sparkle. We might even be considered dull by many people, but I don't believe it. I think that the fact that we are dealing so intensely with concepts outside the layman's ken makes us often not understood by them.
>
> This is actually the engineer's number one problem today. He must learn somehow to communicate more easily—both with his colleagues and with the public. Most of us [engineers], when we have something to say, will qualify our statement to death until we're bogged down and the point is lost to all but those who have the patience to dig to see what we really mean. Even then, one is not often sure.

Ammann suggested teaching more communication skills to student engineers as a way of correcting the problem, but neither he nor the editor who was interviewing him seemed to want to pursue directly what role fundamental traits of personality may have to do with it all. Rather, the interview continued with a digression into Ammann's keen sense of office detail, which was reported to be exemplified by his knowing "most of his employees by name and personality," and by the fact that he "scanned carefully" everything that left the office.

Among the things reported to ruffle Ammann's feathers was any expression of admiration for the "rugged individualist," because "a man like that is nothing but an egotist." Ammann believed that "People are meant to work together. Nobody wants to see a one-man show." There can be little doubt that Ammann's rival, the rugged individualist and egotist David Steinman, was a target of these remarks. It was Steinman, more than Ammann, who had reached out to and communicated with the public with an effective glamour and sparkle.

Steinman's profile, perhaps at his instigation and after an appeal for equal time, appeared under the title of the magazine's cover story, "What Measure for This Man?" He was described as having had a full life, "full of disappointments and frustrations as well as of recognition and financial rewards." By his own admission, his great disappointment was being denied "the focus of my life ambition," the Liberty Bridge he had spent thirty years promoting. *Engineering News-Record,* which had been so much an interpreter of the profession, surmised, moreover, that the "loss of affection

among contemporaries may be the greatest of his sacrifices," for he was a man who wanted "very much to make friends" but whose personality had not been one "to take or leave."

To its own rhetorical question of what Steinman's life added up to, the magazine responded with more questions. Would it be "the mighty Mackinac Bridge"; the book about the Roeblings, *The Builders of the Bridge*; the book for juveniles, *Famous Bridges of the World*; the poems; the National Society of Professional Engineers, which he founded; his tireless efforts for passage of registration laws for engineers; or his later "speech-making campaign when he barnstormed the country" explaining the collapse of the Tacoma Narrows Bridge, which he believed he could have saved? It was this last effort especially that did "not endear him to his contemporaries who had a part in the investigation" of the failure that was so embarrassing to the profession.

According to Steinman, "All my competitors were on a committee to investigate the collapse and I was scrupulously left out." He also allowed that "channels of information" were closed to him, as were "channels of publication," but the anonymous reporter did not feel the engineer said these things with bitterness, only "somewhat sadly." Indeed, one of Steinman's distinguishing traits may have been his willingness to discuss openly engineering embarrassments for the good of the entire profession. In 1929, for example, when heat-treated wire was showing signs of weakness in the cables of his Mount Hope Bridge in Rhode Island and the Ambassador Bridge in Detroit, both then under construction, the cables were dismantled and replaced with conventional cold-drawn wire. Rather than helping the incidents to be forgotten, as some thought human nature and professional pride might dictate, Steinman "distinguished himself by helping to record fully and promptly the findings of this unfortunate experience."

But it was the strictly personal qualities of the man, more separated from professional practice than issues of the cables or instabilities of bridges, that had finally to be addressed in a profile. In the year since Ammann had blasted the rugged individualist in the same department of *Engineering News-Record*, Steinman had added the names of other engineers to his own, and his firm was running easily without "The Doctor," whose identity had sometimes seemed to be one with it. His relationship to his employees was nonetheless reported to be perhaps "an outstanding facet" of his personality: "They call him generous, thoughtful, receptive, ethical, quixotic, brilliant, warm, human, a team man and character-builder." He, for his part, considered all of them his "brother engineers."

Steinman's methods of doing business were perhaps affected by his "quixotic" quality. He admitted to having "put off earnings to fight causes,"

and thus it was not surprising that the practice "barely broke even most years until the Fifties," when the Mackinac Bridge project was realized. His methods of "promoting professional engagements" were considered one likely legacy of his career, for "he would do considerable engineering on a proposed bridge in hopes of some day getting to design it in detail and see it built." His Liberty Bridge was among a list of forty other such proposed bridges. During the 1920s, Steinman had traveled everywhere around the country looking for prospective sites for toll bridges to design, but he later speculated on why he found it difficult to get very far with state highway departments: "I didn't know and don't want to know the political ropes."

Though Steinman may not have known or even wanted to know the politics of bridge building, he did seem to have an instinct for the politics of self-promotion. Perhaps the gentle-looking man who was, like so many builders of large bridges, slight in physical stature, worked hard at promoting his own accomplishments because he had repudiated the more modest but nevertheless essential ones of his parents. Or perhaps he felt that competing for publicity and recognition of a less tangible kind was not quite the same as fighting tooth and nail for a bridge commission. Whatever his motivation, however, Steinman was a notorious self-promoter, leading at least one reporter to state that "perhaps his greatest contribution will some day be judged to be his public relations effort."

Steinman seemed to seek and need the limelight as a flower does the sunlight, and no one knew this more objectively than the press: "Editorial offices for years have been on the receiving end of the Steinman mail—poems, itineraries, news releases, pictures." Although little of the material was usable to editors, it did call constant attention to the profession of engineering. It was estimated that no other engineer since Herbert Hoover or Charles Kettering, the crusty inventor of the electric starter for automobiles, had done more in his time to make engineering known to the public, and in Steinman's case, "he identified himself, indeed integrated himself, with his profession so thoroughly that it would be difficult to say what effort he puts forth for self and which for his profession." Though this perhaps self-generated confusion of himself with engineering did not win the approval of some of Steinman's contemporary engineers, such as Ammann, it was in the final analysis a true measure of the man.

When Steinman died, a little more than a year after the assessment of him appeared in *Engineering News-Record*, the journal editorialized on "Dave Steinman" with the same ambivalence, noting that, "unfortunately, his great accomplishments were sometimes clouded by his personality, which frequently made him the center of controversy." He was likened in ego and outspokenness to Frank Lloyd Wright, and was said to have done

David Steinman the self-promoter, shown here posing among the floor-stay and suspender cables of the Brooklyn Bridge

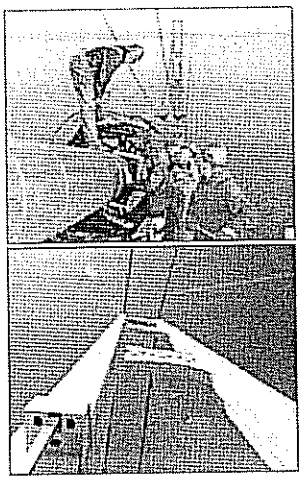
for engineering in his lifetime what Wright did for architecture in his. The question of Steinman's "real contribution" still irked the editors, however. They allowed that he "personified civil engineering" and that he was a "nearly unique" interpreter of his profession to the public, leaving behind too few to fill this important role, but in the end they would not grant him the accolade he no doubt would have most wanted to hear. Not one of his bridges was named in the editorial, not even the great Mackinac or his dream Liberty or his proposed Messina Strait. Instead, the magazine whose predecessor forty-seven years earlier had run a picture of Steinman's first bridge, the modest timber cantilever he built with a troop of Boy Scouts in Idaho, grouped all of his structural achievements anonymously into a single sentence that at the same time negated them: "His bridges, which will remain as great monuments to him, would probably have been designed by others if he had not come along."

Though this kick at the casket might be in one sense true, it diminishes more the editor's credibility as a student of engineering than the greatness of Steinman's accomplishments. No doubt, had Steinman and his colleagues not designed and built the Mackinac Bridge in Michigan, the Deer Isle Bridge in Maine, the St. Johns Bridge in Oregon, the Carquinez Straits Bridge in California, the Florianópolis Bridge in Brazil, or even the timber

cantilever in Idaho, those places might have had their bridges sooner or later, by others if Steinman had not come along. But can anyone, after knowing how the personality of the engineer informs his designs, believe that any of Steinman's bridges would be quite the same span if designed by another? The Liberty Bridge remained a paper bridge, because the Verrazano-Narrows was built—clearly an Ammann bridge, rooted in the same aesthetic as his George Washington and Bronx-Whitestone bridges. Had Ammann not come along and filled the role of chief bridge engineer for the fledgling Port Authority, who knows what the George Washington Bridge and all its descendants would look like today? There is little doubt that bridges would stand where they do now, but they would be different bridges, embodying the personal style and ideas of whosever bridges they were, and they would affect our present sense of bridgeness differently than do those that actually exist. Eads, Cooper, Lindenthal, Ammann, and Steinman each built his own kind of bridge in his own time, and each of them has left a legacy that has influenced the bridges and bridge builders that have followed. This is, and will always be, the essence of the endeavor.

Prentiss M. Brown

Location
History of the Bridge
Facts & Figures
Rules & Regulations
Fare Schedule
Monthly Traffic Statistics
Meet the Board Members
Prentiss M. Brown
Bridge Cam
In Memory Of



"Father of the Mackinac Bridge"

Prentiss M. Brown

1889-1973

Born in St. Ignace, Michigan, Mr. Brown Graduated from LaSalle High school in 1905, Albion College in 1911, and did post graduate work at the University of Illinois. Prentiss married Marion Walker, and practiced law with his father in the St. Ignace area. From 1932 to 1943 he served in the U.S. Congress and Senate. In 1950 Prentiss M. Brown was appointed to the Mackinac Bridge Authority and elected its first Chairman. Mr. Brown, with the assistance of fellow Authority members William Cochran, Murray Van Wagoner, and Charles Fisher, Jr., secured the financing for the Mackinac Bridge. Mr. Brown considered this to be one of his most rewarding accomplishments.

Prentiss M. Brown is well known for his struggle to get the Mackinac Bridge built over the Straits of Mackinac. Mr. Jack Carlisle, in a radio broadcast over WWJ radio station on February 22, 1954, told his listeners of Mr. Brown's struggle. The transcript from Mr. Carlisle's broadcast was later published in a newspaper and is as follows:

" After a 20-year fight which often seemed hopeless, there finally is going to be a five-mile bridge across the Straits of Mackinac. As one of the states most ambitious projects, it will link Michigan's two peninsula's. It will cost about $99 million. It is scheduled for completion in November, 1957.

The bridge project had many stalwart partisans. However, the project actually became a reality through the determination of one man - Prentiss M. Brown, Chairman of the Michigan Mackinac Bridge Authority. Brown, a former United States Senator and Chairman of the Board of the Detroit Edison Company, refused to accept defeat when it seemed inevitable. Prentiss M. Brown just wouldn't stay licked.

His energetic determination to get the Mackinac Bridge financed is undoubtedly due to the fact that he was born and raised in the midst of a daily realization of the need for the bridge. Now 64 years old, Prentiss Brown spent a lifetime in his old home town of Saint Ignace, Michigan. He was once a bellhop at the old Astor Hotel on Mackinac Island. Probably the bridge idea would have died completely in the last year - if it had not been for an incident that happened to Brown 34 years ago. He was 30 years old then and a lawyer. He was scheduled to appear before the State Supreme Court in Lansing to argue a case.

Brown had to get across the Straits to catch a train at Mackinaw City. However, both of the ferry boats were stuck in the winter ice. He and another hardy voyager, who also had important business on the side of the Straits, hired a horse and a cutter. They started across the ice. They ran into ice hummocks ten feet high and had to send the cutter back to Saint Ignace. They proceeded on foot.

They ran into 50 acres of open water, like a big pond, and had to circle it. All in all, they hiked four miles across the ice. The wind was blowing up a small gale. It was snowing. By the time they had spent most of the day walking - well, they missed their train.

Brown said in a recollection today, "That bitter hike across the Straits made a lasting impression on me - for the need of a bridge across the Straits."

Prentiss Brown never forgot. That is the reason that 20 years ago Brown became legal counsel for the first Mackinac Bridge Commission. Back in 1933 under Governor Comstock. And Prentiss worked for love. He would accept no money. Four years ago he became chairman of the Mackinac Bridge Authority. By 1952, it looked like the RFC woud finance the bridge across the Straits. Whereupon, a New York investment broker offered to organize a private syndicate in October, 1952, to do the financing.

He tried to float the Mackinac Bridge bonds in March and again in June, 1953. Both times he failed. As a matter of fact, it looked like the bridge project was a gone goose last June. For lack of financing. Due to the high cost of money. But Prentiss refused to stay licked. The project was revived on the New York bond market in November due to the increase in interest rates and the increase in traffic across the

Straits.

It was only six days ago that a check for $98,500,000 to finance the Straits of Mackinac Bridge was put into Brown's hands in New York. One hundred and fifty investment brokers underwrote the sale of revenue bonds for a commission pot of three million dollars.

Actually, the deal went through last year with just 13 days to spare before the offer of State maintenance for the bridge would have expired. In a four-year battle under Brown to get the bridge finance - this was a slim margin to win a victory.

Michigan will not soon forget the gallant fight of Prentiss M. Brown for the Straits of Mackinac Bridge."

The Mackinac Bridge Authority has created a token in honor of Prentiss M. Brown. To view this and all other tokens visit our token order form

Token Order form

Prentiss M. Brown

From Wikipedia, the free encyclopedia

Prentiss Marsh Brown (June 18, 1889 - December 19, 1973) was a Democratic U.S. Representative and Senator from the state of Michigan.

Prentiss M. Brown

United States Senator from Michigan

In office
1936 – 1943

Preceded by	James J. Couzens
Succeeded by	Homer S. Ferguson

Member of the U.S. House of Representatives from Michigan's 11th district

In office
1933 – 1936

Preceded by	Frank P. Bohn
Succeeded by	John F. Luecke

Born	June 18, 1889 St. Ignace, Michigan
Died	December 19, 1973 St. Ignace, Michigan
Political party	Democratic
Spouse(s)	Marion Walker
Children	Prentiss M. Brown, Jr., Paul W. Brown, Jim Brown, four others
Alma mater	University of Illinois at Urbana-Champaign Albion College

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Biography

Brown was born in St. Ignace, Michigan and attended the public schools there. He attended the University of Illinois at Urbana-Champaign and graduated from Albion College in Albion, Michigan in 1911. He studied law and was admitted to the bar in 1914 and commenced practice in St. Ignace.

Brown married Marion Walker in 1916.[1] The couple had a total of seven children.[2]

Brown was prosecuting attorney of Mackinac County from 1914 to 1926 and the city attorney of St. Ignace from 1916 to 1928. He was an unsuccessful candidate for election in 1924 to the United States House of Representatives and in 1928 for election as justice of the Michigan Supreme Court. He was a member of the State Board of Law Examiners from 1930 to 1942.

Congress

Brown was elected as a Democrat from Michigan's

11th congressional district to the United States House of Representatives for the 73rd Congress and was reelected to the 74th Congress, serving from March 4, 1933, until his resignation, effective November 18, 1936.

He was elected as a Democrat on November 3, 1936, to the United States Senate for the term beginning January 3, 1937, but was subsequently appointed to the United States Senate to fill the vacancy caused by the death of James Couzens for the term ending January 3, 1937. In total, he served from November 19, 1936, to January 3, 1943.

He was chairman of the U.S. Senate Committee on Claims in the Seventy-seventh Congress. He was also a member of the Banking and Currency Committee, and in this capacity was instrumental in helping Franklin D. Roosevelt achieve his desired wage and farm price controls.[3] He was an unsuccessful candidate for re-election in 1942.

After Congress: family

In December 1942, Roosevelt selected Brown to take over as administrator of the Office of Price Administration, replacing Leon Henderson, whose tenure as administrator was listed as one of the major reasons for Democratic losses in the 1942 elections.[3] In 1943 he resumed the practice of law in both Washington, D.C., and Detroit, Michigan. He also served as chairman of the Detroit Edison Company.

In 1951, Brown was named chairman of the new Mackinac Bridge Authority and served until his death. During his chairmanship, this authority oversaw the construction of Michigan's Mackinac Bridge. Brown died in St. Ignace at the age of 84 and is interred there at Lakeside Cemetery.

Two of Brown's children were also active in Democratic party politics. Prentiss M. Brown, Jr., ran unsuccessfully for Congress several times, in 1952, 1956, 1958, and 1960,[1] and was the city attorney for St. Ignace for 50 years.[2] Paul W. Brown was a member of the Board of Regents of the University of Michigan from 1971 until 1994, and ran unsuccessfully for Lieutenant Governor in 1974.[1]

Honors

- In 2004, Albion College renamed its Honors Institute the *Prentiss M. Brown Honors Institute* in memory of the 1911 alumnus.
- Between 1976 and 2001, the stretch of I-75 between the Mackinac Bridge and Sault Ste. Marie, Michigan was known as the Prentiss M. Brown Memorial Highway.[4]
- Since 2001, the Prentiss M. Brown Memorial Highway is designated as the name of I-75 in Mackinac County on the north side of the Mackinac Bridge.[4]
- His accomplishments are commemorated as a "Michigan Legal Milestone" erected by the State Bar of Michigan.[5]

Notes

1. ^ a b c Kestenbaum
2. ^ a b Paquin 2007
3. ^ a b Time 1942
4. ^ a b Barnett 2004, p. 177-178

5. ^ Michigan Legal Milestones. (http://www.michbar.org/programs/milestones.cfm)

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External links

- Albion College press announcement (http://www.albion.edu/ac_news/releases2004-05/brownhonorsinstitute.asp)

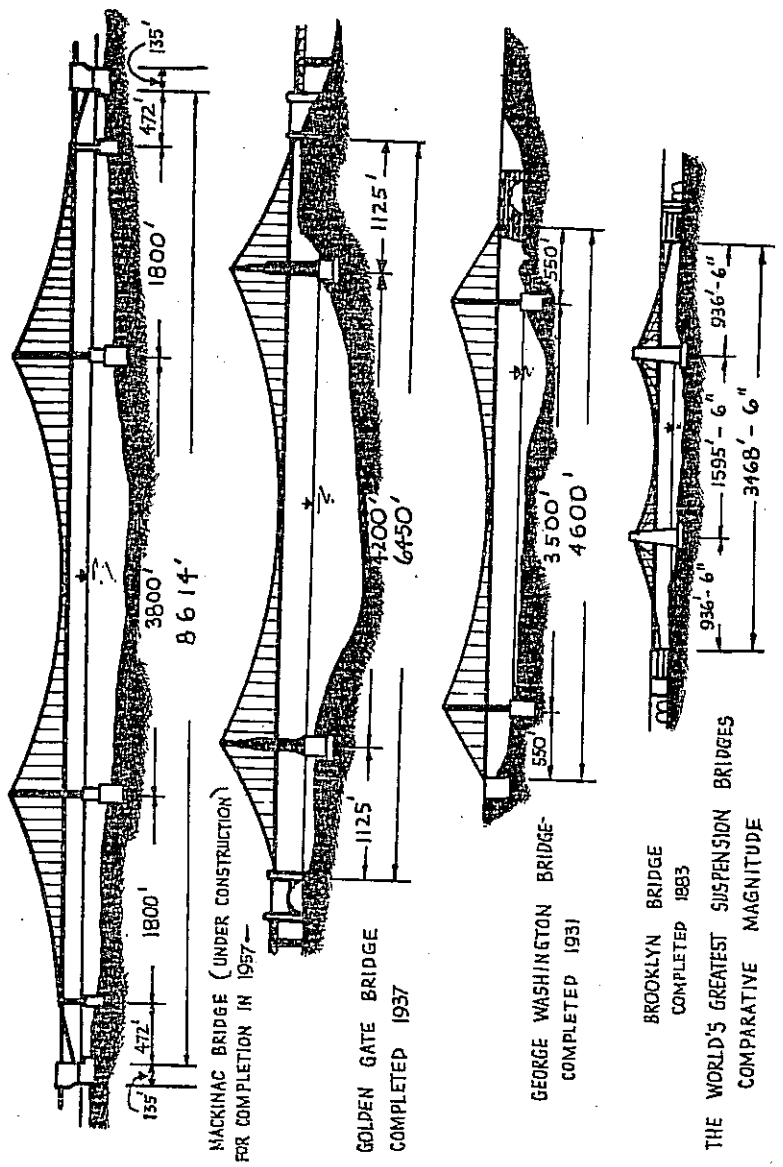
- Prentiss M. Brown (http://bioguide.congress.gov/scripts/biodisplay.pl?index=B000941) at the *Biographical Directory of the United States Congress*

United States House of Representatives		
Preceded by **Frank P. Bohn**	**United States Representative for the 11th congressional district of Michigan** 1933 – 1936	Succeeded by **John F. Luecke**
United States Senate		
Preceded by **James J. Couzens**	**United States Senator (Class 2) from Michigan** 1936–1943	Succeeded by **Homer S. Ferguson**

Retrieved from "http://en.wikipedia.org/wiki/Prentiss_M._Brown"
Categories: 1889 births | 1973 deaths | Members of the United States House of Representatives from Michigan | People from Mackinac County, Michigan | United States Senators from Michigan | Albion College alumni | University of Illinois at Urbana-Champaign alumni

THE MACKINAC BRIDGE STORY

BY PRENTISS M. BROWN



THE MACKINAC BRIDGE STORY

BY PRENTISS M. BROWN

DETROIT WAYNE UNIVERSITY PRESS 1956

Library of Congress Catalog Card Number 56-9807

THE LEWIS CASS LECTURES

1948 Father Gabriel Richard.....Stanley Pargellis
1950 The Importance of Being in Earnest
Raymond C. Miller
1951 Yankees in Wonderland....Frank Woodford
1952 Exploration Unlimited....R. Darwin Burroughs
1953 Local History is Living History....S. K. Stevens
1954 The Yankees Capture York....Milo M. Quaife
1955 The Mackinac Bridge Story
Prentiss M. Brown

Publication of this booklet was made possible by the financial assistance of the Detroit Historical Society Guild

THE CASS LECTURESHIP

In 1948 the trustees of the Detroit Historical Society on the recommendation of the president, Dr. Alfred H. Whittaker, approved the naming of a committee to plan an annual program to be known as the Cass Lecture and to select a speaker who would present to the Society a subject of current or historical interest and significance. Dr. David D. Henry, Monsignor Edward J. Hickey, and Marquis E. Shattuck were appointed to the committee. The first lecture, an appraisal of the life and signal service to Detroit of Father Gabriel Richard, was presented by Stanley Pargellis, librarian of the Newberry Library in Chicago.

In succeeding years, historians and historically-minded men whom the Society has sought to honor have delivered scholarly lectures which the Society has published for distribution to its members. The seventh of these annual lectures was given on the evening of May 25, 1955, in the Hall of Industry of the Detroit Historical Museum, by the Honorable Prentiss M. Brown, president of the Society from

1953 to 1955. His presentation was in the tradition of the Historical Society of Michigan, the first historical organization of the old Northwest Territory. In September 1829, the members of that Society called upon their president, Lewis Cass, the distinguished governor of the Territory, to address the membership on the first anniversary of the formation of the Society. The address on that occasion was subsequently published and is now an invaluable item in the archives of Michigan. In like manner, the Detroit Historical Society seeks to foster historical research and encourage the preparation of manuscripts for publication which will prove valued additions to the public historical libraries of this area and to the private collections of its members.

Marquis E. Shattuck
Chairman
Cass Lectureship Committee

FOREWORD

A Michigan legislator with a gift for metaphor said when the bill was passed to bring the Mackinac Bridge into reality, "The North and the South of the state have long been engaged; they now have a wedding ring." Such being the case, there is every reason to refer to Prentiss Marsh Brown, chairman of the Mackinac Bridge Authority, as a member of the wedding.

All will agree, I think, that Mr. Brown has been the most important member of the wedding between the Northern and the Southern peninsulas. And since this slender volume contains his own modest recapitulation of the fascinating story of the financing of the world's greatest bridge, let us give some consideration to the man whose enthusiasm and sense of history brought it to focus and to a successful issue.

The bridge, even before it takes solid shape before us, most certainly must be accounted the most spectacular of his achievements. At least, that is the way

he now regards it. Already Michigan people are referring to him as "Mr. Bridge," and he doesn't object, even though the designation brushes off some notable past performances: a political career that carried him from prosecuting attorney of Mackinac County to the chairmanship of Michigan Democratic State conventions over a period of years; to a seat in Congress from the Eleventh District, the first Democrat ever to represent that rock-ribbed Republican area; to the United States Senate, where he became a trouble-shooter for Franklin D. Roosevelt; to head of the Office of Price Administration; to the chairmanship of the board of the Detroit Edison Company; to honorary posts in various fields of business and of culture, too numerous to catalog here.

So he rejoices in the name of "Mr. Bridge."

The researcher may find in Mr. Brown's life ample reason why he should, since the very circumstances of his birth indicated a Great Lakes direction. He was born in St. Ignace and is probably the only citizen of Michigan whose entry into the world caused his small corner of it to cease its normal operations and, in a manner of speaking, to cull out a holiday.

His father, James J. Brown, was prosecuting attorney of Mackinac County at the time. Naturally, Judge J. H. Steere, of the Eleventh Judicial Circuit, adjourned court and the new little citizen was made the subject of an official manifesto. Prosecutor Brown went home to tell his new son the news and to point out to him the advantages of a home site that overlooked the majestic straits with the long ships passing.

So Prentiss Brown was singled out by destiny from the beginning. He grew into a man who not only had a deep consciousness of history but a way of making it himself. His concern with it brought him to the presidency of the Detroit Historical Society and the presidency of the Michigan Historical Commission.

Also, the researcher may delve into the early life and deeds of Mr. Bridge and find basic reasons for other directions his lively career has taken. Politics, for instance.

Prentiss Brown cherishes an old photograph, which shows Detroit's official family moving from the old City Hall at the head of Cadillac Square into another City Hall across Woodward, which only recently was abandoned in favor of the monumental City-County Building. Prominent in this group is his father, who was then the city attorney, a post now recognized as corporation counsel. All the marchers are distinguished by Prince Albert coats and tall silk hats. All, that is, but Town Lawyer Brown. He's wearing a jaunty straw, a true non-conformist.

The Browns moved north and in that enchanted country, Prentiss lived out an average American boyhood. This led him to a bellhop's job in a Mackinac Island hotel.

One day an important delegation from Washington, D.C., landed there. Prentiss struggled with the luggage of the more impressive guests—up two flights of stairs. When he looked at the tip, he found it scarcely adequate. For Vice-President Fairbanks had given him but one thin dime.

That was the day Prentiss Brown became a Democrat. Any Republican want to rise to a point of order?

George W. Stark
Detroit Historiographer

PREFACE

The printed page cannot tell the story of the terrific struggle to achieve the result accomplished in the financing of the Mackinac Bridge. Public sentiment had to be aroused in the heavily populated parts of the state to favor the expenditure of a huge sum of money in a sparsely settled area. No large cities were located nearby the bridgeheads. The traffic is seasonal to a considerable extent. Advocates of the ferry system were opposed. A new boat was under construction. Ice, wind, alleged bad rock conditions, deep water, currents, and other adverse factors were cited. The trend of the time was against public expenditures. Nearby financial institutions, such as some of the Mid-West insurance companies, were skeptical. The bonds were not eligible for Michigan bank investment. Interest rates were on an upward trend. Twice we tried and twice we failed. We in the Authority felt much as did General Foch at the Battle of the Marne in 1914 when he is reported to have said, "My right is in retreat, my left is shattered, my center is

wavering: I order that the offensive be renewed." Well, we got the money.

I cannot too highly commend my fellow members of the Authority. Fred Zeder has passed on. He was an enthusiast for the project from the beginning and a mighty factor in our success. He was succeeded by Mead Bricker, who ably took his place. Two outstanding Michigan men from the automobile industry whose drive, effective there, was productive in this effort. George Osborn and Bill Cochran from the Northern Peninsula, ever sure in attendance, who know well the need and feel certain of the success of the bridge, were most helpful. Mr. Osborn handled publicity, his "Sault News" and radio station WSOO covering much of the northern area, and Mr. Cochran spoke extensively throughout the area, both with splendid results. Governor Van Wagoner in his administration advanced the cause and watched our interests in the contract negotiations. His experience in highway contracting was vital in these decisions. Commissioner Ziegler and his aide, George Foster, who usually sat for the commissioner, gave counsel and supplied statistics for the traffic and bridge engineers. Finally, Mr. Fisher, whose work on the Finance Committee and as vice-chairman, based on his extensive financial contacts, opened the doors for us wherever we went in the money mazes of Wall Street. His standing and prestige and his devotion to the task were major factors in our final success.

All subjects dealing with Authority business were thoroughly discussed and often differences of opinion arose; however, in the final voting, the vote always was unanimous on the part of all members present.

Our engineer, David B. Steinman, is among the world's greatest, and with his staff has been a major factor in all phases, not only in design and construction but in financing and publicity. He has been ably aided by Glenn B. Woodruff, his associate.

We are fortunate in having as our contractors Merritt-Chapman and Scott Corporation and the American Bridge Division of the United States Steel Corporation, leaders throughout the world in this type of work.

The Authority secured as its executive secretary Lawrence A. Rubin of Lansing, who has been a tower of strength in the struggle to bring about the success of the project. In the legislative effort, the sale of the bonds, and in the contract negotiations, he has been a constant aid to us.

Three Michigan corporations, the National Bank of Detroit, the Chrysler Corporation and the Detroit Edison Company, loaned such of their facilities as were requested by the Authority. Top men in these devoted much time to the effort. They joined in building the bridge model, shown throughout the state, and aided much in arousing pro-bridge sentiment.

Governor Williams promised the people to do something about the bridge, created the Inter-Peninsula Communications Commission referred to in the lecture, and constantly urged action. His leadership has been a major factor in our success.

The Legislature was controlled by the Republican party. The governor was a Democrat. The leaders of both parties were confronted by some opposition in their ranks. However, wise counsel prevailed and the passage of the various bills necessary to the project were handled without partisanship.

One cannot mention all who made major contributions, and I regret this, but I am sure such an attempted list would leave out many, because hundreds in the Legislature and out worked on the project through its many phases; so I must content myself with what has been said here and in the Cass Lecture.

P. M. B.

The Mackinac Bridge Story

THE MACKINAC BRIDGE STORY

AS FAR BACK AS three generations ago Michigan citizens had varying opinions about a bridge or tunnel at the Straits of Mackinac. Thomas T. Bates, editor-publisher of the "Grand Traverse Herald," wrote in the early winter of 1884 that "if there is to be a great through route from east to west through Michigan there must be a sure and permanent crossing at the Straits." Mr. Bates' comment was pertinent enough to be reprinted in the "Lansing Tri-Weekly Republican" of February 5, 1884. While the emphasis in the news item was on the fact that the experiment to provide year-round steamboat transportation across the Straits had failed (actually, the great ice-crusher "St. Ignace" was built, and with its successors the "Ste. Marie" and the "Chief Wawatam," designed by the Detroit marine architect Frank E. Kirby, gave excellent rail ferry service and continue to do so now), the article was accurately prophetic in stating the real problem of the Mackinac Bridge: "The important

question is, will the business to be done warrant the expenditure of the large amount of money required in the building of such a bridge or the construction of a tunnel under the Straits."

From 1884 to 1920 the idea of a connecting link at the Straits cropped up in many places, and in 1920 an article in "American Highways" by Horatio "Good Roads" Earle, Michigan's first state highway commissioner, created more than passing interest. He suggested a floating tunnel at the Straits of Mackinac and invited his engineering colleagues to comment thereon. Early in 1921, Charles Evan Fowler of New York City made a counter-proposal to build a series of causeways and bridges beginning at a point near Cheboygan across to Bois Blanc Island, to Round Island, over the west tip of Mackinac Island, and then across the channel to St. Ignace.

Nothing came of these proposals at the time, but in response to the growing demand for better Straits crossing facilities, Governor Alex J. Groesbeck urged the Legislature in 1923 to establish a ferry service. This was done. In 1928 the Highway Department published a report stating that a bridge directly across the Straits costing about $30,000,000 would be feasible as a private toll facility. Although some steps were taken to carry out this proposal, they were not completed and the project was abandoned.

Spurred by the depression and the availability of work project funds from the Federal government and urged by Governor William A. Comstock, the Legislature in 1934 created the Mackinac Straits Bridge

Authority to investigate the feasibility of a bridge, issue and sell bonds, build a bridge, and fix and collect tolls. The enabling act was presented by Representative Edward H. Fenlon of the Mackinac-Emmett district (then my law partner, now Circuit Judge for the counties of Emmett, Cheboygan and Mackinac) where the bridgeheads are located.

Stephen T. Stackpole of Detroit, Otto W. Lang of Mackinac Island, and Patrick H. Kane of Port Huron were appointed members of the Authority by Governor Comstock in April, 1934. It was thought the railroads would be interested, and Mr. Stackpole, who was a leading railroad executive in the state, was made a member for that reason. The Authority retained Charles Evan Fowler as temporary chief engineer and me as legal advisor. Fowler's original island hopping plan was revised slightly and in August of 1934 was submitted to the Public Works Administration with a request for a loan of 70 per cent and a grant of 30 per cent to finance the estimated cost of the project, about $35,000,000.

In the meantime, considerable objection to the island route developed throughout the state. With many others I was never in agreement with Fowler. While the crossing from the south mainland southeast of Cheboygan to Bois Blanc Island is comparatively shallow, it is about five miles long over navigable water in constant use by shipping. In addition the proposed route involved a twelve mile road on the island and two water jumps from Bois Blanc to Round and Mackinac islands, the latter over a major

surveys of several routes were made and finally a straight line from Mackinaw City almost due north to a point in the southwest corner of St. Ignace was selected. Soundings and borings were taken along this line, traffic data were obtained, geological studies were made, and all the information turned over to Modjeski and Masters, who filed a preliminary report in June of 1940.

The report called for the construction along the aforementioned line of a double suspension span, one of which would be the world's longest at 4,600 feet. It also called for a causeway from St. Ignace 4,200 feet south into shallow water. It recommended that this causeway be used as a fair-weather ferry boat dock during bridge construction, thereby shortening the trip and increasing the ferry capacity without any additional investment in ships. It estimated that the structure would cost $24,340,000. Both Leon S. Moisseiff, internationally famous bridge designer, and James Cissell endorsed the report.

The Highway Department let a contract for the construction of the causeway, which was completed in 1941. But the outbreak of World War II put an end to work on the bridge by the Mackinac Straits Bridge Authority, and the state Legislature abolished the Authority in 1947. Soon thereafter funds were appropriated to construct a double ended ice-breaker ferry that would carry 150 vehicles. Plans for a new dock at St. Ignace to shorten the ferry sailing time were drafted, and it was expected that these measures

would take care of the foreseeable demand for Straits crossing service.

Others saw the situation differently and in 1948 Governor G. Mennen Williams created the Inter-Peninsula Communications Commission. One of the functions of this commission, headed by the chairman of Michigan's Public Service Commission, John H. McCarthy, was to explore the possibility of a connecting link at the Straits.

Shortly thereafter, W. Stewart Woodfill, president of the Grand Hotel on Mackinac Island, interested a group of leading businessmen from all parts of the state to join with him in a Mackinac Bridge Citizens Committee. The immediate objective of this committee was to secure creation of another Mackinac Bridge Authority to finance and build a bridge after thoroughly investigating its feasibility.

The efforts of both these bodies along with constant prodding by Governor Williams brought partial results in 1950 with the Legislature's creation of the Mackinac Bridge Authority, limited, however, to studies of feasibility with no power whatsoever to finance and build. Governor Williams appointed six of a seven man commission, to serve without compensation, comprised of three Democrats and three Republicans and the state highway commissioner, who was named a member in the legislation creating the Authority. The members took their oaths of office on June 6, 1950. They were Fred M. Zeder (now deceased and his vacancy filled by Mead L. Bricker), Charles T. Fisher, Jr., George A. Osborn, Murray D.

Van Wagoner, William J. Cochran, state Highway Commissioner Charles M. Ziegler and I. Shortly thereafter, the Michigan Senate unanimously confirmed these appointments.

Public Act Number 21 of the Public Acts of 1950 creating the Mackinac Bridge Authority carefully spelled out the Authority's functions. First, it was to determine physical feasibility. Could a structure actually be built at the Straits of Mackinac that would withstand all the forces of nature in that area: the winds, the ice, the currents, the depths of water and the allegedly unsafe rock under the Straits? Second, it was to determine costs. Could such a structure be build at a reasonable cost? In other words, could it be self-liquidating? The act provided an appropriation of $100,000 to cover the expense.

To obtain the answers to these questions the Authority was ordered by the Legislature to consult with a board of three of the world's greatest long-span-bridge engineers. These consultants were to be selected at the recommendation of the Dean of Engineering of the University of Michigan. Meeting at the Straits of Mackinac on June 24, 1950, the Authority invited the three top men on Dean Crawford's list: O. H. Ammann and D. B. Steinman of New York City, and Glenn B. Woodruff of San Francisco. On July 12, these three men came to the Straits and accepted the commission to advise the Authority on the physical feasibility of a bridge and its probable cost. The act creating the Authority specified that none of the engineers retained to determine feasibility

July 12, 1950 to Jan. 10, 1951 to cover up original mistake

could eventually be retained to design the bridge. The purpose of this provision was to eliminate the temptation to file a favorable report in the hope of obtaining the assignment to draw the final plans. I did not like this provision. Men of character in the profession would not be affected by thought of personal gain.

Next, the Authority entered into an agreement with the traffic engineering firm of Coverdale and Colpitts of New York City, recognized for their ability to predict traffic on toll facilities such as bridges, turnpikes, terminals and similar projects. While the design engineers were developing their report the traffic analysts were conducting interviews at the Straits of Mackinac and in other areas from where traffic mainly originated and to where it was going.

Finally, on January 10, 1951 the Authority received preliminary reports from Messrs. Ammann, Steinman and Woodruff, and from the firm of Coverdale and Colpitts. The former said in effect that a bridge could be built connecting Michigan's two peninsulas along the direct straight route from Mackinaw City north and utilizing the causeway built in 1941, that it would withstand all the physical forces in the area, that additional borings would be required before the precise location of each foundation could be determined, and that such a structure was estimated to cost $76,300,000.

The Authority retained the services of two expert consulting geologists. It had been alleged that there were huge caverns in and under the rock on which

the foundations would be placed and consequently the structure would be in jeopardy because the weight of the foundations would cause the caverns to collapse, thus bringing the bridge down on top of them. The consulting geologists, Sidney Paige and Charles P. Berkey, studied the problem and filed a report stating that the so-called caverns had collapsed thousands of years ago and had consolidated into rock.

The Coverdale and Colpitts report stated that such a structure could be financed by selling bonds, the interest and principal on which would be paid for out of tolls based upon those charged for crossing by ferry. It was estimated such financing would cost about $11,000,000, thereby requiring a total sale of $87,000,000 worth of bonds.

The question of putting a railroad on the bridge was discussed by the engineers, and an estimate of $60,000,000 additional was made. This matter was discussed with prominent railroad men, and it was felt that the interest and payment of the bonds would be a heavier charge than the cost of operation of the ferry system long used by the railroad companies. Nothing further was done along this line.

The Authority promptly filed the reports with the Legislature but did not recommend additional legislation at this time since it was impossible to obtain steel without a certificate of necessity indicating that the project was for the purpose of civilian defense. However, the Authority was granted an additional $75,000 to proceed with its investigation of feasibility, particularly in connection with the bearing

qualities of the rock on which the foundations would rest.

Load bearing tests were carried out during the early winter of 1951. They were made on material at the Straits that was deemed the weakest of all found in the area. It was concluded from these tests that this weakest of all the rock at the Straits would support four times the full load placed on it by the bridge foundations.

By late 1951 and early 1952 the steel situation had eased sufficiently for the Authority to proceed. Two bills were drafted for consideration by the Legislature. One bill simply appropriated $2,000,000 out of highway funds for the purpose of engaging an engineer to draw final plans for the structure. It gave the Authority no right to finance or build, but merely to obtain plans.

The second bill, which was the primary objective of the Authority, covered all the powers necessary for financing and constructing a bridge. The Legislature refused the use of highway funds for bridge plans but promptly enacted the complete enabling legislation, with one amendment. The section appropriating $40,000 to the Authority to accomplish the bridge financing and construction was amended to appropriate one dollar for these purposes. This made a total of $175,001 appropriated to the Authority, of which over $24,000 was subsequently returned.

The next task was to persuade the Legislature to authorize the Authority to proceed with financing and construction. I presented our case to a joint

session of the Senate and the House and with our engineers submitted to questions by the legislators. We submitted a bill which we had drafted. It authorized us to bond and build if it could be done without state guaranty of the bonds. We also asked that since the restriction against the use of the engineers had served its purpose and since they were best informed by their investigation, they be considered for design engineers for the project. The Legislature was favorably impressed by Messrs. Ammann, Steinman, and Woodruff, and the restriction was eliminated.

After several months of committee study and floor discussion, and many conferences with the Authority, the Legislature passed this bill by more than two-thirds majorities in both houses. It was given immediate effect and the Governor signed it into Public Act No. 214 of the Public Acts of 1952, on April 30, 1952.

The Authority immediately filed an application with the Reconstruction Finance Corporation for that agency to purchase the bonds to be issued by the Authority.

While the RFC was investigating the application, traffic at the Straits was increasing at a rate far greater than that predicted by the traffic analysts. Instead of the 6 per cent a year increase in 1951 and 1952, the trend was better than 15 per cent a year. This encouraged private investment bond bankers to

become interested in the project, and the Authority requested the RFC to hold its application in abeyance.

Careful consideration was given to the question of Reconstruction Finance Corporation or private financing. There was a general nationwide sentiment that the RFC should curtail its operations; an election was on and a change in Administration probable. The Authority, through Mr. Fisher, requested an expert bond financier, Milton S. Bosley of the National Bank of Detroit, to report on the possible RFC proposition and an alternative under discussion. The private financing looked a little more favorable from Mr. Bosley's figures. At that time the RFC interest charge was 4¼ per cent, and the proposal by the underwriter was 4 per cent. There had always been a strong feeling on the part of the Authority that the bridge project should stand on its own, without Federal funds if possible.

In November, 1952 the Authority entered into an agreement with a leading New York revenue bond underwriter to manage the bridge financing, selected D. B. Steinman as designing engineer, and recommended Glenn B. Woodruff as consulting engineer. Tentative contracts contingent upon successful financing were entered into for the substructure and the superstructure. All the necessary legal and financing documents were prepared and the Authority was ready to market its bonds in late March, 1953. By that time, the money market which had been tightening up steadily since the first of the year was unable

to absorb the $96,000,000* bridge revenue bond issue, and financing was postponed.

Members of the Authority and others had pointed out to the traffic engineers that the ferry operation was suffering heavy operating losses, reaching figures considerably over half a million dollars annually, without consideration of the interest or depreciation on the docks and ships. Consequently, the traffic engineers recommended that the Authority request the Legislature to appropriate a similar amount annually to pay the cost of operating, repairing and maintaining the bridge. This would make the sale of the bonds more attractive, since all revenues produced by the structure would be available for the payment of interest and liquidation of bonds.

In May, 1953 an act was passed appropriating $417,000 a year for that purpose, if and when the structure was opened to traffic. It took an immense amount of effort to bring this result about. Mr. Fisher, former Governor Van Wagoner, other members of the Authority and I made many trips to consult with various legislative committees and groups. Governor Williams, both party leaders, and many

*The difference between this figure and the $87,000,000 previously mentioned is due to an interest factor, the interest having to be figured on two bases. (Rates also had gone up slightly.) As a governmental agency, the RFC could pay out the money when needed on the contracts for construction. Investment bankers cannot do this on non-state guaranty bonds; they must know that all the money is subscribed and in hand so that the project can be completed. Hence, interest on the total amount had to be included in the figure and paid during construction.

others urged the action, and it was finally taken. The Legislature put a time limit on this offer so that unless the bonds were sold by December 31, 1953, the $417,000 would be withdrawn.

Another effort was planned for June, 1953, and it likewise was called off because of bond market conditions. The summer months saw no improvement in financial circles and it was not until mid-autumn that some encouragement appeared. In the early fall, Mr. Fisher and I spent considerable time calling upon insurance company executives and bond underwriters in New York, Montreal, Chicago and Milwaukee trying to interest them in financing the Mackinac Bridge. The first encouraging result from this effort was a trip made by Stuart Silloway, financial vice-president of the Mutual Life of New York, who drove up to the Bridge locality and satisfied himself that the project had real merit from a financial standpoint. He so advised Mr. Fisher and indicated that his company would give careful consideration to a $2 million participation.

Meanwhile, James S. Abrams, Jr., a New York investment banker with Allen and Company, proposed a novel plan for financing the structure. Mr. Abrams called me and I arranged to go to New York with Mr. Fisher and Mr. Lawrence A. Rubin, our most able secretary, on November 11, 1953. Mr. Abrams proposed two series of bonds with first and second liens on the revenues. Inasmuch as difficulty had already been experienced marketing only first lien bonds, there was considerable doubt as to the marketability

of the second lien bonds, even though, according to Mr. Abrams' recommendation, they would carry a higher interest rate. Consequently, the Authority was extremely careful and checked as closely as possible all the aspects of Mr. Abrams' plan.

It was decided that Mr. Abrams ally himself in the management of this financing with other investment bankers. Joseph D. Murphy, of Stifel, Nicolaus and Company, had been interested in the proposal and was allied with C. S. Mott, of Flint. The firm had handled successfully a Mackinac Island issue of some years back. Mr. Murphy provided leadership and suggested to the Authority that Allen and Company and Stifel, Nicolaus and Company consider additional underwriters. This was accomplished with the addition of Union Securities Corporation and A. C. Allyn and Company.

On December 8, 1953, the Authority's able Michigan counsel, John H. Nunneley, of Miller, Canfield, Paddock and Stone, and New York counsel Mitchell and Pershing, with Mr. Rubin were in New York. The Authority's finance committee, Mr. Fisher, Mr. Van Wagoner, and I, were in Detroit. Considerable contact with friends and associates in the banking and industrial world had been had. The phones were pretty busy with discussion of details, and the final go-ahead was given the underwriters. The Authority was determined not to fail the third time.

According to the plan as finally worked out by the underwriters and the Authority and their lawyers, the Authority would offer for sale $79,800,000 worth

of first lien bonds carrying a 4 per cent coupon. An additional $20,000,000 of second lien bonds with a 5¼ per cent coupon would be held by the underwriters and offered for sale to the public at their discretion.

This offer had to be subject to "public sale" as required by law. Further, it had to be approved by the state Administrative Board. The public notice appeared in legal publications for seven days beginning December 10, 1953.

The Authority appeared before the state Administrative Board on December 15 to explain the entire arrangement with the request that the Board recess until December 17 to adopt a resolution approving the sale of the bonds which would be made at 10 a.m. that morning. The resolution covering this Board action as well as the trust indenture and notice of sale had already been thoroughly studied by representatives of the state treasurer and the state attorney general.

However, at the Administrative Board meeting on December 15, one of the members raised the objection that the financing method was too expensive and that the entire proposition ought to be subjected to a public vote so that the bonds could be backed by the faith and credit of the state, if the vote were favorable. Obviously, such a move was impossible at this late date. Lieutenant Governor Vandenberg, Speaker Van Valkenburg, several Senate leaders, Joseph E. Warner, chairman of the House Ways and Means Committee and many members of the Legislature had

always insisted that the financing must be done without issuing state supported bonds. No state supported bond bill could have been passed. It was explained that such faith and credit financing could be voted upon by the public at any time in the future if the project was successful and the bonds refunded at a considerable saving. The Administrative Board agreed to recess until December 17 as requested.

On December 16, Senator Haskell Nichols of Jackson filed a petition with the clerk of the Supreme Court requesting that body to prohibit the Administrative Board from approving the sale of the bonds. In his petition he stated a number of reasons why he thought the entire procedure was illegal. Had this petition been granted and the Administrative Board enjoined from approving the sale, the bridge financing would have been set back for a full year. It would have been impossible to get a decision on the matter until after the first of the year. The authorization for operation and maintenance money previously appropriated by the Legislature would have expired and new legislation would have been necessary. Experience indicated that such legislation would have taken at least three months to pass, if it would have passed at all. By that time, new contracts would have to be negotiated, new financing arrangements made and another construction season would have been lost.

Fortunately, the Authority attorneys and I were in Lansing on the day the aforementioned petition was filed and we had an audience with several members of the Supreme Court. The real impact of granting such a petition was explained to the court members. It was further explained that the Authority had no desire to deprive Senator Nichols of his day in court, but merely wished to consummate the sale of the bonds on December 17 as planned. The Authority actually welcomed a court test. It was pointed out that a complete court hearing could be held on the matter between December 17, 1953 and February 17, 1954, the projected date of the delivery of the bonds. If the senator were on legal grounds, then the court could enjoin the Authority from delivering the bonds. If the procedure were legal, then nobody would suffer a damage. The members of the court present agreed with this reasoning. Subsequently, on January 22, 1954 the court handed down a unanimous decision upholding the complete legality of the Authority's position.

On December 17, 1953 at 10 a.m. in Governor Williams' office at the State Capitol, bids were accepted on the sale of the Authority's $79,800,000 worth of Class A 4 per cent bonds and $20,000,000 worth of Class B 5¼ per cent bonds. One bid was received from the aforementioned management group in the amount of $95,858,000. This was accompanied by a certified check for $100,000. The Authority met immediately thereafter and adopted a resolution approving the sale of the bonds. Directly following this meeting, the state Administrative Board convened after a two-day recess and a motion to adopt a

99,800,00

resolution approving the sale of the bonds was passed unanimously.

The next problem was the distribution of the bonds by the four underwriting partners. I spoke to large groups of bond dealers in Chicago and New York on January 5 and 6 to interest them in the Mackinac Bridge project. The final day for such dealers to commit themselves was set for Thursday, January 7, 1954. At 5 p.m. of that day only $35,000,000 worth of bonds had been committed. By the following Monday sales had been made to several insurance companies; the big one was the New York Life Insurance Company, which agreed to purchase $10,000,000 worth of bonds. The marketing of the entire issue was soon completed. These were hectic days.

On February 17, 1954, the Authority met with the underwriters in the directors' room of the Bankers Trust Company in New York City and received a check from Joseph King, president of Union Securities Corporation, for $96,400,033.33. The slight variation from the bid is due to accrued interest. On the same date, the Authority's contractors were given letters to proceed with construction, and they began mobilizing their equipment.

Merritt-Chapman and Scott Corporation has the contract to build thirty-three marine foundations for a lump sum of $25,735,600. This contract has no provision for escalation of any items of cost, including labor, materials and quantities.

The contract for the superstructure with the American Bridge Division of the United States Steel

Corporation is in the amount of $44,532,900. It protects the Authority against escalation of wage and material prices but not quantities, which on the superstructure can be closely estimated.

These contracts were made before the amount of the bond issue was determined. It is obvious that financial interests could not absorb an issue without firm contracts, within the total authorized issue. They had to know the bridge could be completed with the money borrowed, so the contracts came before the bond bids were asked.

Additional contracts will be let for paving approaches, administration building, toll gates, and electrical equipment. These amount to approximately $5,500,000. The cost of engineering is $3,500,000, bringing the total construction cost to $79,274,250, more or less. Real estate, preliminary expenses, and administration amount to $800,000.

The following statistics list the proportions of the structure:

Length of suspension bridge (including anchorages)	8,614	feet
Length of main span	3,800	feet
Total length of steel superstructure	17,918	feet
Length of north approach (including mole)	7,791	feet
Length of south approach	486	feet
Total length of bridge and approaches	26,444	feet
Height of main towers above water	552	feet
Depth of tower piers below water	200	feet
Number of main cables	2	
Diameter of main cables	24¼	inches

Number of wires in each cable	12,876
Diameter of each wire	0.196 inches
Total length of cable wire	41,000 miles
Weight of cable, wire and fittings	12,500 tons
Total estimated weight of superstructure	66,000 tons

The ceremonial groundbreaking for the structure took place on May 7 and 8, 1954 at St. Ignace and Mackinaw City, respectively, the two terminal communities for the structure. Mrs. Prentiss M. Brown wielded the shovel on the northside and Mrs. Charles T. Fisher, Jr., did the honors on the south side. The contracts call for completion of the bridge by November 10, 1957.

When completed, the bridge, in more respects than any other bridge, will be entitled to the accolade "the Greatest Bridge in the World." It is by far the longest suspension bridge from cable anchorage to cable anchorage, 8,614 feet, exceeding the next in size, the 6,450 foot long Golden Gate Bridge, anchorage to anchorage, by 2,164 feet. Its main foundations are in deep and often turbulent water. From the west and northwest, seas generated by over 120 miles of clear sweep in high winds dash forty feet up the towers. Foundations go 200 feet down, and towers rise 750 feet from bedrock—552 feet from the water surface, as high as Michigan's tallest building, the Penobscot in Detroit. The entire project is just forty-four feet more than five miles, all without any intervening land surface. Ice floes pushed by heavy winds race through the four-mile wide channel and at times

have piled thirty feet high, and in forty feet of water have often reached the bottom of the Straits.

What will the bridge do? It will reduce the crossing time, including waiting time, from an average of one and a half hours in winter or two and a half hours in summer, to just ten minutes. At present there have been waiting periods as long as nineteen hours during rush seasons with corresponding line-ups of cars as long as seventeen miles on U.S. 27 and seven on U.S. 131. The capacity of the bridge is 6,000 cars per hour compared with 462 cars per hour of the state ferry system. By cutting out as many as a hundred crossings during a twenty-four hour period, it will eliminate the danger of marine collisions between north and south going ferries and the scores of great ore, grain, and coal ships which steam east and west. Its economic effect on the state will be tremendous. But most of all, it will join the two peninsulas. In the words of Representative Morrison when the final bill was passed, "The North and South of the state have long been engaged; they now have a wedding ring!"

All of us, the engineers, the contractors, the courageous high bridge workers and deep foundation men, the Legislature, and the Governor are proud of this stupendous undertaking. We in the Authority are proud, too. We feel like the pioneer railroad builder who when asked, "What do you like best to do in life," replied, "Plan some big piece of helpful work that everybody says can't possibly be done, and then jump in with both feet and do it."

Designed by Peter Gilleran

Text set in Metrolite by the Jackson Typesetting Co.,
Jackson, Michigan

Engravings by Detroit Gravure Corporation

Printed on India Beckett Text by
Esterling Printing Company, Detroit

Cover, Hamilton Victorian

Bound by Commercial Bindery, Inc., Detroit

Section 3

Historical Significances

The Algonquin Native Americans called the straits and the surrounding area "Michilimackinac", meaning "the jumping-off place" or "great road of departure". Since the last ice age the straits have been the end of the trail. For 70 years, discussion of a potential bridge linking the state was only a dream, until brilliant minds and an unwavering workforce of 3,500 men on site constructed what would be the largest suspension bridge in the World, connecting Michigan's two peninsulas in less than four years.

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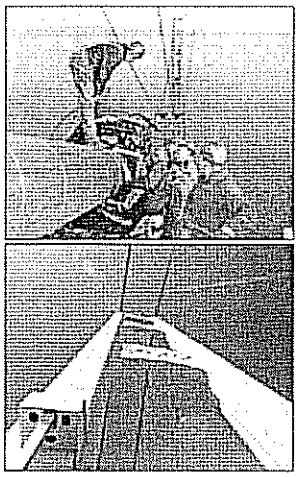
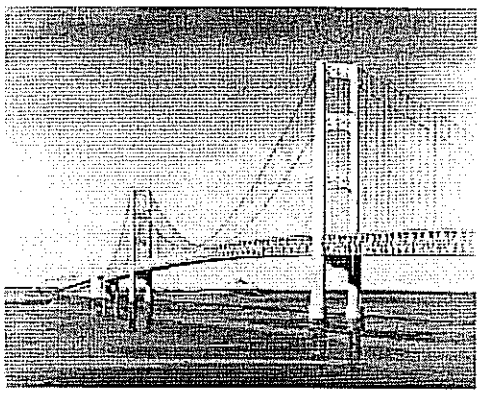
History of the Bridge



History of the Bridge



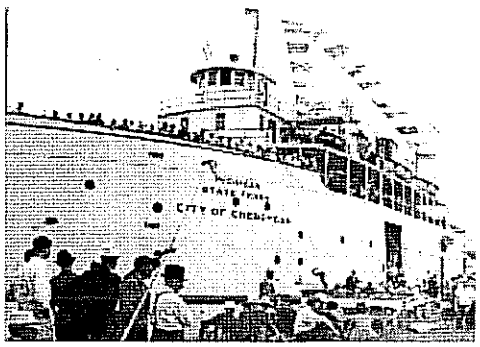
A newspaper, the Lansing Republican, dated February 5, 1884, reprinted a story from the Grand Traverse Herald pointing out that the experiment to provide all-year service across the Straits by boat had failed, and that if a great east-west route were ever to be established through Michigan a bridge or tunnel would be required. The editor considered both as practicable; the only question in his mind was that of cost.

The dedication of the Brooklyn Bridge in 1883 gave Mackinac Bridge backers encouragement. A St. Ignace store owner in 1884 reprinted an artist's conception of the famous New York structure in his advertising and captioned it "Proposed bridge across the Straits of Mackinac."

On July 1, 1888, the board of directors of the famous Grand Hotel at Mackinac Island held their first meeting and the minutes show that Cornelius Vanderbilt said: "We now have the largest, well-equipped hotel of its kind in the world for a short season business. Now what we need is a bridge across the Straits." The great Firth of Forth Bridge in Scotland was under construction then and completed in 1889.

During the ensuing years there were a few farfetched ideas about the connection of Michigan's two peninsulas. In 1920 the state highway commissioner suggested a floating tunnel. He invited other engineers to suggest ideas for crossing the Straits. Mr. C. E. Fowler of New York City came forward with an ambitious project to solve the problem with a series of bridges and causeways that would start at Cheboygan, some 17 miles southeast of Mackinaw City, traverse Bois Blanc and Round Islands, touch the southern tip of Mackinac Island, and leap across the deep channel at St. Ignace.

In 1923 the Legislature ordered the State Highway Department to establish a ferry service at the Straits. Within five years traffic on this facility became so heavy that the late Governor Fred Green ordered the same agency to make a study of bridge feasibility. The report was favorable and its cost was estimated at 30 million dollars. Some strides to get the project underway were taken but it was eventually dropped.



"City of Cheboygan" Ferry- 1937

Writing in the Michigan Alumnus-Quarterly Review, spring 1937, the late James H. Cissel, Secretary of the Mackinac Straits Bridge Authority, said:

"Early in 1934 the matter was again revived and proposed as a suitable P.W.A. project. In the extra session of 1934 the Legislature created the Mackinac Straits Bridge Authority of Michigan and empowered it to investigate the feasibility of such construction and to finance the work by issuance of revenue bonds. The Authority began its studies in May 1934 and has been continuously active since that date.

Although limited funds precluded full and complete preliminary studies, the Authority was able to reach the conclusion that it was feasible to construct a bridge directly across the Straits at an estimated cost of not more than $32,400,000 for a combined two lane highway and one-track railway bridge. In its studies the Authority utilized soundings made by the War Department Engineers and was aided by the gratuitous counsel and advice of engineers and contractors experienced in work of this magnitude."

The Authority made two attempts between 1934 and 1936 to obtain loans and grants from the Federal Emergency Administration of Public Works, but P.W.A. refused both applications despite endorsement

by the U.S. Army Corps of Engineers and the report that the late President Roosevelt favored the bridge.

Notwithstanding these setbacks, bridge backers resumed their efforts with their usual vigor. From 1936 to 1940 a new direct route was selected, borings were made, traffic, geologic, ice and water current studies of a very comprehensive nature were completed. A mole or causeway jutting 4,200 feet into the Straits from St. Ignace south was constructed. Preliminary plans for a double suspension span were drawn and the possibility of a bridge became very real. But the Armies of Europe began to march and bridge progress came to a halt. Finally, in 1947, the State Legislature abolished the Mackinac Straits Bridge Authority.

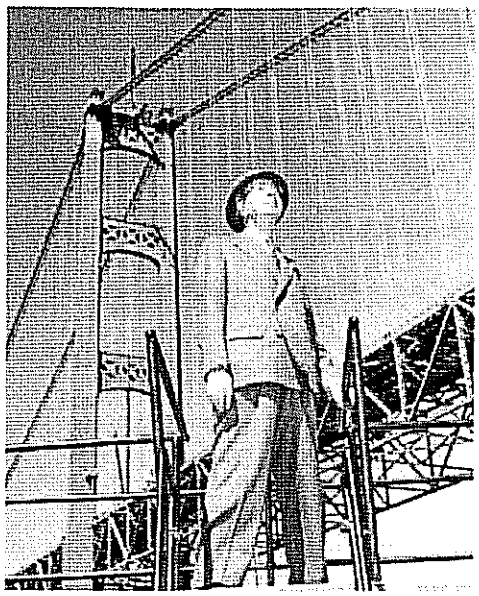
Again, the bridge backers swung into action and a citizens' committee was established to obtain legislation recreating a bridge authority. By 1950 the legislation was enacted, but it limited the newly created Authority to determine feasibility only. The law required the Authority to consult with three of the world's foremost long span bridge engineers and traffic consultants for advice on physical and financial feasibility.

In January of 1951 the Authority submitted a very favorable preliminary report, stating that a bridge could be built and financed with revenue bonds for $86,000,000 but because of the shortage of materials due to the Korean outbreak, legislation to finance and build the structure was delayed until early in 1952. Immediately, the Authority asked the Reconstruction Finance Corporation to purchase $85,000,000 worth of bonds.

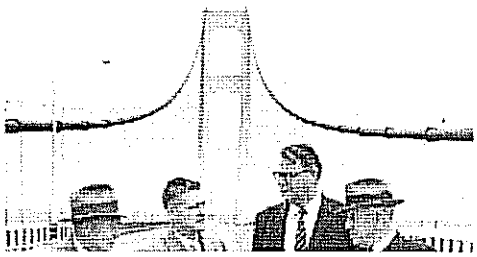
While this agency was studying the request, a private investment banker became interested in the project, and offered to manage a group of investment companies which would underwrite the sale of the bonds. The Authority accepted the offer and was ready to offer its bonds for sale by March of 1953. There were not enough takers to guarantee successful underwriting. The money market had weakened.

In order to make the bonds more attractive, the Legislature passed an act during the Spring of 1953 whereby the operating and maintenance cost of the structure, up to $417,000 annually, would be paid for out of gasoline and license plate taxes. Another effort to finance with this added inducement in June of 1953 was likewise unsuccessful, but toward the end of the year the market recovered and $99,800,000 worth of Mackinac Bridge bonds were bought by investors all over the country. Contracts which had been awarded contingent upon this financing were immediately implemented.

The five-mile bridge, including approaches, and the world's longest suspension bridge between cable anchorages, had been designed by the great engineer Dr. David B. Steinman. Merritt-Chapman & Scott Corporation's $25,735,600 agreement to build all the foundations led to the mobilization of the largest bridge construction fleet ever assembled. The American Bridge Division of United States Steel Corporation, awarded a $44,532,900 contract to build this superstructure, began its work of planning and assembly. In U.S. Steel's mills the various shapes, plates, bars, wire and cables of steel necessary for the superstructure and for the caissons and cofferdams of the foundation, were prepared. The bridge was officially begun amid proper ceremonies on May 7 & 8, 1954, at St. Ignace and Mackinaw City.


Dr. David B. Steinman

The bridge opened to traffic on November 1, 1957 according to schedule, despite the many hazards of marine construction over the turbulent Straits of Mackinac. The last of the Mackinac Bridge bonds were retired July 1, 1986. Fare revenues are now used to operate and maintain the Bridge and repay the State of Michigan for monies advanced to the Authority since the facility opened to traffic in 1957.



FROM
W. W. McLaughlin
To Harry Parkin

REPORT

ON A

PROPOSED CROSSING

FOR THE

STRAITS of MACKINAC

MODJESKI and MASTERS
CONSULTING ENGINEERS
Harrisburg, Pennsylvania June, 1940

WITH SUPPLEMENTS

Reprinted by
THE MACKINAC STRAITS BRIDGE AUTHORITY OF MICHIGAN
LANSING JUNE 1940

THE MACKINAC STRAITS BRIDGE AUTHORITY OF MICHIGAN

700 OLDS TOWER BUILDING
LANSING, MICHIGAN

June 25, 1940

Honorable Luren D. Dickinson
Governor of Michigan
Lansing, Michigan

Honorable Murray D. Van Wagoner
Michigan State Highway Commissioner
Michigan State Highway Department
Lansing, Michigan

Gentlemen:

The Mackinac Straits Bridge Authority transmits herewith a report on a proposed structure to link Michigan's upper and lower peninsulas. This report includes an analysis of the project and recommendations by our engineering consultants, Modjeski and Masters. of Harrisburg, Pennsylvania. together with exhibits and certain other material produced by the Authority.

The Authority concurs in the recommendations of the consulting engineers and submits that a bridge across the Straits of Mackinac is definitely feasible from an engineering standpoint and that such a structure will solve transportation problems now existing at the Straits.

The proposed bridge would be constructed from a point south of St. Ignace directly across the Straits to a point on the northerly shore of the lower peninsula at Mackinaw City.

There would be two main spans of the suspension type, one 2,950 feet long and the other 4,600 feet long. The latter span would be the longest in the world. The center of the structure would clear the waters of the Straits by 150 feet. The water gap to be crossed has a total width of four miles.

The total financial requirement to complete the structure ready for traffic is estimated at $26,740,900. Of this amount $24,340,000 would be required for actual construction costs and $2,400,000 for interest charges during the four-year period of construction.

#2 6-25-40

Hon. Luren D. Dickinson

Hon. Murray D. Van Wagoner

The Authority is continuing its studies of the project giving consideration to feasible toll schedules, possible revenue and the various Federal agencies which might participate in this work. On the basis of these studies we will submit several possible plans for financing this work. Sufficient funds have already been authorized to the Authority to complete this remaining preliminary work.

Total cost of the work leading up to this report has been $175,000 which is 0.67 per cent of the total estimated cost of the bridge--a very low percentage for preliminary engineering investigations for structures of such magnitude.

As a result of the studies to date, the Authority joins with the consulting engineers in recommending the immediate construction of a causeway approximately 5,500 feet long from the north shore of the Straits. This causeway would eventually become a part of a bridge project but it would have an immediate benefit in shortening the route of the present state ferry system from nine miles to three miles. This would step up the capacity of the ferry service by about 50 per cent and also bring about decreased operating costs. Although facilities are adequate to present traffic demands, anticipated traffic increases will soon make necessary added facilities at the Straits.

The Mackinac Straits Bridge Authority gratefully acknowledges the complete cooperation of the Michigan State Highway Department and its staff. As Chairman I wish also to acknowledge and thank the other members of the Authority for their work and cooperation. These include Mr. Patrick H. Kane whose term expired recently at the end of six years of service, Mr. Otto Lang, and Mr. Joseph Green, the latter succeeding Mr. Kane. I wish to thank also Mr. Richard Barkell, of the state highway department, for his effective work as secretary for the Authority. Neither Mr. Barkell nor the writer have received any remuneration for their work with the Authority.

This report for the first time provides a scientific and factual approach to the problem of linking Michigan's two peninsulas. This engineering analysis eliminates the guess-work which has surrounded previous approaches to the problem. Michigan can now proceed to a feasible and sound solution.

Very truly yours,

Donald Kennedy
CHAIRMAN

GDK:

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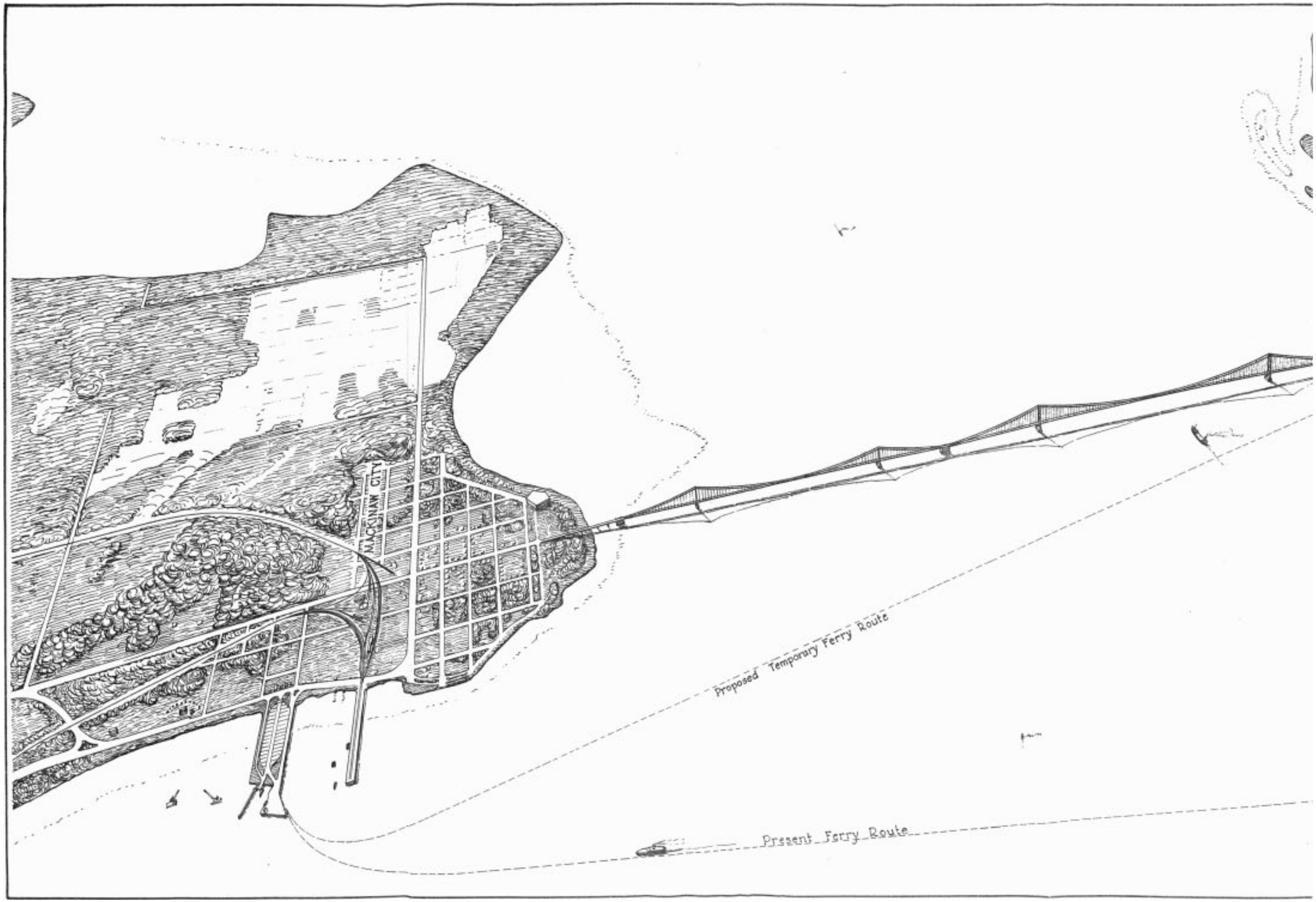

MACKINAW CITY
Proposed Temporary Ferry Route
Present Ferry Route

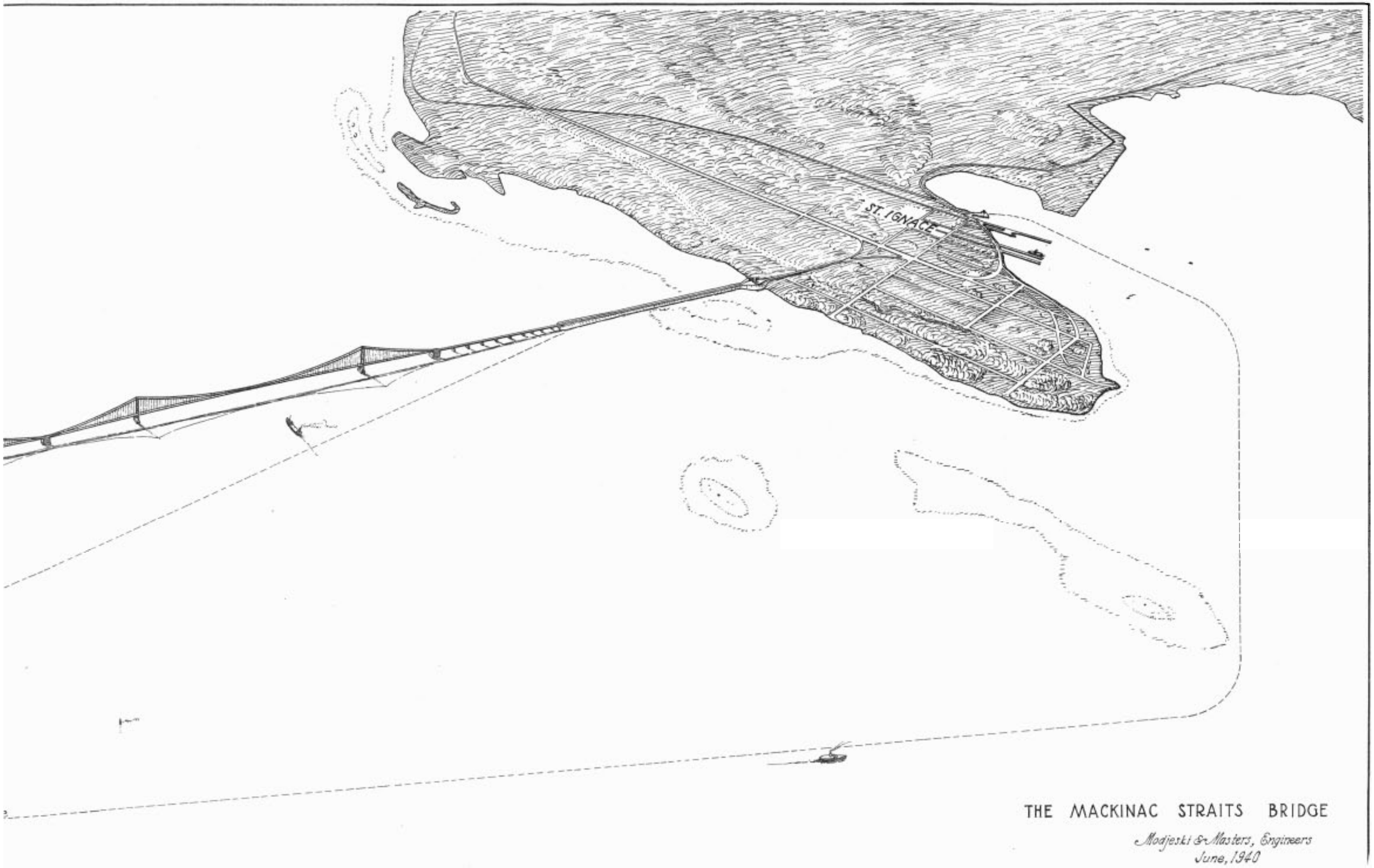
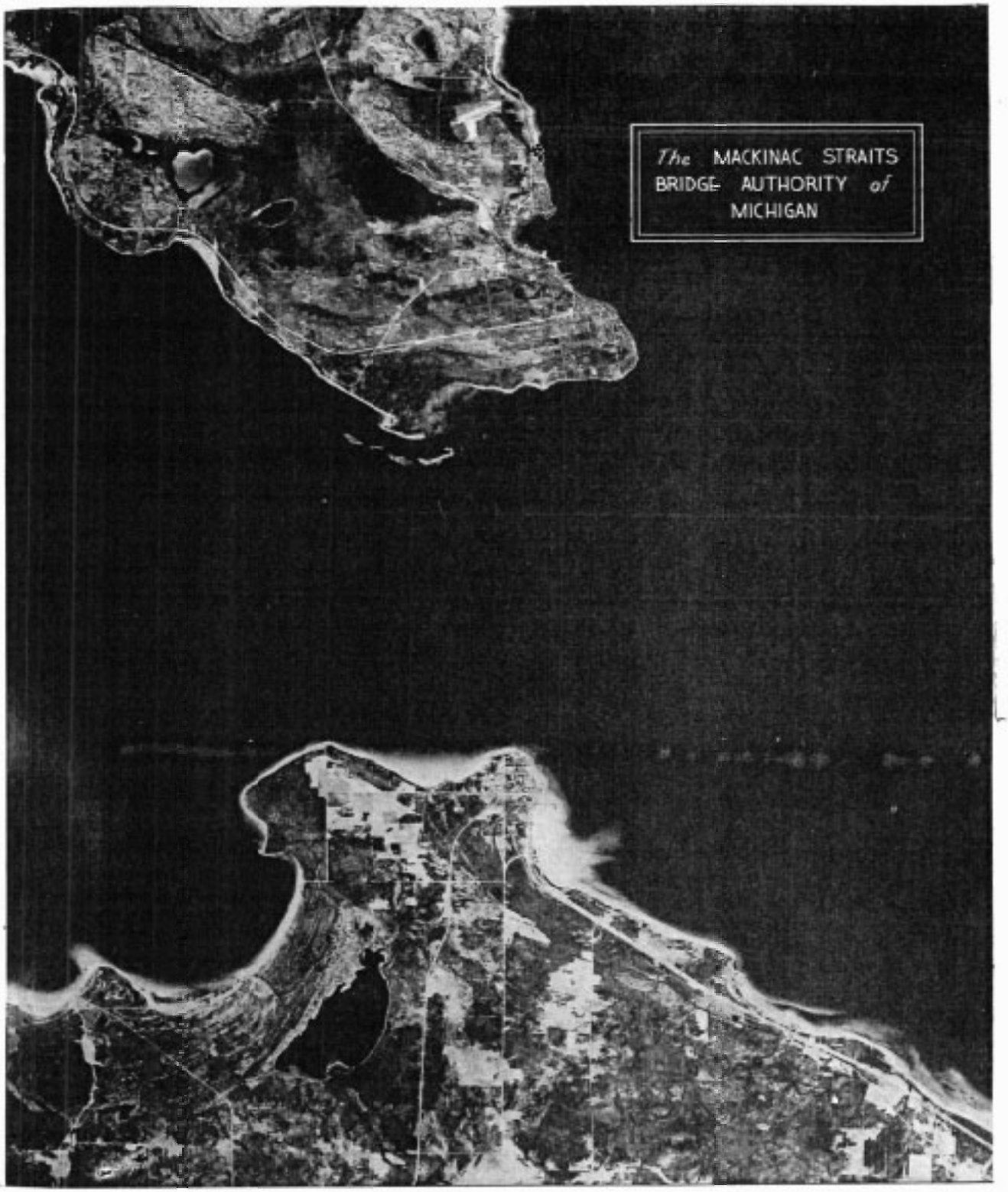

ST. IGNACE
THE MACKINAC STRAITS BRIDGE
Modjeski & Masters, Engineers
June, 1940

PLATE NO. 1



AERIAL SURVEY *of the* STRAITS TERRITORY

Plate No. 2

MODJESKI AND MASTERS
CONSULTING ENGINEERS

RALPH MODJESKI
FRANK M. MASTERS
MEMBERS AM. SOC. C. E.

G. H. RANDALL
PRINCIPAL ASSISTANT ENGINEER
C. W. HANSON
ASSISTANT ENGINEER

STATE STREET BUILDING
HARRISBURG, PA.
52 VANDERBILT AVENUE
NEW YORK, N. Y.
ARCHITECTS BUILDING
PHILADELPHIA, PA.

Harrisburg, Pa.
June 3, 1940

G. Donald Kennedy, Chairman
Mackinac Straits Bridge Authority
700 Olds Tower Building
Lansing, Michigan

Gentlemen:

The accompanying detailed report contains our recommendations for the construction of a proposed crossing of the Mackinac Straits to replace the existing ferries. The following is a brief summary of the conclusions reached and the recommendations contained in the report.

We recommend the immediate construction of a causeway approximately one mile in length southward from the St. Ignace shore, from the end of which the ferries can be operated until a permanent crossing is built, thus increasing the present ferry capacity about 50% without greatly increasing the investment in ferry properties, this causeway to become an approach to the recommended crossing. The cost of this causeway is estimated at approximately $825,000, the buildings and toll plaza at approximately $40,000, the connecting highway at approximately $100,000, temporary ferry dock at approximately $250,000, making a total cost of project $1,215,000.

A tunnel crossing of the Straits is not recommended on account of the excessive cost, prohibitive grades, great depth of water, the limited capacity and the continuing high operating and maintenance costs.

A combined railway and highway bridge is not recommended as the topographic and geologic conditions require the construction of long span suspension bridges. Suspension bridges, on account of their flexibility, would require special operating equipment with restricted loads in order to negotiate the heavy grades. The long spans

designed to carry the railway loadings, even though restricted, would require an additional investment in the crossing far in excess of any amount that could be amortized by reasonable rental charges.

We recommend the construction of a three-lane highway bridge consisting of two long suspension spans over the deep waters of the Straits with necessary approaches at each end. The construction cost of the bridge project, ready for traffic, is estimated at $23,375,000, to which should be added the cost of the causeway, toll plaza and connecting highway, which become a part of the bridge project when the bridge replaces the ferries, estimated at $965,000, and the cost of interest during construction estimated at $2,400,000, making a total cost of the project of $26,740,000.

If the bridge is completed, ready for traffic, by the Spring of 1947, and the tolls on the bridge are the equivalent of the present ferry tolls, we estimate that the gross revenue from tolls for the first year of bridge operation will be not less than $925,000. The annual maintenance and operating costs should not exceed $160,000.

In our opinion it is both feasible and practicable to safely construct the recommended structure-, which will serve as a useful means of joining the two major peninsulas comprising the State of Michigan.

We acknowledge with thanks the cooperation of the various State agencies and individuals who have assisted in the compiling of the data and information necessary to reach the above conclusions.

Respectfully submitted

MODJESKI and MASTERS
Engineers

By F. M. Masters

FMM:IH
Encls.

Harrisburg, Pa.
June 3, 1940

MACKINAC STRAITS BRIDGE REPORT

Introduction and Prior Work

The State of Michigan is divided into two major portions, the upper and lower peninsulas, which peninsulas are bounded by the Great Lakes Superior, Michigan and Huron. The longer axis of the upper peninsula lies at an angle of approximately 90° with the longer axis of the lower peninsula. kt the tips of the peninsulas Lake Huron is connected with Lake Superior by the Soo or St. Marys River and with Lake Michigan by the Straits of Mackinac, the latter lying between the tips of the two peninsulas. The direct natural travel route between these two major portions of the State is across the narrow Straits of Mackinac.

The advent and development of the automobile and modern highways as an economical means of transportation has made possible a closer connection of the two heretofore more or less isolated portions of the State. The increased traffic due to the development of the highway system in these two separated portions of the State met with serious delays to travel across the Straits by means of the existing ferries. In order to keep abreast of the traffic demands, the ferry capacity has been increased from time to time, resulting in a constantly increased investment in these ferries, and only during the year 1939 and up to date in 1940 has the ferry capacity been sufficient to handle the traffic without serious delays. If the traffic continues to increase at its present rate it will become necessary to still further increase the capacity of the ferries. For a long time there has been a demand for a physical joining of the two peninsulas of Michigan for political, economic and transportation reasons, as well as to further induce tourist travel to the upper peninsula. This demand resulted in the creation of the Mackinac Straits Bridge Authority by Act of the State Legislature dated 1934, as amended by Act 223 of the 1937 Session. This Authority hes power to construct and operate an adequate means of transportation ecross the Straits.

Prior to the creation of this Authority, the Michigan State Highway Department, in order to provide facilities for the constantly increasing traffic had, by authority of Legislative Acts, established the existing ferries between Mackinaw City on the south shore and St. Ignace on the north shore. These ferries, due to increasing trsffic, as shown in Exhibit "J", until the past year of 1939 have been unable to handle all trevel at peak times of the tourist seasons without great inconvenience and delays. The necessity for Constantly increasing the ferry facilities has added greatly to the capital investment in the ferries, so much so that the growth of investment in ferry facilities has about paralleled that of the traffic, as shown by the comparison of the traffic with the cumulative capital investment on Exhibit "K", prepared by the Finance Division of the Michigan State Highway Department, which shows that the investment per car handled has remained fairly constant for a number of years operation.

Upon the creation of the Mackinac Straits Bridge Authority, preliminary studies were made of possible crossings in the region covered by the Vicinity Map, Exhibit "A", the results of which studies are covered by an

article prepared by Mr. James H. Cissel, Member of the American Society of Civil Engineers, and Professor of Structural Engineering of the University of Michigan, published in the October, 1937 issue of "Civil Engineering", and discussed in Later issues. The first crossing considered followed a circuitous route, starting at a point east of Cheboygan, crossing to Bois Blanc Island, thence to Round Island, thence to Mackinac Island and from Mackinac Island to St. Ignace, the total length of this crossing approximating 23.98 miles. It was to have four highway lanes and a double track railway, and was estimated at that time to cost approximately $35,000,000.

Mr. Cissel recommended a more direct route for connecting the two peninsulas which should be obtained at a much lower cost and studies were made of a bridge to connect Mackinaw City with St. Ignace, passing over the Graham Shoals. This crossing was estimated in the article to cost approximately $32,383,265. This estimate, however, was preliminary in its nature and Mr. Cissel's article pointed out the necessity for a more thorough investigation of foundation conditions and a further study to properly determine the best direct crossing. This bridge provided for two highway lanes and a single track railway.

Mr. Cissel's article also properly eliminated the further study of any proposal for constructing a tunnel built on the shortest line for the following reasons:

"Building such a structure on the shortest line would necessitate constructing the invert, at its lowest point, some 350'-below water level, The over all length would probably be about six miles. Based on costs of vehicular tunnels completed during recent years it is believed that the cost would be two or three times that of a bridge; moreover, the annual operating cost would probably place a prohibitive burden on such a project."

In a discussion of this article in the February, 1938 issue of "Civil Engineering", Mr. C. F. Goodrich estimated that the cost of the necessary preliminary engineering studies and investigations for, the project would be at least $200,000.

Our review of the early studies made for the Authority led us to concur in the recommendation of Professor Cissel that a direct route should be found which would shorten the time and travel distance between the two communities. We do not recommend the construction of a crossing on the circuitous route, as this route does not sufficiently reduce the travel distance, requires excessive maintenance and operating costs, and presents difficulties in keeping the route open during winter seasons. Further, it might be possible to operate high speed ferry service which could successfully compete with this route during the peak months of traffic, and this route does not adequately connect the already developed highway systems of the State. Furthermore, this route makes no provision for handling the increasing ferry traffic during the time of constructing another crossing.

In 1937, prior to our engagement by your Authority for the preparation of this report, the problem of an adequate crossing had been discussed by us with Mr. Murray D. Van Wagoner, State Highway Commissioner, and with Mr. G. Donald Kennedy, Deputy State Highway Commissioner and Chairman of the Mackinac Straits Bridge Authority and Mr. V. B. Steinbaugh, Chief Engineer of the Michigan State Highway Department. All of the traffic data during the period of the operation of the ferries had been furnished us, together with

studies relative to the demands for and cost of additional ferry facilities.

A review of these data clearly indicated the intimate relation of the ferry operation to any proposed crossing to be constructed by the Authority and involved the problem of handling the increasing traffic during the time of construction of an adequate crossing without, if possible, having to increase greatly the investment in the ferries, as it would be difficult to salvage the ferry investment after another crossing is built. Hence, we recommended at that time the development of some plan of increasing the ferry capacity without greatly increasing the ferry investment. This can best be done by reducing the length of the ferry travel, consequently reducing the time of the trip and thus increasing the capacity of the existing facilities.

A study of the available naps of the Straits clearly indicated that if a satisfactory location could be found on the shortest and most direct route, it would be possible to construct an inexpensive causeway through the shallow waters southward from the north shore, from the southern end of which the ferries could be operated; this would reduce the travel distance for the ferries from about nine miles to about three and one-half miles. This saving in distance should increase the ferry capacity about fifty percent and enable the ferries to handle the traffic during the time of constructing another more adequate crossing without greatly increasing the large sums already invested in the ferry operation, the causeway when built serving as en approach to and becoming a part of the new crossing.

The proposed causeway to be economically constructed must be built in shallow waters, which are found to exist on Line "A". These waters are sheltered on the west by Point La Barbe and Green Island and on the east by Graham Shoals.

Discussions with the captains operating the ferry boats confirm our opinion that there would be no difficulty in operating the ferries from the end of the causeway to Mackinaw City during the open navigation season. Should ice conditions become too severe during the winter months of low traffic, the ferries could be operated on their present routes between the St. Ignace docks and the docks at Mackinaw City and they will have ample capacity for handling all travel during the winter season,

The recommendation, based on the preliminary data available, that a causeway be built to increase the present ferry capacity during the time of constructing a crossing led us to a conclusion that additional sites directly connecting the south shore with the north shore should be studied with a view to determining the most feasible, practicable and econonical type of crossing which could be built to meet adequately all of the requirements of both the present and future traffic across the Straits.

The existing maps and surveys did not contain sufficient information relative to sub-soil and foundation conditions for us to properly study and recommend the best and most economical crossing and it became necessary to secure such information before a report could be made. It was, accordingly, agreed that your Authority would request Mr. Murray D. Van Wagoner, State Highway Commissioner, to have the Michigan State Highway Department, using its well organized staff of engineers, and the other agencies of the State secure for us such data relative to the sub-soil, foundation, geologic, physical and topographic conditions as we would need in connection with our studies and that such information should be furnished for use in the preparation of this report.

Acknowledgment is given here of the cooperation of Mr. Murray D. Van Wagoner, State Highway Commissioner, and the Michigan State Highway Department in the assembling of the data required; and of the assistance furnished us by Professor J. H. Cissel, of the University of Michigan, who had prepared preliminary studies for the Authority; also to the heads of the various Divisions of the Michigan State Highway Depertment who prepared the Exhibits published in this report which were used as a basis for reaching our conclusions, and to the Chief of the Geology Division of the Michigan Department of Conservation,

Before preparing the agreement for our services, the site was visited on September 20, 1938, with officials of the Authority and of the Michigan State Highway Department, We were accompanied by Mr. Leon S. Moisseiff, our associate on the preparation of this report. Trips were made along each shore and over the adjacent highways and all available data studied. An agreement was entered into for the preparation of this report November 7, 1938, under the terms of which the Authority would furnish us with the studies and preliminary data which had been prepared relative to a bridge at the Straits of Mackinac and would furnish traffic and geologic data as a basis for selecting tentative sites for the proposed crossing, The Authority, after the selection of tentative sites, was also to furnish soundings, and surveys of the physical properties at these sites as a basis for determining the best location for the construction of the crossing, Yo Authority also agreed to make borings at selected site or sites and to have boring samples analyzed by the State Highway Laboratory, and agreed to plot all surveys, soundings, borings, soil analyses, traffic data and similar information necessary to determine the proper site and type of construction, The cost and expense of obtaining all of this information for our use was to be paid by the Authority. We in turn agreed, after studying the available data and physical conditions, to prepare with our staff and organization an economic study to determine the most feasible and practicable type and design of structure to be used at the crossing, and to study the economic possibilities of a combination railroad and vehicular structure and to confer with representatives of the United States Army Engineer Corps relative to the necessary navigation clearances for the structure. We further agreed to prepare preliminary general plans of the type of structure recommended and cost estimates based on prevailing construction prices of the recommended type of structure, and to furnish you with this report for use in developing plans and financing the construction of the work. We also agreed to act in a consulting and advisory capacity in all matters, furnishing necessary instructions and specifications for carrying out all phases of the work and to furnish the services of Mr. Leon S. Moisseiff, a Consulting Engineer of New York City, to cooperate in the economic studies and designs and act throughout on the preliminary report as an associate.

Preliminary Selection of Sites

In order to determine the best site for the construction of a crossing meeting all of the traffic requirements, the sounding maps of the Straits area made by the U. S. Lakes Survey Office, of the U. S. Army Engineer Corps were secured, These surveys had been published in 1907.

These soundings indicated that the most direct route suitable for the construction of a causeway and other type of crossing was on a line extending almost due north across the Straits from the point at which highway routes U. S. 31 and U. S. 23 converge on the south shore. However, the 1907 soundings also indicated that better foundation conditions might be expected

at locations east and west of this line. It was accordingly decided to investigate the foundation conditions in all areas by means of probings to rock through the overburden, over the area from Point La Barbe on the west to the shoals area on the east. These preliminary lines, namely Lines "A", "B" and "C", shown on Exhibit "C" and discussed in the report of Mr. K. R. MacDuff, Survey Chief, Michigan State Highway Departnent, were selected for purposes of making accurate surveys of the Straits area, and Line "A" was selected as the line for starting probings to determine rock elevations.

Since it was not possible to estimate with any degree of accuracy the amount of work to be done to determine foundation conditions, an arrangement was made with the Luedtke Engineering Company, of Frankfort, Michigan, which had equipment available at the site, to do such work as would be required, working under the direction and supervision of representatives of the Michigan State Highway Department, and to develop the best, speediest and most economical way of securing the desired information as the work progressed. It was shortly determined that information relative to the thickness of the overburden could be secured by means of jetting through a pipe driven to rock, and this work proceeded rapidly.

New Soundings

Since the latest soundings in the Straits area had been published in 1907, in order to determine if any changes had taken place due to scour or ice conditions, and to furnish data for the plotting of accurate profiles of the Straits bottom at any site to be selected, we recommended making new soundings over the entire navigable areas of the Straits.

The making of such soundings required skilled operators with special equipment and an agreement was made with the Lake Survey Division of the U. S. Army Engineer Corps to make and plot new soundings of the entire area of the Straits in water 50 feet and deeper. In depths less than fifty feet soundings are plotted from data secured during the making of the rock probings.

Contours at intervals of fifty feet, as well as the rock probings, are all shown on the topographic map marked Exhibit "C". Profiles plotted from these soundings indicate that except for some slight scouring just north of the Mackinaw shore, there has been for all practical purposes little, if any, change in the cross section of the water area in the Straits since the last soundings made in 1907.

Selection of Site

While the soundings were being made and plotted, work was proceeding with the rock probings along Line "A". On receipt of the completed soundings the profiles were plotted and studied for indications of more suitable locations for a crossing. These soundings indicated that at some points east and particularly west of Line "A", rock might be located at higher elevations than on Line "A", and the work of probing to rock was shifted to such points east and west of Line "A".

The plotting and study of the rock probings east and west of Line "A" shows that Line "A", the most direct route across this narrow portion of the Straits, apparently lies over the higher rock formations, and that sites east and west of this line are not as suitable as Line "A" for the construction of the proposed crossing. It was therefore decided to return

to Line "A" and to determine in detail the thickness and character of the rock overburden and the rock profile along Line "A", as it is clearly the best and most suitable site for the location of the proposed crossing.

The rock profile was not completed across the deeper areas of the gorge in the Straits, as the taking of deep probings in rough water at this great depth is hazardous, difficult and expensive. The depths and slopes of rock in this deep ravine exceed those at which structures could be safely and economically built during the short working season, so that any type of bridge crossing would of necessity have to span this deeper navigable portion of the channel.

Types of Crossings Considered

On account of navigation and ice conditions, a pontoon structure such as is now being constructed across Lake Washington near Seattle would not be suitable for this location.

The construction of a tunnel is not recommended because of the limited capacity, the heavy grades, the time and hazards of construction, the great depth of the channel, the increased length of the crossing, the excessive cost, which would be several times the cost of a bridge, and the further fact that such a crossing could never be freed of tolls or operated at a low cost, as it would require continuous expenditures for policing, lighting and ventilation, the latter two items being almost as great for the winter months of low traffic as they are for the months of peak traffic. A study of the geologic and topographic conditions developed, as shown on Exhibit "G", clearly indicate the difficulties and great expense entailed in the construction of a tunnel.

The problem, therefore, becomes one of designing a bridge of suitable capacity which will have horizontal and vertical clearances satisfactory for the safe marine navigation of the Straits area.

Construction Materials Available.

In order to determine the location of materials for constructing the causeway and connecting highways on the north shore, extensive studies were made under the direction of Mr. W. W. McLaughlin, Testing Engineer of the Michigan State Highway Department, consisting of topographic surveys and borings in the area north of the proposed location. These materials were tested and reported upon by Professor W. H. Housel, Research Consultant of the Michigan State Highway Department. The results of these investigations are shown on Exhibit "D", which exhibit also contains data relative to available construction materials along the south shore.

These studies show that both heavy rock and loose fill materials satisfactory for the filled portions of the causeway can be secured cheaply at nearby sites.

Foundation Explorations

When the decision had been reached that a bridge is the only practical and economical type of crossing it became necessary to determine the character of the overburden materials through which the foundations must pass and the character of the rock on which they are to be built. After

various types of structures had been studied and preliminary designs had been prepared, samples of the overburden materials at eight different locations in the approach areas were taken by the Luedtke Engineering Company, and the results were analyzed and are discussed in Professor W. H. Housel's report on "Clay Overburden Borings on Line 'A'", Exhibit "F".

In order to determine the character of the rock at the approximate sites of the principal foundations to be constructed, bids were taken and contract awarded to the low bidder, Sprague and Henwood of Scranton, Pa., for the securing of preliminary rock cores and the taking of additional overburden samples. This work was carried to completion in the late Fall of 1939. The overburden samples were submitted to Professor W. H. Housel, Research Consultant of the State Highway Department of Michigan, and the rock cores to Mr. R. A. Smith, Chief of the Geology Division, Michigan State Department of Conservation.

The report of Professor Housel clearly indicates that the overburden materials are not suitable for the founding of any of the piers. The overburden materials consist of hard compact clays with some gravel and boulders overlaying strata of much softer plastic clays, with possibly some boulders and harder materials directly over the rock. No particular difficulty should be experienced in sinking carefully designed foundations through these materials. The softer plastic clays may be displaced by the heavy surcharge of the causeway, causing some future settlement for a period of time, which can be corrected as needed by the addition of fill until the materials have become stabilized. Because of this possible fill subsidence, a viaduct protected against ice damage by heavy rock is recommended for the higher portions of the causeway.

The discussions with the Geology Division, Michigan Department of Conservation, indicate that the large foundations required for the support of the recommended type of structure can be safely carried through the overburden materials and securely founded on suitable rock strata.

Mr. R. A. Smith, Chief of the Geological Division, Michigan Department of Conservation, with his assistants, studied the rock cores recovered and advised that they were not sufficiently comprehensive to definitely locate the changes of strata necessary to fully correlate them across the Straits area. However, he agreed that the character of the rock is adequate for supporting the loads which will be imposed and the general dip of the strata is from the north to the south in about the same degree as is indicated elsewhere in this northern portion of the State.

The rock borings, as located from the preliminary studies of proposed structures, do not all come at the exect sites of the foundations in the recommended structure. Before proceeding with the final plans for the foundations, at least one additional rock core should be taken at all important foundation sites, and probings should be made around the indicated perimeter of each foundation to determine the slope of the rock. The estimated cost of such additional cores and probings is included in the cost of the project.

The results of the soundings, rock probings, overburden borings and rock cores, taken along Line "A", have been plotted and are shown on Exhibit "G".

Current Reedings

In order to determine construction difficulties due to overburden scour while sinking the foundations to rock, current readings were thken while the rock probings were being made. The results of these readings were plotted and are shown on Exhibit "E" herewith. These readings indicate that the maximum currents exist near the water surface and are caused by winds; and that there is very little current in the deeper waters at the surface of the overburden. Hence, the scour should be very slight.

Weather Conditions

The Straits of Mackinac are subject to unusually severe weather during the winter months and construction work on the foundations cannot be carried on safely and economically after winter weather sets in. This requires the design of foundations which can be constructed from the water level to, and sealed on, the rock in one short working season. Contracts for the construction must be awarded in the early Fall so that the contractor can assemble the plant and materials during the winter months and be ready to start work as soon as the ice moves, in order to take advantage of the full working season. Any other program would be too hazardous and expensive.

The ice conditions have been carefully studied by observations at the Straits, and the assembly of all available data is shown in Exhibit "H". The severity of the ice conditions makes it necessary to design foundations which will withstand the pressure of maximum ice loads without overturning or overloading the rock or the foundations, and these pressures have been appraised and taken into account in computing the strengths, loads and quantities required to construct adequate foundations.

Traffic Capacity

In determining the recommended three lane width for the bridge, the data relative to past and future growth of traffic st the Straits and the report of the Planning Survey of the Michigan State Highway Department on Vehicular Traffic at the Straits of Mackinac, published as Exhibit "J", have been carefully studied and discussions have been held with departmental heads of the Michigan State Highway Department, due consideration having been given to the peak hour requirements.

A long bridge structure containing no intersecting roadways and not permitting parking or stopping of cars, has a traffic lane capacity in excess of highways where traffic is slowed by intersecting roadways and parked cars. Existing toll bridges are handling an excess of 1000 cars per lane per hour. A three lane bridge with two lanes operated in one direction, if required, during the peak hours, will have a capacity in excess of 2000 cars per hour on these two lanes, with 1000 cars per hour in the opposite direction on the single lane, or if the structure is normally operated as a three lane roadway permitting passing in the center lane, the capacity during peek hours of traffic will be in excess of 1200 cars per hour in each durection, which we believe to be far in excess of any future traffic demands at the Straits. Four lanes of traffic could be provided at an additional construction cost of about 20%. We are of the opinion that this edditional expenditure would not be justified and recommend that the bridge be designed, as estimated herein, for a three lane structure.

In order to collect tolls without delaying traffic two lanes for toll collection should be provided for each traffic lane on the bridge. The toll collection facilities should be located preferably on the north shore, where there is ample room available for the construction of an adequate toll plaza. This plaza should contain, in addition to the toll collection booths, an administration building and a maintenance building, with adequate toilets, locker rooms, and storage space necessary for the equipment, maintenance and operation of the bridge.

Railway Traffic

Consideration has been given to the desirability of carrying, in addition to the highway traffic, a single line of railway traffic to handle the business now being carried by the railroad ferries at this site.

The physical conditions revealed require the construction of an unusually long span to cross the deep gorge and meet the navigation clearance requirements. Due to the physical strengths and limitations of available suitable steels for bridge construction the suspoosion type is the only structure that can be built. The suspension type is of its very nature much more flexible than other types of structures and due to this flexibility and the great length of the span, is subject to changes in vertical grade and horizontal movements under extreme load and temperature which, added to the grades required to meet navigation clearances, would produce grades which could not be negotiated with existing motive power.

The most economic design of suspension bridge to carry combined railway and highway loadings will be subject to a change i nvertical grade due to maximum loading conditions of approximately 2-1/2% which, added to the minimum grades necessary to meet vertical clearances, would produce railway operating grades in excess of 4%. In order to study all phases of this question the problem was submitted to motive power manufacturers, who advised that new type Diesel electric engines might be built capable of handling a maximum of ten loaded cars on a grade not exceeding 4%.

The loads of this equipment and train were applied to preliminary designs of the structure, and the results of these studies indicated that the increased cost of the structure, without giving consideration to the cost of the special operating equipment and restricted load capacity, would approximate $16,000,000.

As a result of these studies it is our opinion that the present or the future railway business to be expected at this crossing is not and will not become sufficiently large to amortize this additional cost through the payment of rentals during the immediate years ahead. The heavy tonnage materials will in the future, as they have in the past, continue to be moved from the upper peninsula by the economical means of water transportation; lighter materials and commodities, with the further development of the highway system, will be transported by trucks.

Navigation Clearances

In order to secure the aid of the U. S. Army Engineers in determining probable navigation clearances required, Major General Schley, Chief of Engineers, instructed the Detroit District Office to accept for discussion, without prejudice to their rights to reject any plan or require other clear-

ances, various types and arrangements of structures in order to develop a plan which would be the least objectionable from the standpoint of navigation.

Early studies of span arrangements, pending the completion of foundation and ice studies, were submitted. These plans contained not only structures similar to the recommended plan, but also other combinations, especially one containing a cantilever type of construction off the south shore, extending north to the south anchorage of the longer span. Early studies had indicated some possible saving in the use of cantilever construction for this portion of the bridge.

As the studies advanced and quantities were accurately computed,, the great depth to rock, the ice pressures demanding massive piers, the length of time required to construct the numerous foundations and to erect the superstructure, all proved that the twin type of suspension bridge over the deep water area will be the most economical and will be better suited to the requirements of navigation.

The recommended plan, Exhibit "I", on which the proposed nnvigation clearances are shown, should meet all requirements and provide a structure which, with the piers protected with cushion type of fenders, and equipped with lights, radio beams and warning signals, will be safe against possible damage to either the structure or shipping due to collision during stormy or foggy weather.

Description of Recommended Structure

The proposed types of construction with the span arrangements and design requirements are shown on Exhibit "I".

Starting at a suitable point near the entrance to the historic park of Fort Michilimackinac, the roadway of the bridge will ascend between retaining walls faced with native stone for approximately 340' in length, thence on continuous steel girder spans to the south anchorage of the smaller of the two suspension bridges. This anchorage is located in a sufficient depth of water to permit the use of floating construction equipment and can be easily built inside cofferdams.

From this anchorage at about Station 6+55 to Station 58+35 there will be a suspension bridge, 5180 feet long between anchoreges, of the approximate proportions shown on the exhibit. At the north end of this bridge a common anchorage will be built on the high rock, by means of which the two suspension bridges will be tied together, this anchorage to be so designed that the live loads of the one bridge will be partially sustained by the other. However, it will be of such proportions that the dead load of either span can be supported by the anchorage without danger of movement or displacement of the anchorage. From the common anchorage at about Station 58+35, another suspension bridge 7942 feet long between anchorages will cross the important navigation area of the Straits to about Station 137+77, at which point the north anchorage will be built on the higher rock formation. From the northernmost anchorage the roadway will be carried on continuous spans to a pier to be located at the southern end of the causeway. This causeway, about 5470 feet in length, will consist of protected viaduct type of structure and rock filled embankment from Station 166+00 to the shore line at Station 216+80. North of the shore line at the most suitable location, toll plaza, maintenance and operating buildings are to be constructed, for the maintenance

and operation of either the ferry or bridge. From the toll plaza the roadway will extend northward to connect with the existing improved highways just outside the City of St. Ignace.

Bridge and Navigation Protection

The roadway is to be of three lanes in width, thirty-three feet between curbs, with sidewalks on each side for pedestrian use in case of car trouble. Situated at frequent intervals along each side of the roadway there will be telephone stations for communication with each end of the bridge for car service and policing uses. The stiffening members of the suspension spans are to be of the girder type with the tops of the girders extending above the roadway level to provide adequate protection to the traffic and pedestrians. The pedestrian walks and roadway are to be built of open steel grid construction in order to reduce the suspended weight, prevent the filling of the roadway with ice and snow and to reduce any uplift from pocketing winds. The open grid type of floor will greatly reduce the cost of the original construction as well as the maintenance costs due to ice and snow removal.

The roadway is to be lighted at the entrances only. The curbs can be painted with a luminous paint and reflector bottons installed to facilitate night driving.

In order to protect the bridge and navigation against hazards of collision in stormy or foggy weather, aerial beacons will be installed on the tops of each high tower. Radio beams for guiding ships will be located at points to be designated and agreed upon by the U. S. Engineer Corps, the Department of Commerce and the navigation interests, and adequete pier and clearance lights will show at all required points. These lights should burn on two sources of current so arranged that in case of failure of one source another will cut in automatically. Sirens for warning navigation will be installed, which will operate in foggy weather. Lightweight scaffolds are to be hung under each of the long suspended structures for future painting and maintenance work, and all parts of the suspended structure will be accessible from these platforms.

The foundations in the navigable areas are to be protected with a cushion type of timber fender, so designed that they can be raised clear of the water during the winter ice conditions, when navigation is closed.

Final approval of the navigation clearances has not been obtained and the relative lengths of side to main spans may be changed slightly to meet requirements when the final detailed construction plans are made. These adjustments should be minor and should not greatly affect the cost of the project. The boring and foundation data have been carefully plotted and studied, and sites selected for the piers and anchorages at which they can be safely, quickly and economically built. All foundations will be carried to the rock strata.

Design Data

For the purpose of computing the time required to construct the project and compute the amount of work and material involved, preliminary design calculations have been made for the recommended construction, The designs were based on the following requirements:

The unit stresses and strengths of materials are to be the equivalent

of those used in similar structures of like magnitude, and the workmanship is to be of the best quality of modern practice.

The causeway and short approech spans are to be designed for the H-20 loading of the Michigan State Highway Department. The long suspension spans are to have an H-20 floor system and the suspended structure will be designed for a uniform live load of 500 lbs. per lineal foot per lane of traffic in any position and length. The wind load shall be taken as 30 lbs. per square foot on one and one-half times the projected vertical area of the structure plus an allowance of 200 lbs. per lineal foot for wind on the live load, or 50 lbs. per square foot on one and one-half times the projected area of the unloaded structure.

The mean temperature is to be taken as c50° F with a minimum of -30° F and a maximum of +100°F. The suspension structures are to be designed for a vertical change in grade under maximum loading and temperature conditions of not more than 2-1/2% and a lateral change in direction below 4%.

The design calculations are based on the theories and methods used at present in calculating the stresses and design of long span suspension bridges and are conservative and accurate in all respects. However, on account of the great length of the larger suspended span and the resulting slenderness ratio of width to length, in order to determine if a span of these proportions might be subject to oscillations or periods of hermonic vibration due to external wind or live load forces in such a magnitude as to affect the driving conditions, a small scale model of the span should be constructed to which external forces can be applied. If the results of the model analysis show any objectionable oscillations or vibrations in the structure, means should be provided to dampen or control such movements; the cost of providing such control is included in the estimate.

Estimated Cost of Project

In order to assist us in accurately estimating the cost of the project and to compute the time required to complete the work ready for traffic, preliminary designs have been made of the recommended construction and submitted to some of the principal contractors who have built structures of like magnitude, for their opinion of the time, hazard and difficulties of the proposed construction. Those to whom designs were submitted are in agreement that this bridge can be safely and economically built within the time scheduled herein for completion.

Based on the opinions and data received from these contractors and our experience and cost data of other large structures of like magnitude, we have computed the following estimated cost of the two projects.

The cost hes been developed by computing accurately the quantities of work of each class and pricing these quantities as of this date. The costs will, of course, vary dependent upon the economic conditions at the time contracts are let but factors to cover these changed conditions can be applied to the estimate to adjust it to the conditions that will exist at the time bids are received.

The cost of the causeway project extending from the north shore Southward to about Station 166+00, and the cost of the toll plaza and connecting roadway have been estimated as a separate project, since our studies of the ferry operating costs and the traffic data as submitted by Mr. L. B. Reid,

Director of Finance, Michigan State Highway Department, Exhibit "K", clearly indicate that the construction of the roadway, buildings and causeway as a separate project would be justified for the ferry operation alone, should the bridge construction be delayed for some length of time. The cost of the causeway would approximate $825,000, and the toll plaza, and buildings $40,000, connecting roadways $100,000, and temporary ferry dock possibly $250,000, making the entire cost of this ferry causeway project approximately $1,215,000.

The cost of the causeway, roadway and toll plaza buildings has been added to the cost of the bridge to show the entire project cost when the ferries have been replaced with a bridge.

We estimate the cost of the bridge project as follows:

2755 1. f.	North Approach Continuous Spans Substructure	$ 505,800.00
2755 1. f.	North Approach Continuous Spans Superstructure	633,500.00
1324.4 1. f.	Suspended Spans Substructure	9,052,800.00
1324.4 1. f.	Suspended Spans Superstructure	9,265,470.00
684 1. f.	South Approach Continuous Span Substructure	86,250.00
684 1. f.	South Approach Continuous Span Superstructure	116,930.00
352 1. f.	South Approach on Retained Fill	56,000.00
	Additional Foundation Explorations	50,000.00
	Pier Fenders	100,000.00
	Navigation and Aerial Lighting	30,000.00
	Roadway Telephone System	30,000.00
18035 1. f.	Total Length of Bridge	
	Construction Cost	$19,946,750.00
	Contingencies, 10%	2,003,250.00
	Total Construction Cost	$21,950,000.00
	Preliminary Survey Costs to Date	175,000.00
	Architects	20,000.00
	Engineering, Design & Supervision	950,000.00
	Inspection of Materials	70,000.00
	Model Analysis & Investigations	35,000.00
	Real Estate	50,000.00
	Legal Expense	50,000.00
	Administration Expense	75,000.00
	Cost of Bridge Project	$23,375,000.00
	Cost of Causeway, Roadway & Buildings	965,000.00
	Total Cost of Entire Crossing	$24,340,000.00

The cost of financing and the interest during construction are not included in the above project costs, as these items cannot be accurately estimated until the interest rates and proposed plan of financing have been determined.

If the above cost can be financed at par for 4% revenue bonds and the bonds sold as needed to meet maturing obligations, the interest during construction would approximate 4% on half the amount of money for the estimated time of construction of four years, approximating $2,400,000.

Traffic and Gross Earnings

The State Highway Department Planning Survey Division has, with the records of the past ferry operations, prepared an accurate record of the past volume of traffic and estimated the future volume of traffic that can be expected to use the ferry in future years We have reviewed all of these data and have adv ed and conferred in the a embling and preparation of same and in our opinion the estimated future vol e of traffic is made on a conservative basis.

At all comparable locations where a ferry has been replaced with an adequate bridge structure there has been a stimulation in the traffic volume due, principally, to the saving in time and the greater convenience provided. Much available data relative to similar crossings heretofore completed have been assembled and studied with the State Highway Planning Survey Division, and the resulting stimulation and future traffic, as shown on Exhibit "J", in our opinion has been computed on a sound and conservative basis, due consideration being given to the proposed average toll in use on the ferries.

If the recommended construction schedule is accomplished and the bridge completed ready for operation by early Spring in 1947, the estimated gross earnings for the first full year of operation would be not less than $925,000, based on the present average toll per vehic e.

Maintenance and Operating Costs

Based on the experience in the operation and maintenance of many toll bridge projects owned and operated by public bodies, he foll ing estimate of these costs for this project has been prepared in luding t three principal headings of Administration @ $42,000, Operation including Insurance @ $66,000, and Maintenance Costs @ $52,000, making a total Maintenance, Insurance and Operating Cost of $160,000. per year. This estimate is based on the assumption that the bridge will be maintained and operated by your Authority and the cost of maintenance and operation will be paid from toll revenues, and the further assumption that part, if not all, of the construction costs will be raised by the sale of revenue bonds.

If all costs of maintenance and operation are paid from toll revenues, the amount available for bond service at the end of the first year of operation would be not less than $765,000.

Program of Completion

If construction permits are secured early this Fall of 1940, the required foundation explorations could be made at the approved foundation sites, and with an experienced organization familiar with the design of these unusually large foundations, the contracts and plans for the substructure work could be completed ready for receipt of bids early in the Fall of 1941. The bidders should have eight to twelve weeks time to prepare proposals for these large foundations.

If the substructure work is divided into several contracts, with a view to obtaining maximum speed with minimum plant cost, at the end of the two full working seasons or in the Fall or early Winter of 1943, sufficient foundation work should be completed to start superstructure work. Due to the design features the plans for the superstructure, especially the towers and anchorage devices of the suspension bridges, must be prepared along with the foundation plans, and the plans for the superstructure could, with an experienced design organization, all be completed ready for superstructure bids by the Fall of 1942, thus giving one year's time for the rolling and fabrication of the steelwork and the assembling of the erection forces and equipment. After superstructure erection has started in early Spring of 1944, it will require possibly two working seasons to complete, ready for traffic, the superstructure erection. It might be possible to start traffic in the Fall of 1946, but surely in the early Spring of 1947. The actual time will depend on the weather conditions and a proper scheduling of all of the contracts so as to coordinate all parts of the work in such a way that the items of work requiring the greatest time for completion will proceed simultaneously.

We recommend the construction of the bridge project described herein, and are of the opinion that it is feasible and practicable to build this structure and that it is the best and most suitable type of crossing to meet the demands for better transportation facilities between the two major peninsulas comprising the State of Michigan.

Respectfully submitted

MODJESKI and MASTERS
Engineers

By F. M. Masters

FMM:IH

I have kept in constant touch with the work of Modjeski and Masters in the preparation of this report. I have prepared my own independent calculations of the design of the proposed bridge structure and have been furnished with full and complete data relative to all surveys and foundation work, and have served in an advisory capacity in connection with all designs and construction estimates, and this is my approval of the type of crossing recommended herein.

Leon S. Moisseiff
Consulting Engineer

June 27, 1940

Modj ski and Mas rs
Consulting Engineers
Harrisburg, Pennsylvania

Gentlemen:

In accordance with your request of June 11, I have reviewed your report on the Mackinac Straits Bridge Project dated June 3, 1940, and have examined the exhibits referred to therein.

The earlier studies of this project, mentioned in e report, were of necessity based upon meager physical data, and the assertions then made as to the feasibility and probable cost of the project were therefore subject to dispute. The information which has now been obtained on the location which you have selected should leave no doubt as to the practicability of constructing a bridge directly across the Straits.

I concur n your recommendat on concerning the immediate construction of causeway on the S . Ignace side of the channel to servo as a f ry terminal until permanent bridge is built.

Although no tentative plans or cost estimates for possible tunnel construction are given in the report, I agree with your conclusion that the construction and operating costs of such a project would probably be prohibi tive.

Your conclusion that rail traffic would not justify the corresponding increased cost of bridge construction, confirms that reached in the earlier studies of the project. I therefore agree with your recommendation that the proposed bridge should provide for highway traffic only.

The structure which you recommend has presumably been evolved from many design studies and estimates of cost. I have had no contact with these studies and the limited time made available to e for the review of this report has precluded an independent vestigation of these matters.

The studies of "Vehicular Traffic Acros s the Straits of Mackinac" presented in Exhibit J, appear to bo unusually comprehensive and clearly indicate the necessity o completing the bridge project at an early date.

Respectfully submitted

J. H. Cissel
Consulting Engineer
Ann Arbor, Michigan

JHC:LED

cc/ G. D. Kennedy

LIST OF EXHIBITS TO ACCOMPANY
MACKINAC STRAITS BRIDGE REPORT

Frontispieces - A perspective view of project entitled "THE MACKINAC STRAITS BRIDGE" prepared by Modjeski and Masters; and "AERIAL SURVEY OF THE STRAITS TERRITORY", provided by the Authority. (Plates 1 and 2)

Exhibit "A" - "VICINITY MAP" reproduced from Corps of Engineers, War Department, "Survey of Northern and Northwestern Lakes - Straits of Mackinac - 1936". (Plate 3)

Exhibit "B" - Report and plan by K.R. MacDuff, Survey Chief, Michigan State Highway Department, entitled "REPORT OF THE PRELIMINARY FIELD WORK", dated Jan. 15, 1940. (Plate 4)

Exhibit "C" - "TOPOGRAPHIC MAP", prepared by Modjeski and Masters from Master Topographic Map of Michigan State Highway Department. (Plate 5)

Exhibit "D" - Report on "AVAILABLE FILL MATERIALS" by F. J. Hagan, Asst. Engineer of Soils, Research and Testing Division, Michigan State Highway Department, dated December 20, 1938; and "REPORT ON SOIL BORROW AREA NO. 1 FOR MACKINAC STRAITS BRIDGE" by W. S. Housel, Research Consultant, Michigan State Highway Department, dated April, 1940.

Exhibit "E" - Report and Data on "STRAITS CURRENT READINGS" by R. W. Rice, Engineer of Road Location, Michigan State Highway Department, dated Jan. 2, 1940. This is supplemented by a chart entitled "MAXIMUM OBSERVED CURRENT VELOCITIES", prepared from these data by Modjeski and Masters, and dated May, 1940. (Plate 6)

Exhibit "F" - Report on "CLAY OVERBURDEN BORINGS" by W. S. Housel, Research Consultant, Michigan State Highway Department, dated April, 1940.

Exhibit "G" - Plan. entitled "FOUNDATION DATA" showing substructure conditions along Line "A", prepared by Modjeski and Masters and dated May, 1940. (Plate 7)

Exhibit "H" - "STUDY OF ICE CONDITIONS, WINTER OF 1938 and 1939" by K. R. MacDuff, Survey Chief, Michigan State Highway Department.

Exhibit "I" - Plan entitled "GENERAL DRAWING" showing recommended design of bridge, prepared by Modjeski and Masters and dated May, 1940. (Plate 8)

Exhibit "J" - "VEHICULAR TRAFFIC AT THE STRAITS OF MACKINAC" by F. C. Taylor, Director, Highway Planning Survey, Michigan State Highway Department, dated August, 1939. (Plates 9,10,11,12 and 13)

Exhibit "K" - "A CHRONOLOGICAL OUTLINE OF TH3 DEVELOPMENT OF THE MICHIGAN STATE FERRY SYSTEM", prepared by the Finance Division, Michigan State Highway Department, dated January, 1940; together with chart entitled "A COMPARISON OF VEHICULAR TRAFFIC ACROSS THE STRAITS OF MACKINAC TO THE CUMULATIVE CAPITAL INVESTMENT OF THE STATE FERRY SYSTEM". (Plate 14)

Plate No. 3

VICINITY MAP

Reproduced from "Survey of the Northern and Northwestern Lakes" compiled by the War Department, Corps of Engineers this map shows the immediate surrounding land and water areas. Superimposed are lines connecting Mackinaw City and St. Ignace indicating location of the proposed bridge as well as present and proposed ferry boat routes.

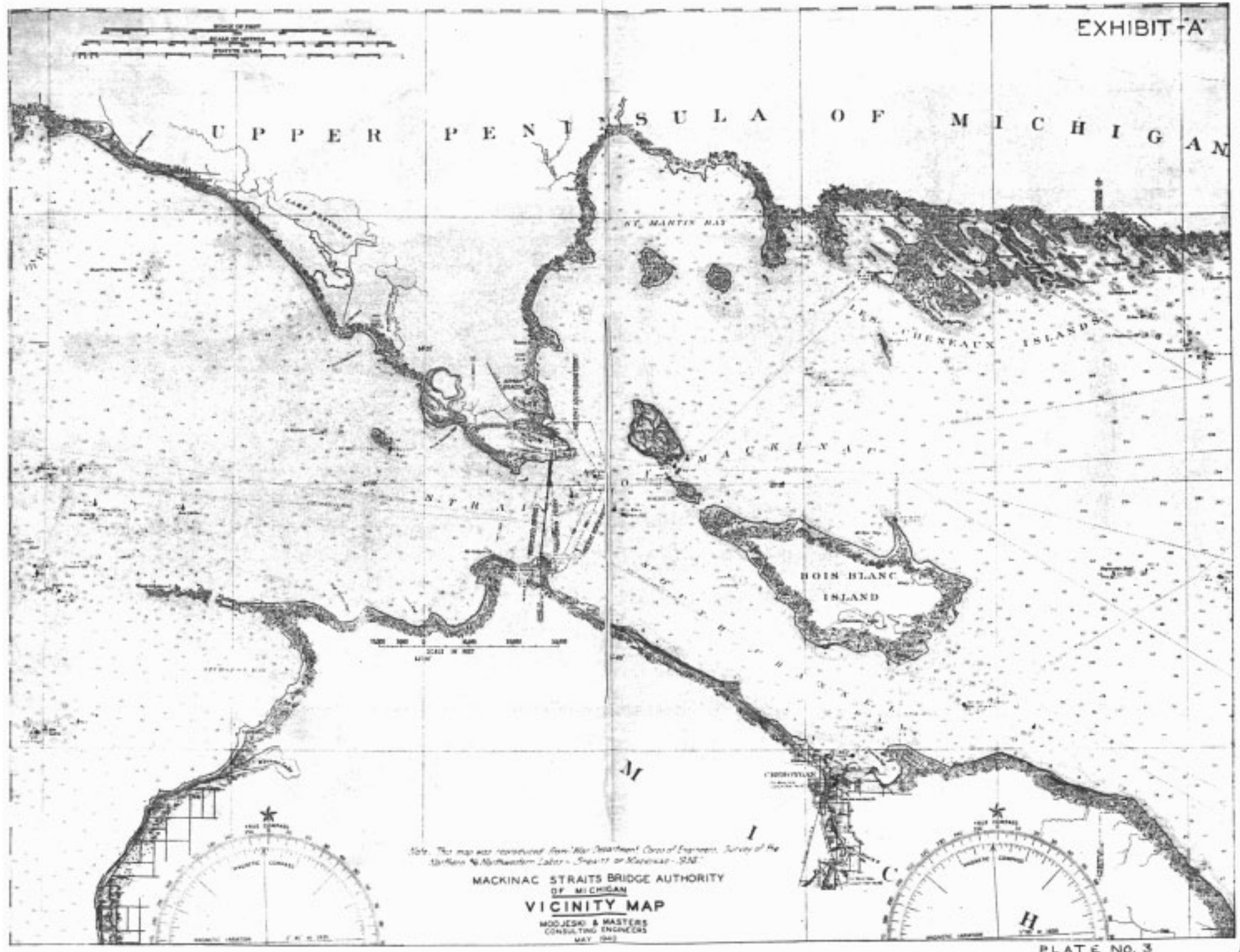


EXHIBIT "A"
UPPER PENINSULA OF MICHIGAN
ST. MARTIN BAY
LES CHENEAUX ISLANDS
MACKINAC
BOIS BLANC ISLAND
LAKE MICHIGAN
Note: This map was reconstructed from War Department Corps of Engineers Survey of the Northern & Northwestern Lakes - Straits of Mackinac - 1938
MACKINAC STRAITS BRIDGE AUTHORITY
OF MICHIGAN
VICINITY MAP
MOOJESKI & MASTERS
CONSULTING ENGINEERS
MAY 1940

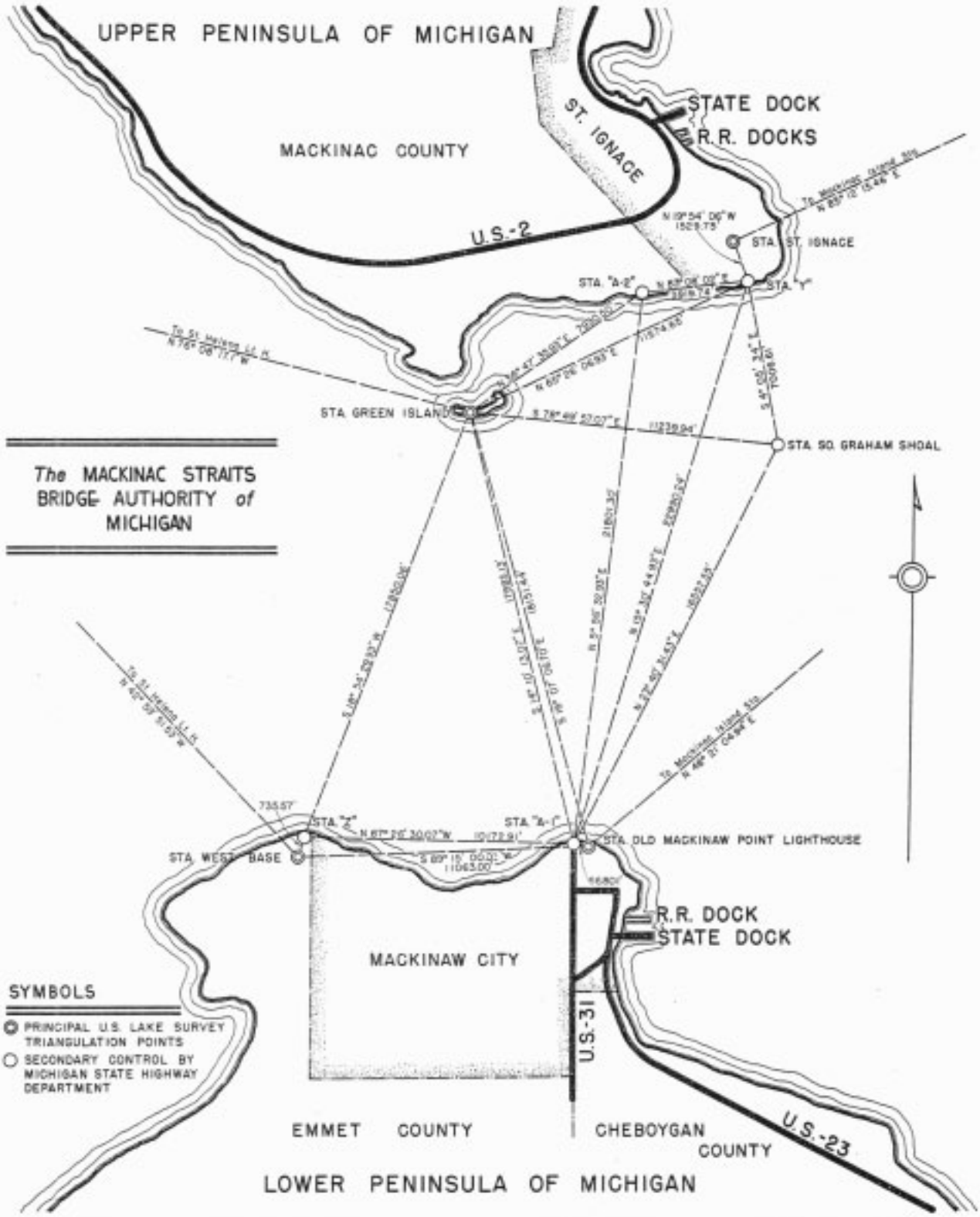
PLATE NO. 3

Plate No. 4

SURVEYS MADE TO DETERMINE POSSIBLE BRIDGE LOCATION

Necessary to consideration of the most feasible location for the bridge was establishment of a triangulation system from which accurate distances could be computed and control points fixed.

These lines, when once laid down, served as the basis for subsequent studies and investigations such as location of sites for borings and probings, computation of span lengths and cost estimates.



SURVEYS MADE TO DETERMINE POSSIBLE BRIDGE LOCATIONS

Plate No. 5

TOPOGRAPHIC MAP

This drawing shows the three tentative lines which were considered and information relative to these lines. Soundings made by the U. S. Lake Survey furnished data for the contours; probings and drillings made under direction of the Authority supplied information for plotting depths to overburden and to bed rock. Additional contours, topography and other information are contained in individual maps prepared by the Michigan State Highway Department and from which this map was plotted.

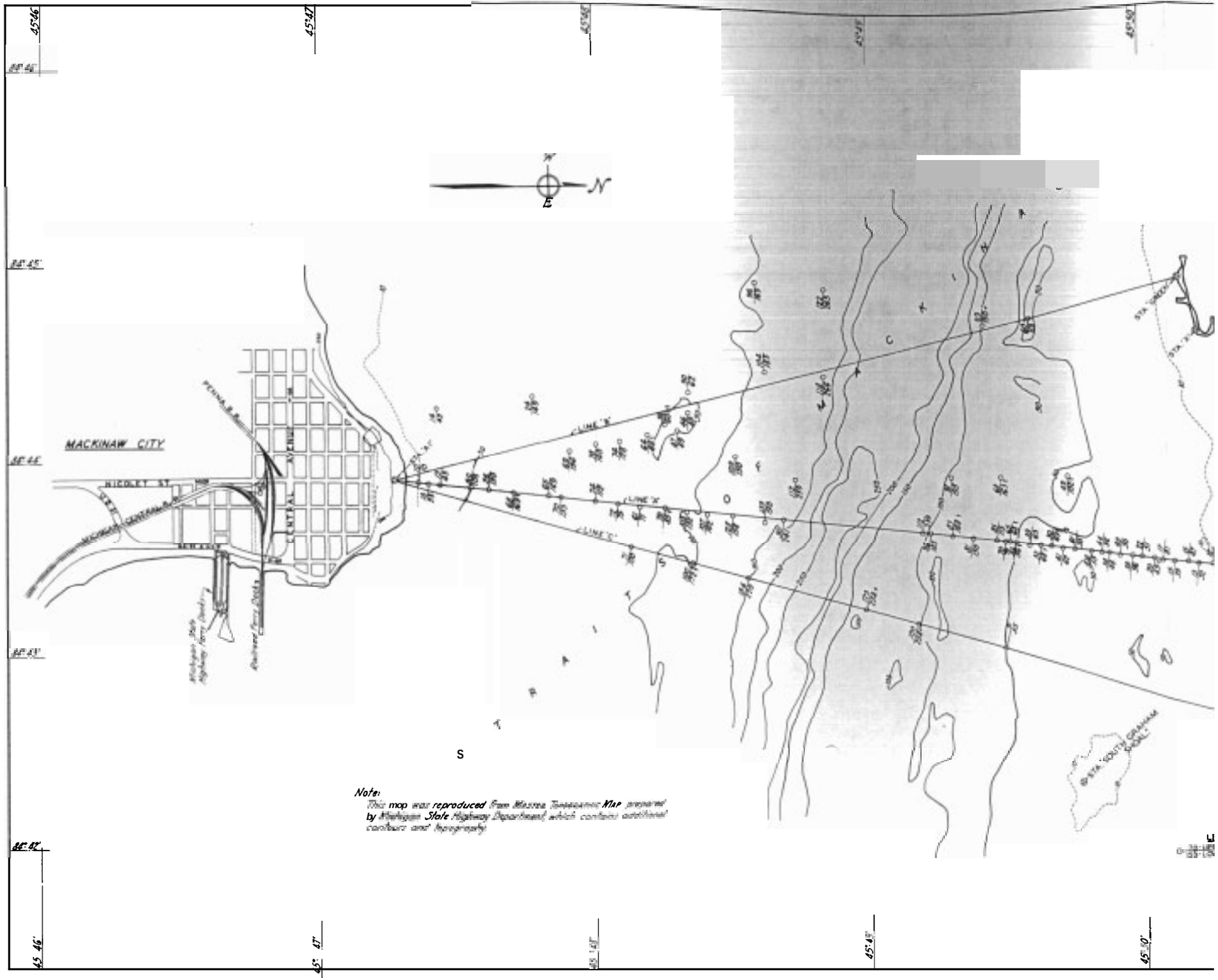
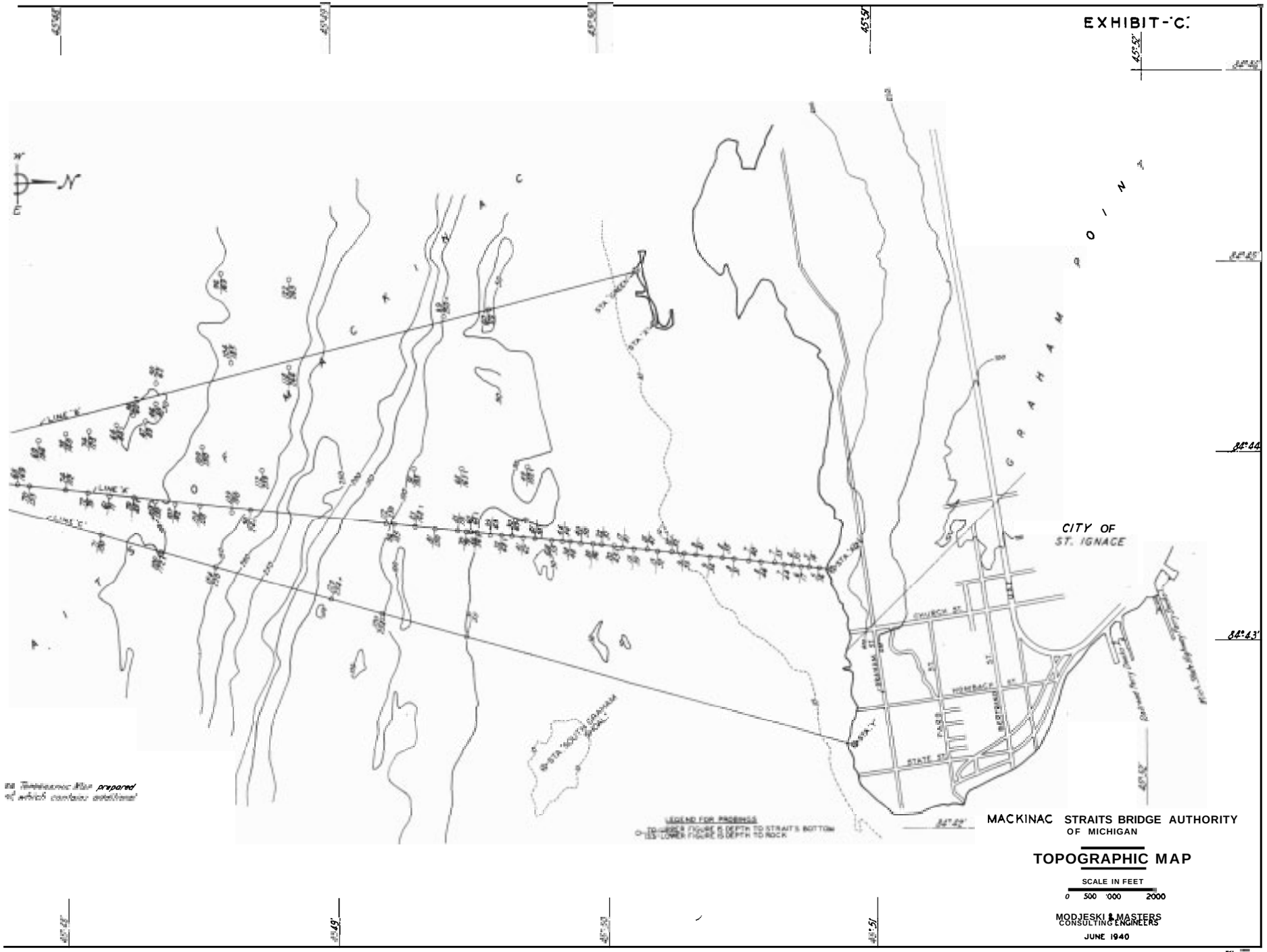

MACKINAW CITY
NICOLET ST.
CENTRAL AVENUE
LINE 'A'
LINE 'B'
LINE 'C'
N
E
S
Note:
This map was reproduced from Mackinac Tombolo Map prepared by Michigan State Highway Department which contains additional contours and topography

EXHIBIT-"C."



MACKINAC STRAITS BRIDGE AUTHORITY
OF MICHIGAN

TOPOGRAPHIC MAP

SCALE IN FEET
0 500 1000 2000

MODJESKI & MASTERS
CONSULTING ENGINEERS

JUNE 1940

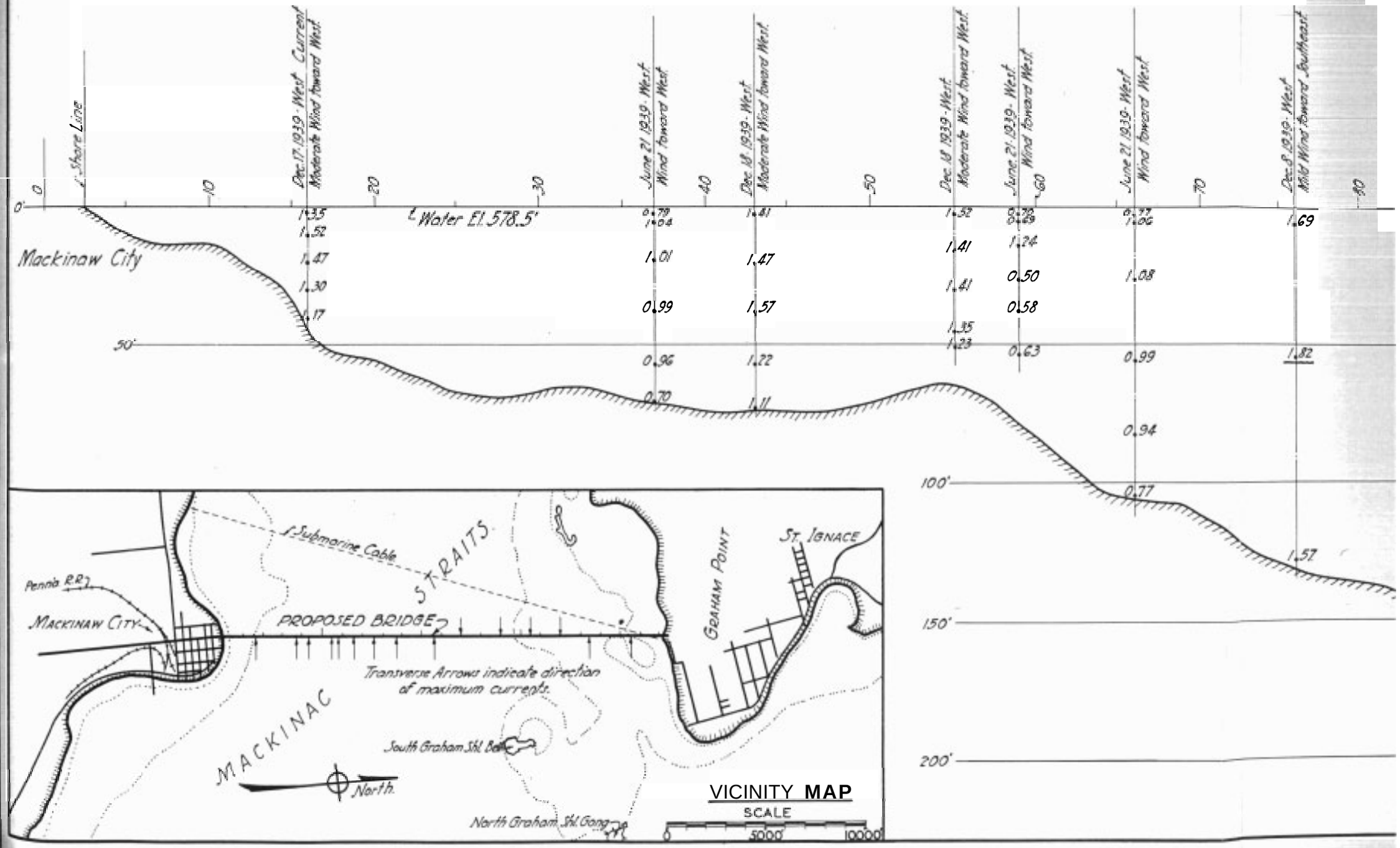
PLATE NO. 5

Plate No. 6

MAXIMUM OBSERVED CURRENT VELOCITIES

This drawing contains data compiled from meter readings taken at the surface of the water and at various depths. Also noted was wind direction at the time readings were taken.

These studies are important inasmuch as they deal with the possible effects of the current on foundations both during and after construction.


Shore Line
Dec. 17, 1939 - West Current
Moderate Wind toward West
June 21, 1939 - West
Wind toward West
Dec. 18, 1939 - West
Moderate Wind toward West
Dec. 18, 1939 - West
Moderate Wind toward West
June 21, 1939 - West
Wind toward West
June 21, 1939 - West
Wind toward West
Dec. 8, 1939 - West
Mild Wind toward Southeast
0
10
20
30
40
50
60
70
80
0'
50'
100'
150'
200'
Water El. 578.5'
Mackinaw City
1.35
1.52
1.47
1.30
1.17
0.79
1.04
1.01
0.99
0.96
0.70
1.41
1.47
1.57
1.22
1.11
1.52
1.41
1.41
1.35
1.23
0.78
0.69
1.74
0.50
0.58
0.63
0.77
1.06
1.08
0.99
0.94
0.77
1.69
1.82
1.57
Submarine Cable
STRAITS
Penna R.R.
MACKINAW CITY
PROPOSED BRIDGE
GRAHAM POINT
ST. IGNACE
Transverse Arrows indicate direction of maximum currents.
MACKINAC
South Graham Sh. Bell
North Graham Sh. Gong
North
VICINITY MAP
SCALE
0
5000'
10000'

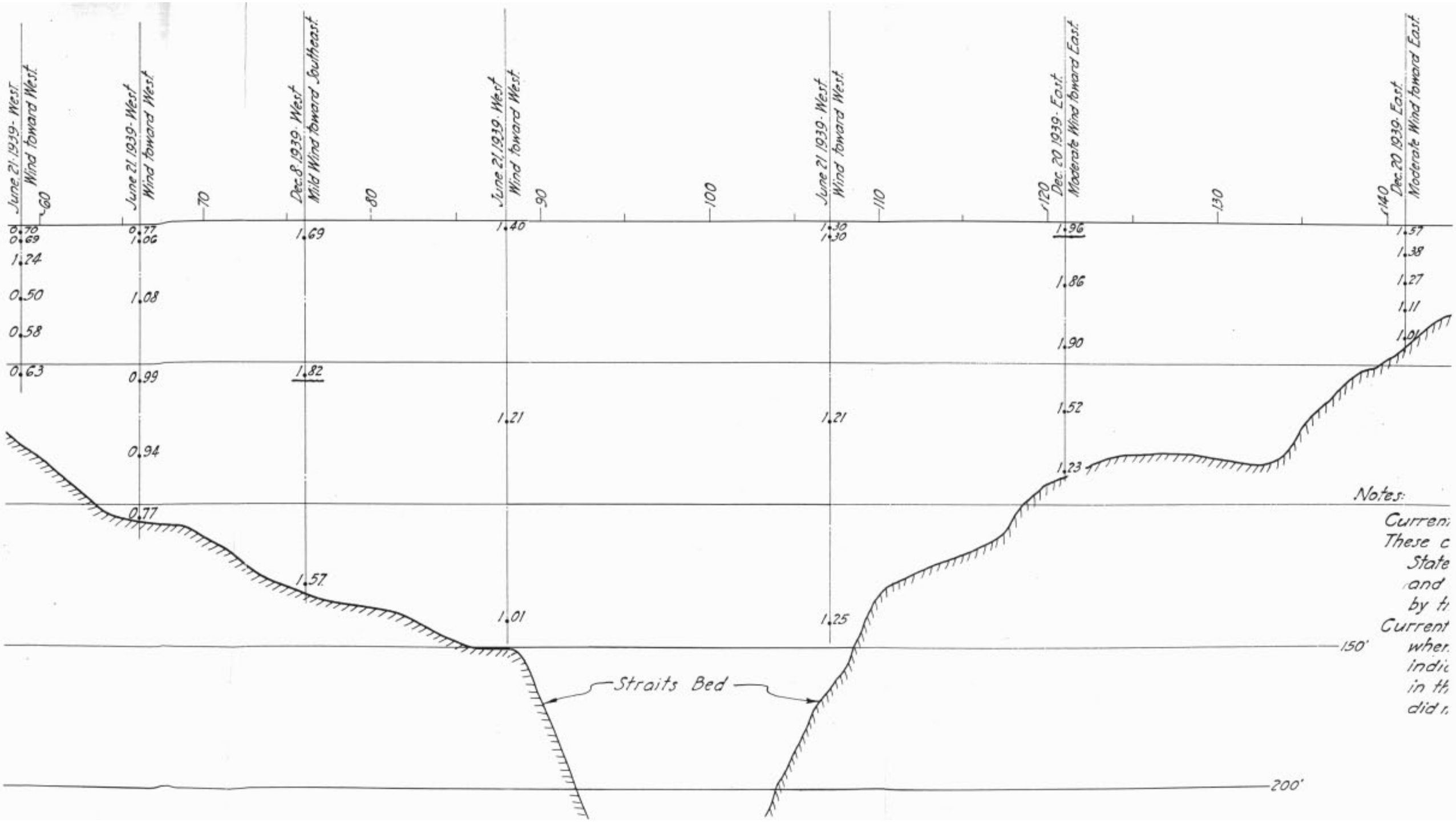
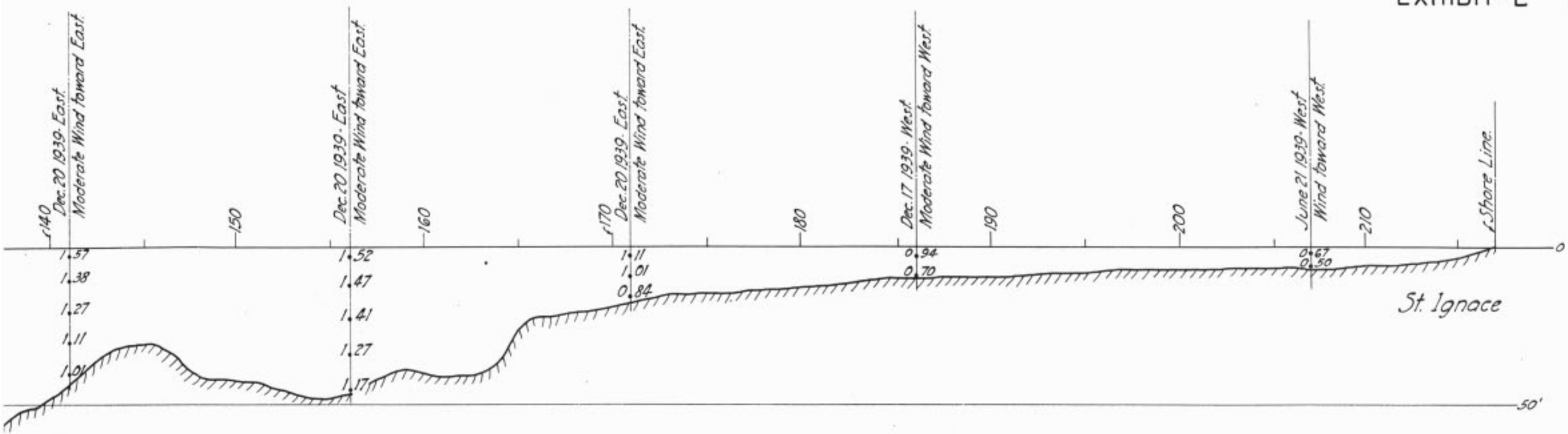

June 21, 1939 - West
Wind toward West
June 21, 1939 - West
Wind toward West
Dec. 8, 1939 - West
Mild Wind toward Southeast
June 21, 1939 - West
Wind toward West
June 21, 1939 - West
Wind toward West
Dec. 20, 1939 - East
Moderate Wind toward East
Dec. 20, 1939 - East
Moderate Wind toward East
60
70
80
90
100
110
120
130
140
0.70
0.69
1.24
0.50
0.58
0.63
0.77
1.06
1.08
0.99
0.94
0.77
1.69
1.82
1.57
1.40
1.21
1.01
1.30
1.30
1.21
1.25
1.96
1.86
1.90
1.52
1.23
1.57
1.38
1.27
1.11
1.01
150'
200'
Straits Bed
Notes:
Curren
These c
State
and
by t
Current
wher
indic
in th
did n

EXHIBIT-"E"



Notes:

Current velocities are given in miles per hour.

These current readings are based on observations made by the Michigan State Highway Department in the period from June 21 to Dec. 22 1939, and summarize the maximum conditions recorded in a detailed report by them.

Current velocities recorded here are given in groups taken on those days when the maximum values were observed. The directions of current indicated are the directions of the maximum currents found; currents in the opposite directions were also obtained of each station but they did not reach these maximum values.

SCALES: { HORIZONTAL - 0 5000' 10,000'
VERTICAL - 0 10' 20' 30' 40' 50' 60' }

MACKINAC STRAITS BRIDGE AUTHORITY
OF MICHIGAN

MAXIMUM OBSERVED CURRENT VELOCITIES

SCALES AS NOTED

MODJESKI & MASTERS
CONSULTING ENGINEERS

JUNE 1940

PLATE NO. 6

H.J.E. - C.F.R.

Plate No. 7

FOUNDATION DATA - LINE A

Early probings made along the several tentative lines soon indicated that Line "A" was the most practicable route. Accordingly, further investigations were concentrated there. This drawing shows the detailed data of the underlying rock structure attained from the investigations.

Deep rock drillings made at ten stations along the line as well as probing results are plotted and shown in relation to a profile of the Straits floor.

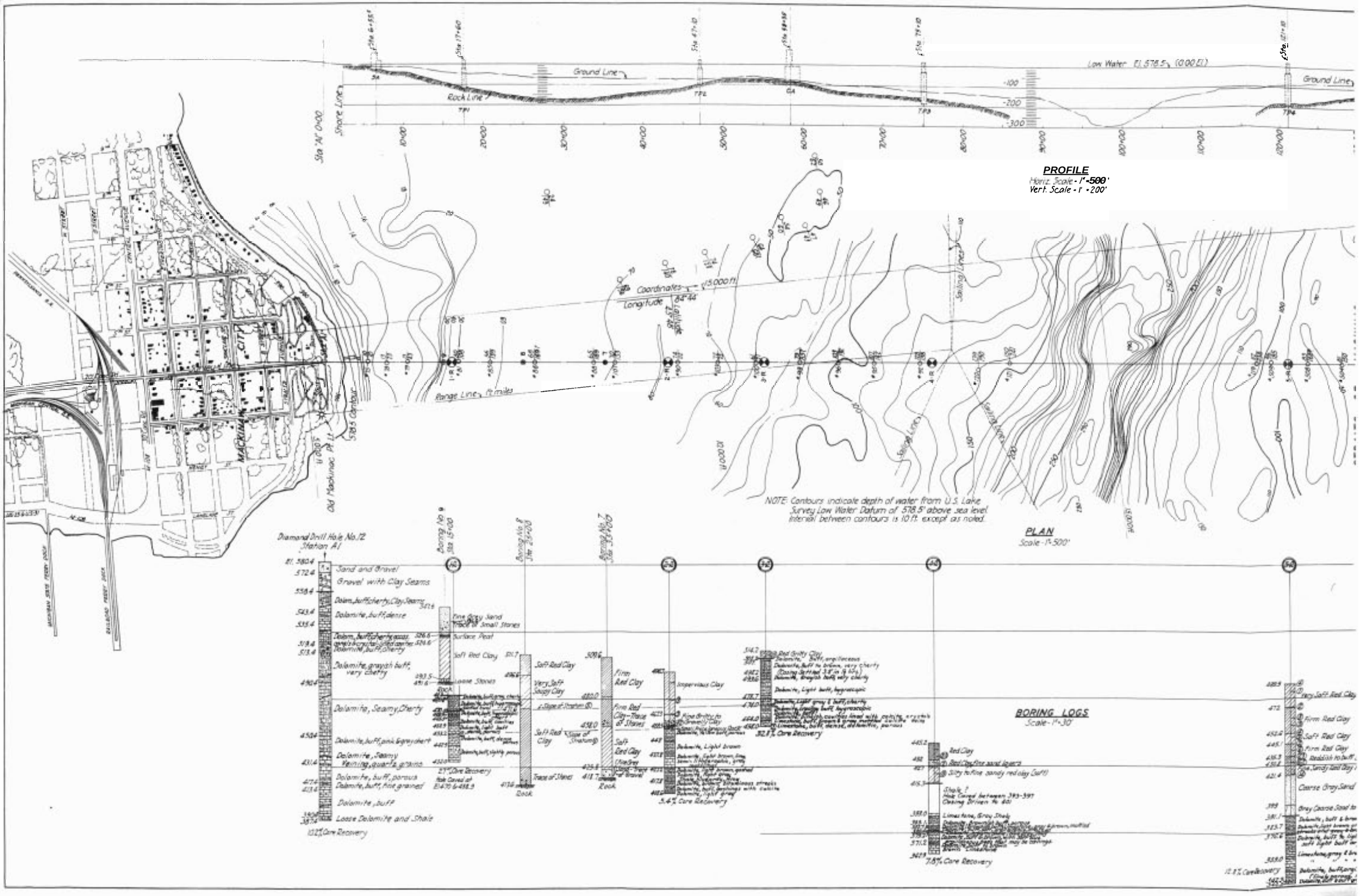

PROFILE
Horiz. Scale - 1" = 500'
Vert. Scale - 1" = 200'
Low Water El. 578.5' (0.00 ft.)
Ground Line
Rock Line
Shore Line
Sta. "A" 0+00
NOTE: Contours indicate depth of water from U.S. Lake Survey Low Water Datum of 578.5' above sea level. Interval between contours is 10 ft. except as noted.
PLAN
Scale - 1" = 500'
Coordinates
Longitude
Range Lines (1 mile)
Sailing Lines
Leading Lines
MACKINAC CITY
Old Mackinac Pt. Lt.
585 Contour
BOARDWALK
BOARDING HOUSE
BOARDING HOUSE
BOARDING HOUSE
BOARDING HOUSE
BOARDING HOUSE
BOARDING HOUSE
BOARDING HOUSE
BOARDING HOUSE
BORING LOGS
Scale - 1" = 30'
Diamond Drill Hole No. 12
Station A1
Sand and Gravel
Gravel with Clay Seams
Dolomite, buff, dense
Dolomite, grayish buff, very cherty
Dolomite, Seamy, Cherty
Dolomite, buff, porous
Dolomite, buff, fine grained
Dolomite, buff
Loose Dolomite and Shale
12.2% Core Recovery
Boring No. 9
Sta. 15+00
Fine Gray Sand
Surface Peat
Soft Red Clay
Loose Stones
Rock
27% Core Recovery
Boring No. 8
Sta. 29+00
Soft Red Clay
Very Soft Sandy Clay
Soft Red Clay
Trace of Stones
Rock
Boring No. 7
Sta. 35+00
Firm Red Clay
Firm Red Clay - Trace of Stones
Soft Red Clay
Rock
Impervious Clay
5.4% Core Recovery
Red Shifty Clay
32.8% Core Recovery
Red Clay
Red Clay, fine sand layers
Silty to fine sandy red clay (soft)
Limestone, Gray Shaly
7.87% Core Recovery
Very Soft Red Clay
Firm Red Clay
Soft Red Clay
Firm Red Clay
Coarse Gray Sand
Gray Coarse Sand to
12.2% Core Recovery

EXHIBIT-"G"

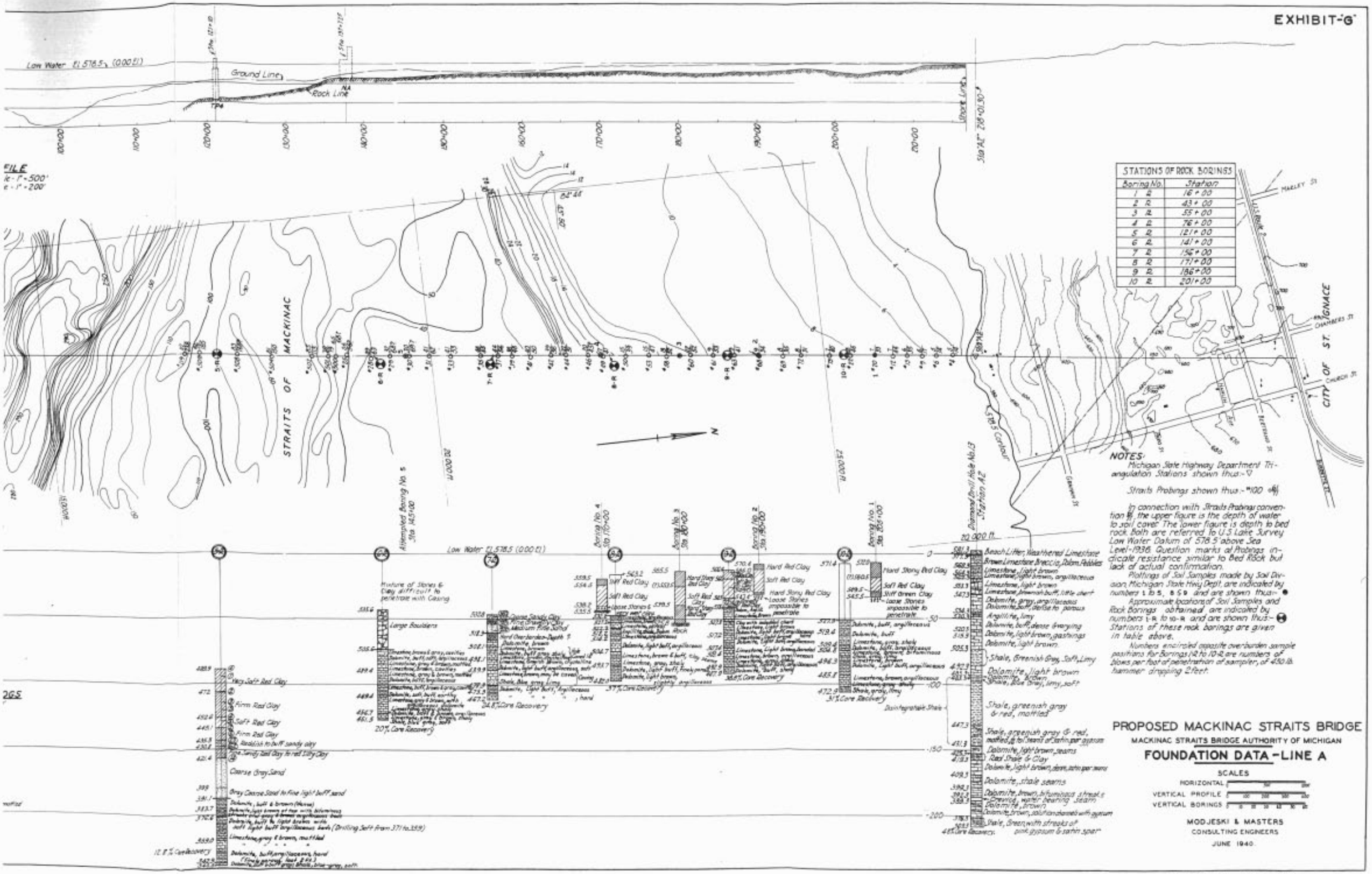


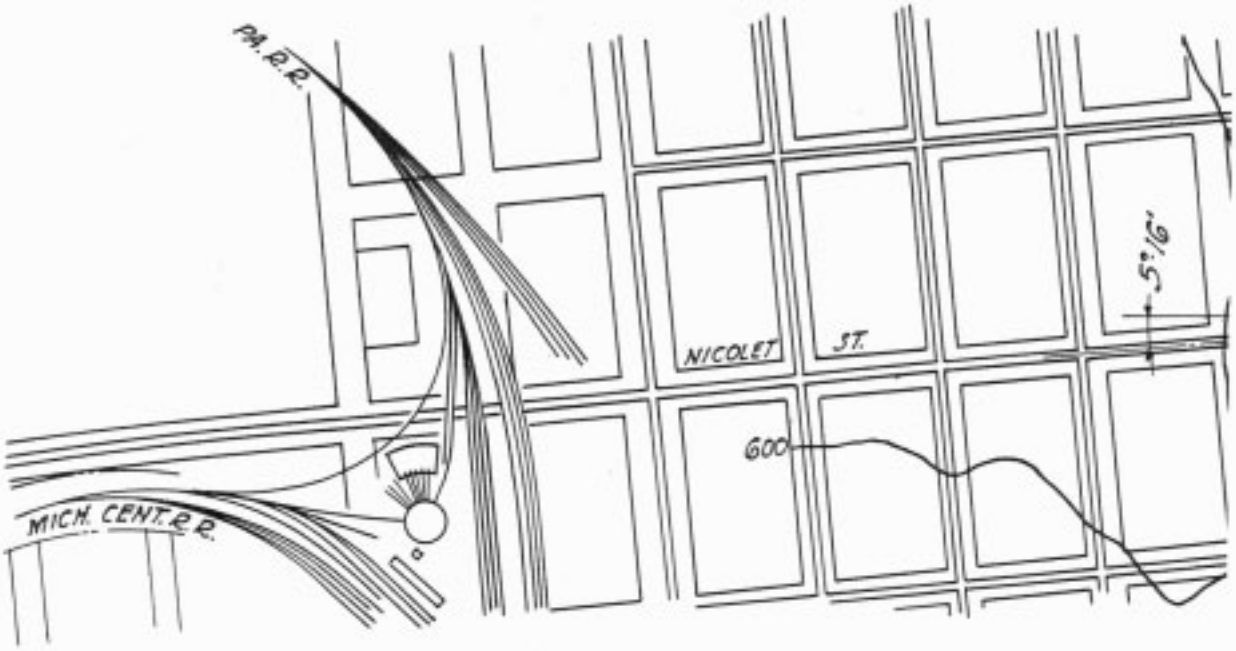
PLATE NO. 7

Plate No. 8

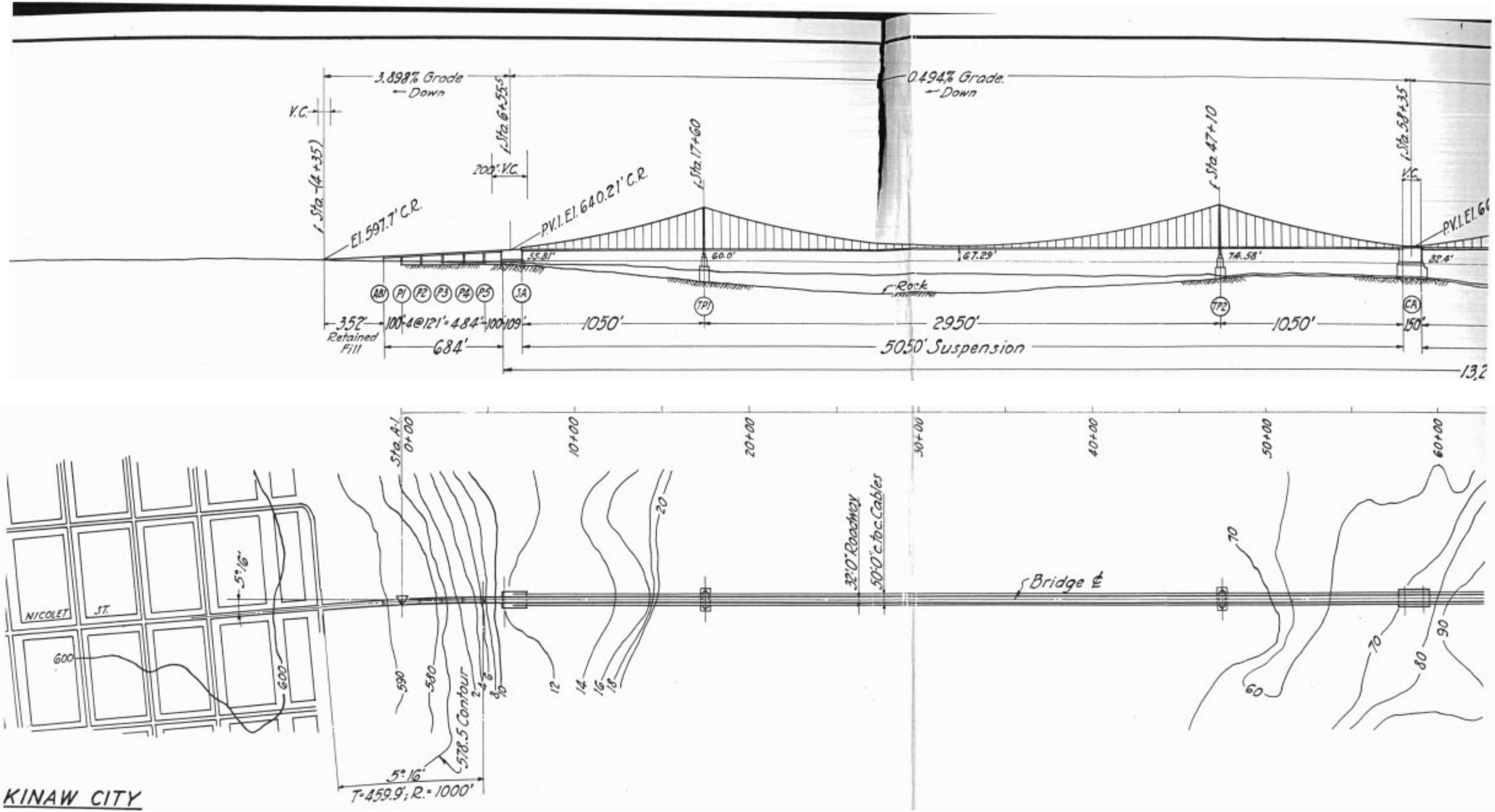
GENERAL DRAWING

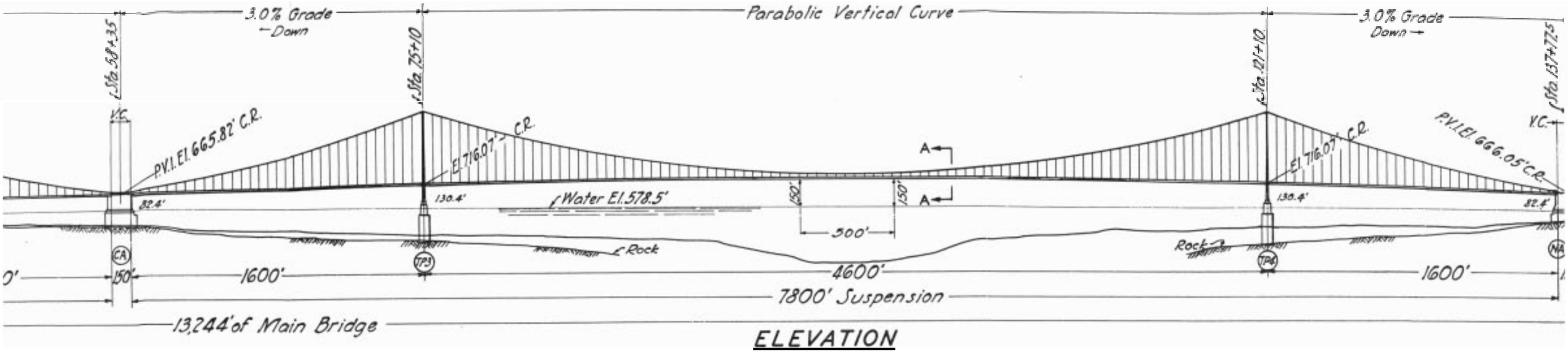
In a way, this drawing reflects the sum Total of all the investigations. From all the information that was gathered and from all the design studies that were made a general plan was developed from which cost estimates could be made; to which critical analysis could be applied.

As shown, the bridge exclusive of causeway construction for the north approach is 18,035 feet in length with two suspension spans - one 2950 feet long and the other 4600 feet long, the latter being the longest suspension span in the world. From shore to shore the total length of the crossing is 21,801 feet or slightly more than four miles.

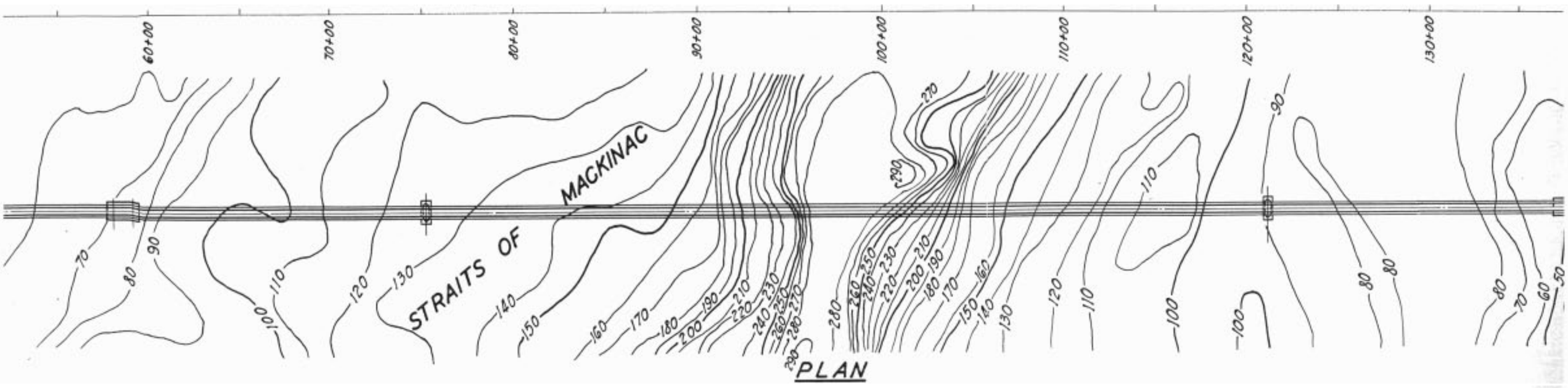


MACKINAW CITY

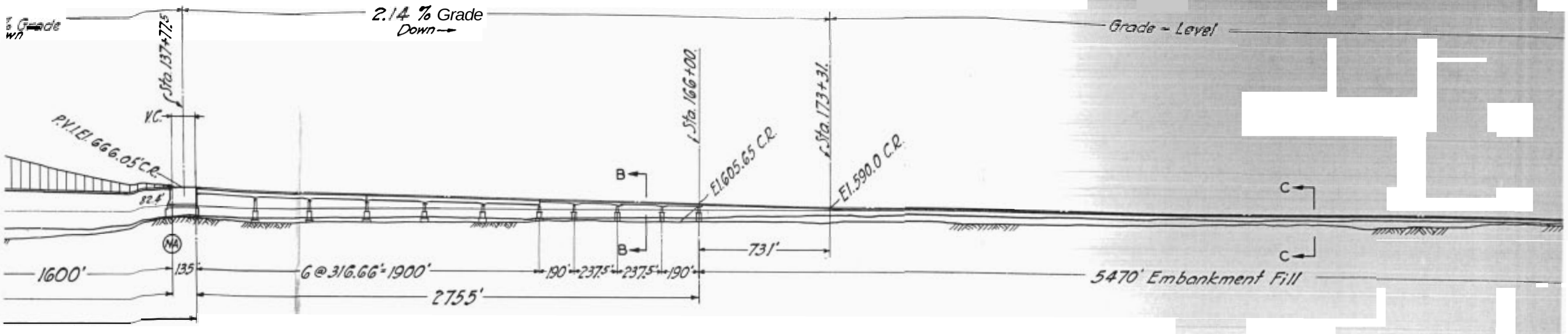

3.898% Grade
← Down
0.494% Grade.
← Down
V.C.
℄ Sta. 6+55.5
℄ Sta. 17+60
℄ Sta. 47+10
℄ Sta. 58+35
℄ Sta. -(4+35)
200' V.C.
V.C.
El. 597.7' C.R.
P.V.I. El. 640.21' C.R.
P.V.I. El. 60
55.81'
60.0'
67.29'
74.58'
82.4'
℄ Rock
AB
P1
P2
P3
P4
P5
SA
TP1
TP2
CA
352'
Retained Fill
100'
4@121' = 484'
100'
109'
1050'
2950'
1050'
150'
684'
5050' Suspension
13,2
Sta. A-1
0+00
10+00
20+00
30+00
40+00
50+00
60+00
NICOLET ST.
5°16'
600
590
580
578.5 Contour
12
14
16
18
20
32'0" Roadway
50'0" c. to c. Cables
℄ Bridge
70
60
70
80
90
5°16'
T=459.9'; R.=1000'
KINAW CITY

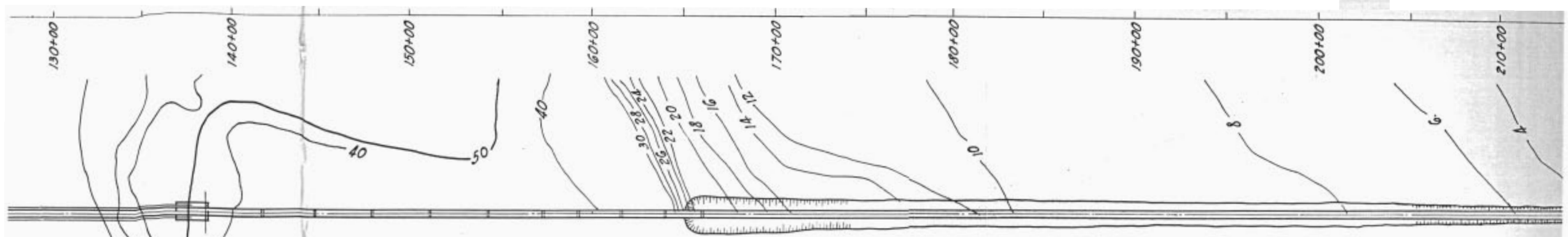


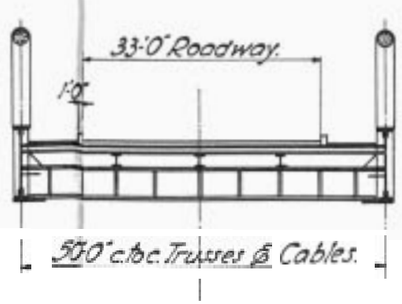
ELEVATION



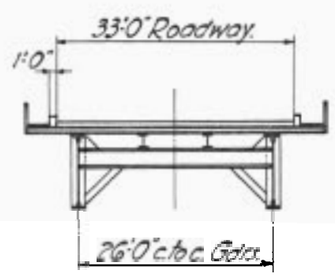
PLAN



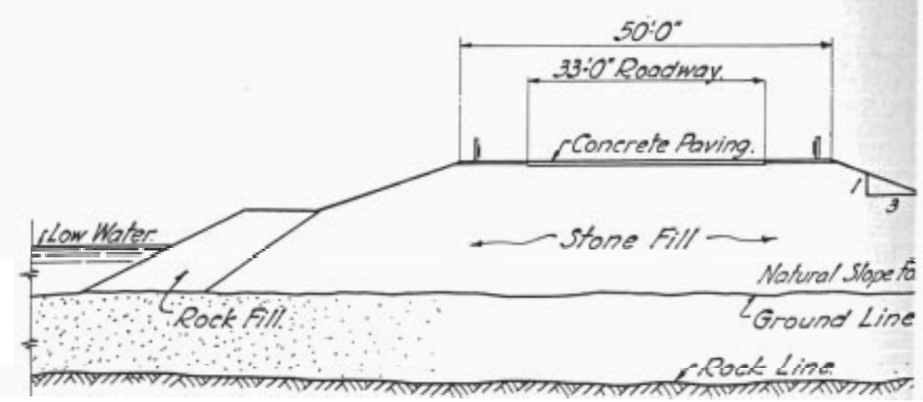




SECTION A-A



SECTION B-B

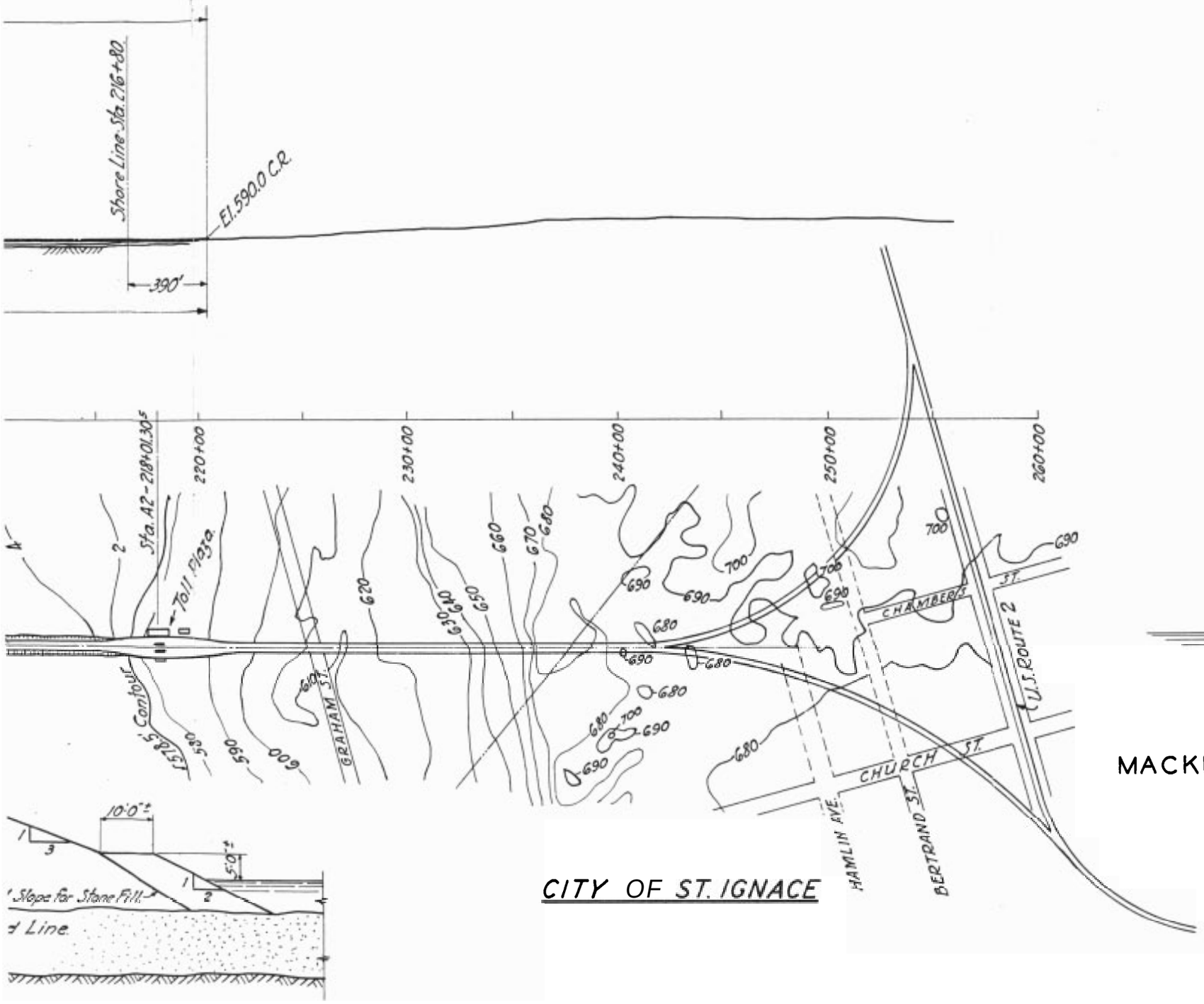


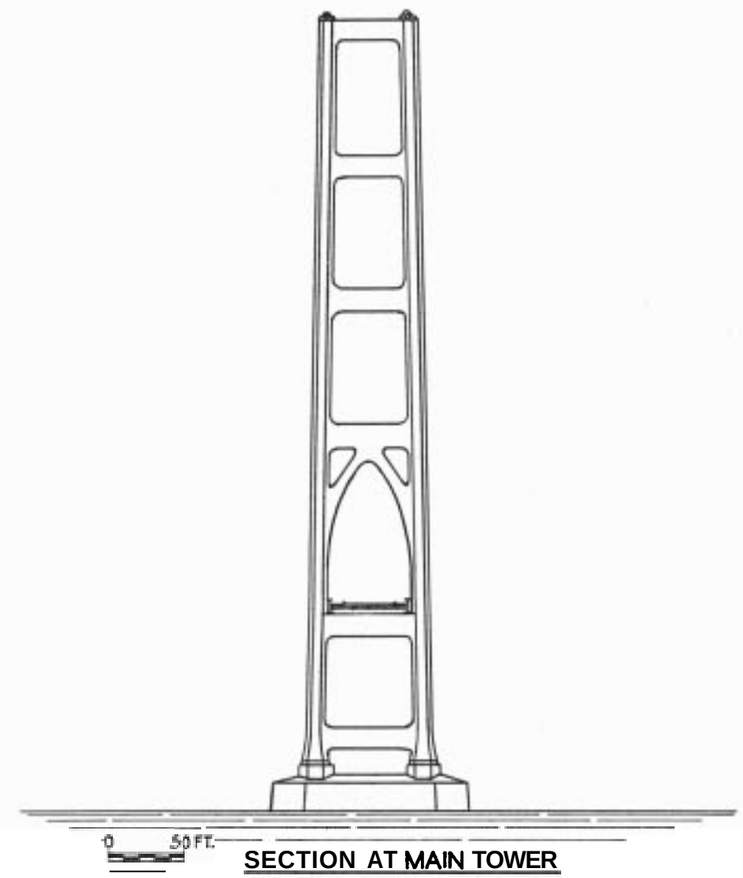
SECTION C-C

10 0 10 20 30 FT.

SCALE FOR SECTIONS

EXHIBIT-"I"





SECTION AT MAIN TOWER

PROPOSED BRIDGE

MACKINAC STRAITS BRIDGE AUTHORITY OF MICHIGAN

GENERAL DRAWING

SCALE IN FEET

0 500 1000

MODJESKI & MASTERS
CONSULTING ENGINEERS

JUNE 1940

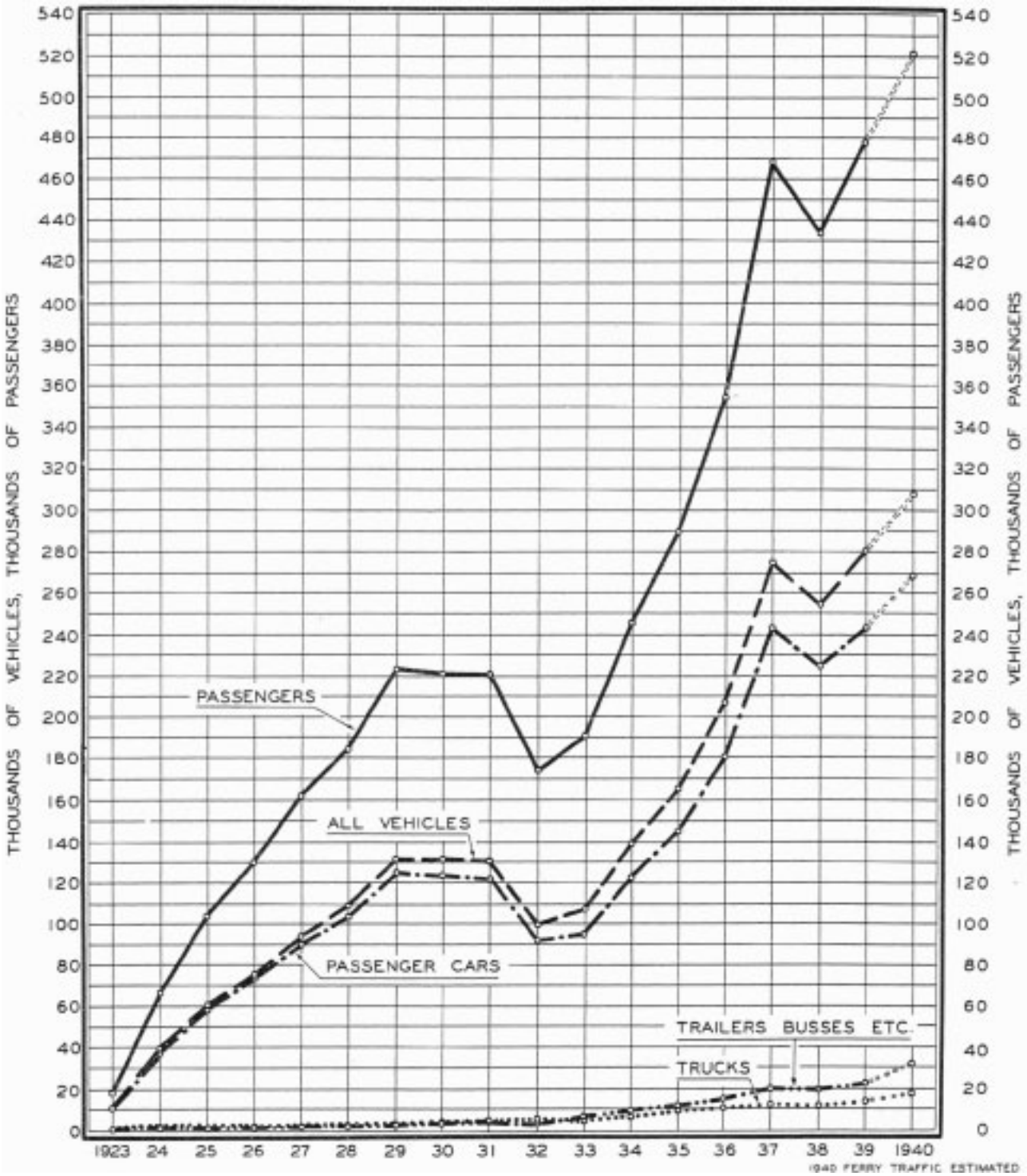
PLATE N0.8

Plate No. 9

ANNUAL VARIATIONS OF VEHICULAR AND
PASSENGER TRAFFIC ACROSS THE STRAITS
OF MACKINAC BY OPERATING SEASONS 1923-40

With the exception of two years, 1932 and 1938, traffic at the Straits has shown a steady increase. The rapid rate of growth of ferry traffic since inception of the system in 1923 is graphically shown in this chart. Interesting to note is the steady growth of truck traffic during recent years which indicates an expanding commerce between the two peninsulas.

ANNUAL VARIATIONS of VEHICULAR and PASSENGER TRAFFIC across the STRAITS of MACKINAC by operating seasons 1923-40



1940 FERRY TRAFFIC ESTIMATED

PLATE NO. 9

Plate No. 10

DAILY VARIATION IN VEHICULAR TRAFFIC
ACROSS THE STRAITS OF MACKINAC IN 1937

A difficult operating problem is graphically protrayed in this chart which shows the heavy seasonal demand upon the state ferry system. In order to meet traffic demands on a comparatively few days during the year, facilities far in exces of average requirements must be maintained. Peak day traffic has totaled as much as 4,000 cars per day while minimum-day traffic is often as low as 40 or 50 cars.

DAILY VARIATION in VEHICULAR TRAFFIC ACROSS the STRAITS of MACKINAC in 1937

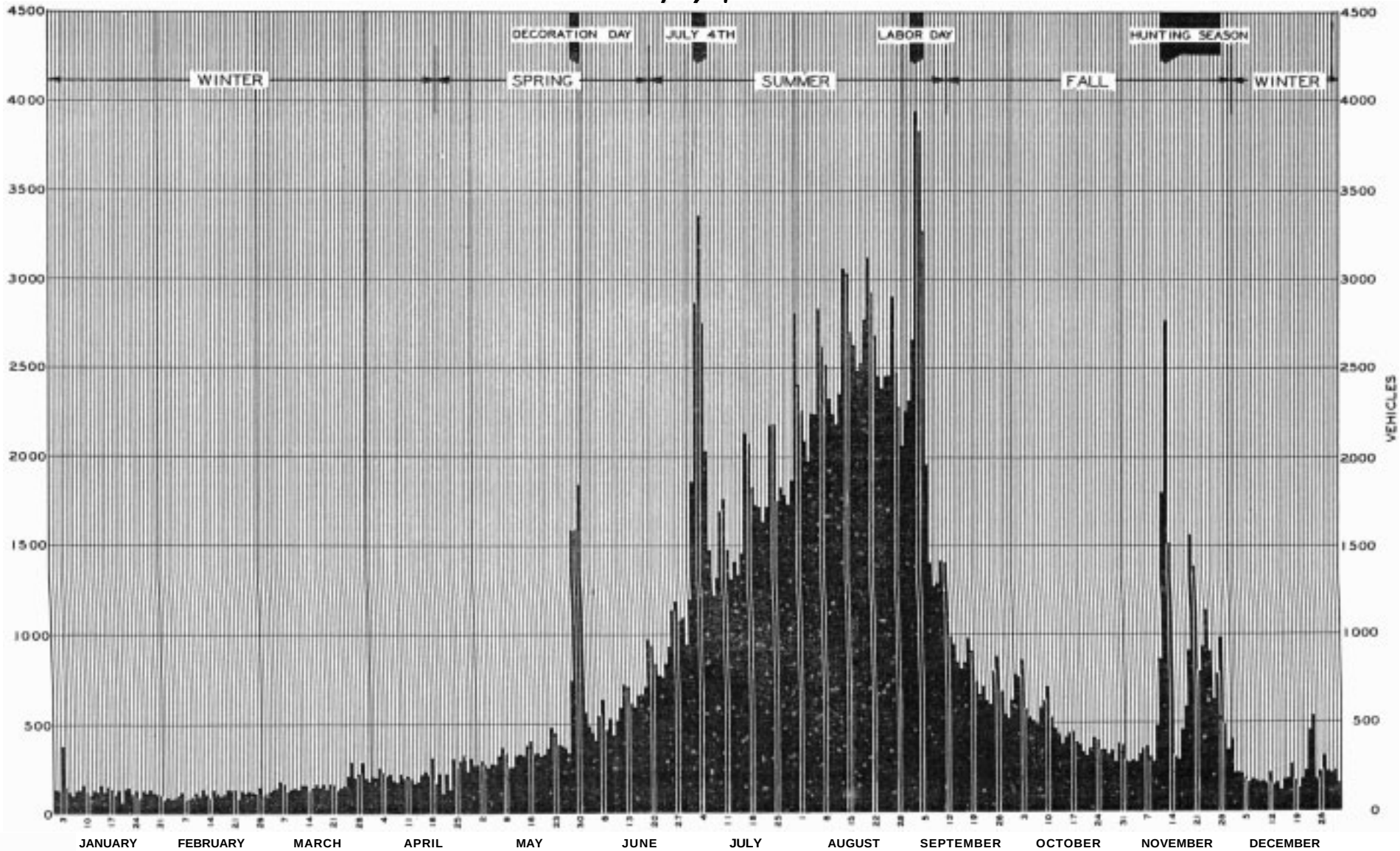


PLATE NO. 10

Plate No. 11

CONTRIBUTIONS OF COUNTRIES AND STATES
OTHER THAN MICHIGAN TO MACKINAC STRAITS
FERRY TRAFFIC IN 1937

The wide radius of origin and destination of traffic at the Straits is reflected in this illustration which shows contributions from every state in the union as well as Canada, Mexico and several foreign countries. The information contained in this map was gathered from samplings taken during 1939 and applied to the typical year, 1937.

MICHIGAN
STATE HIGHWAY DEPARTMENT
MURRAY D. VAN WAGONER
STATE HIGHWAY COMMISSIONER

HIGHWAY PLANNING SURVEY
CONDUCTED IN COOPERATION WITH
FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

CONTRIBUTIONS of COUNTRIES and STATES OTHER THAN MICHIGAN to MACKINAC STRAITS FERRY TRAFFIC in **1937**

CONTRIBUTIONS OF THE COUNTIES OF MICHIGAN
TO MACKINAC STRAITS FERRY TRAFFIC IN 1937

Like the previous plate, this map emphasizes the universal use which is made of the ferry system. Especially significant is the contribution of Wayne county from which 57,890 cars came to the Straits during the year. Equally significant is the comparatively small traffic contribution made by counties in the upper peninsula and those in the northern part of the lower peninsula.

MICHIGAN
STATE HIGHWAY DEPARTMENT
MURRAY D. VAN WAGONER
STATE HIGHWAY COMMISSIONER

HIGHWAY PLANNING SURVEY
CONDUCTED IN COOPERATION WITH
FEDERAL WORKS AGENCY
PUBLIC ROADS ADMINISTRATION

CONTRIBUTIONS of the COUNTIES of MICHIGAN to MACKINAC STRAITS FERRY TRAFFIC IN 1937

PLATE NO 12

FAST AND FUTURE TRENDS OF TRAFFIC VOLUME ACROSS THE STRAITS OF MACKINAC COMPARED WITH AUTOMOBILE TRAFFIC IN MICHIGAN IN PERCENTAGES OF 1936 VALUES

The steadily rising trend of traffic across the Straits is compared here with the trend of state-wide automobile traffic. In 1939 and, based upon estimates, in 1940 the actual ferry traffic is far in excess of the trend indicated on the chart. The increment expected following construction of a bridge at the Straits has been computed from figures based on experience of comparable structures at a number of locations.

PAST and FUTURE TRENDS of TRAFFIC VOLUME ACROSS the STRAITS of MACKINAC COMPARED with AUTOMOBILE TRAFFIC in MICHIGAN in PERCENTAGES of 1936 VALUES

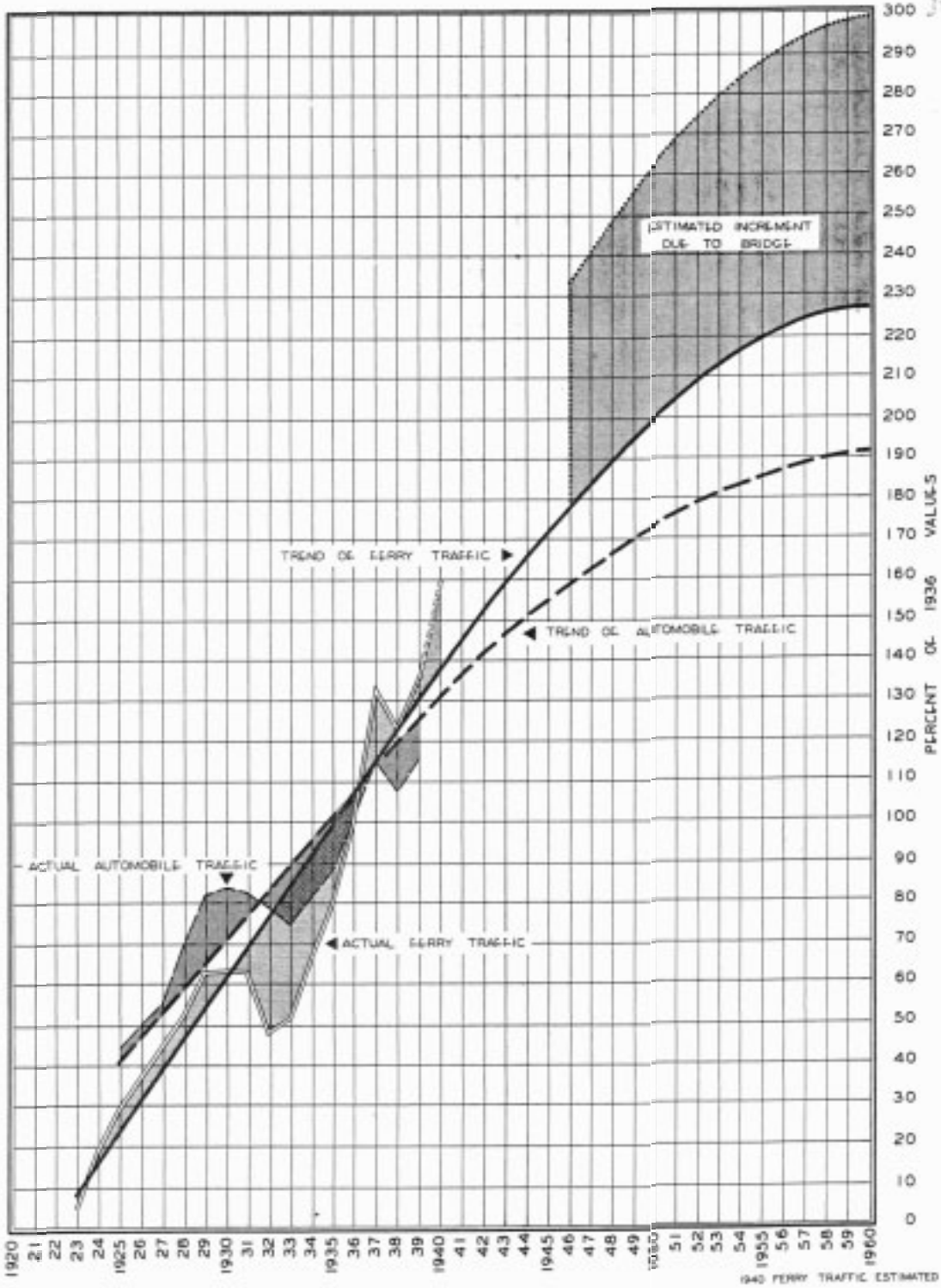


PLATE NO. 13

A COMPARISON OF VEHICULAR TRAFFIC ACROSS THE STRAITS OF MACKINAC TO THE CUMULATIVE CAPITAL INVESTMENT OF THE STATE FERRY SYSTEM

The amount of capital investment necessary to meet the demands of traffic across the Straits has increased steadily since 1923 to a total slightly less than three million dollars. This expansion has closely paralleled the volume of traffic as shown by the two curves in this chart. It may be noted that approximately ten dollars of capital investment is necessary to transport each car across the Straits.

A COMPARISON of VEHICULAR TRAFFIC across the STRAITS of MACKINAC to the CUMULATIVE CAPITAL INVESTMENT of the STATE FERRY SYSTEM

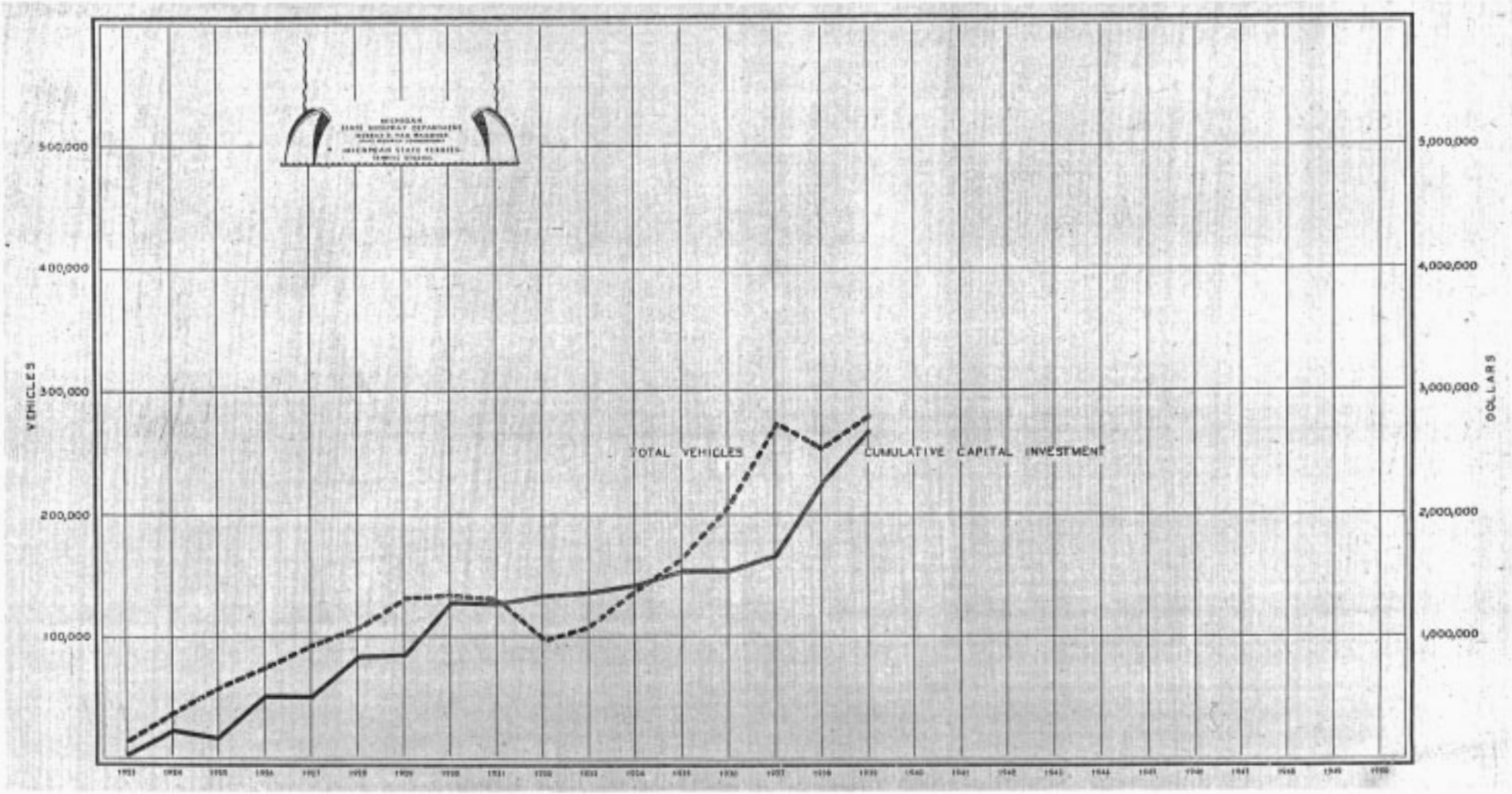
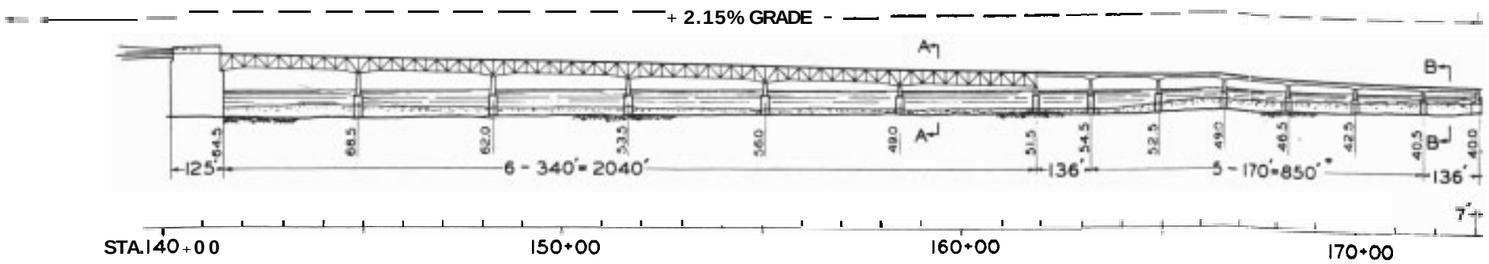


PLATE NO. 14

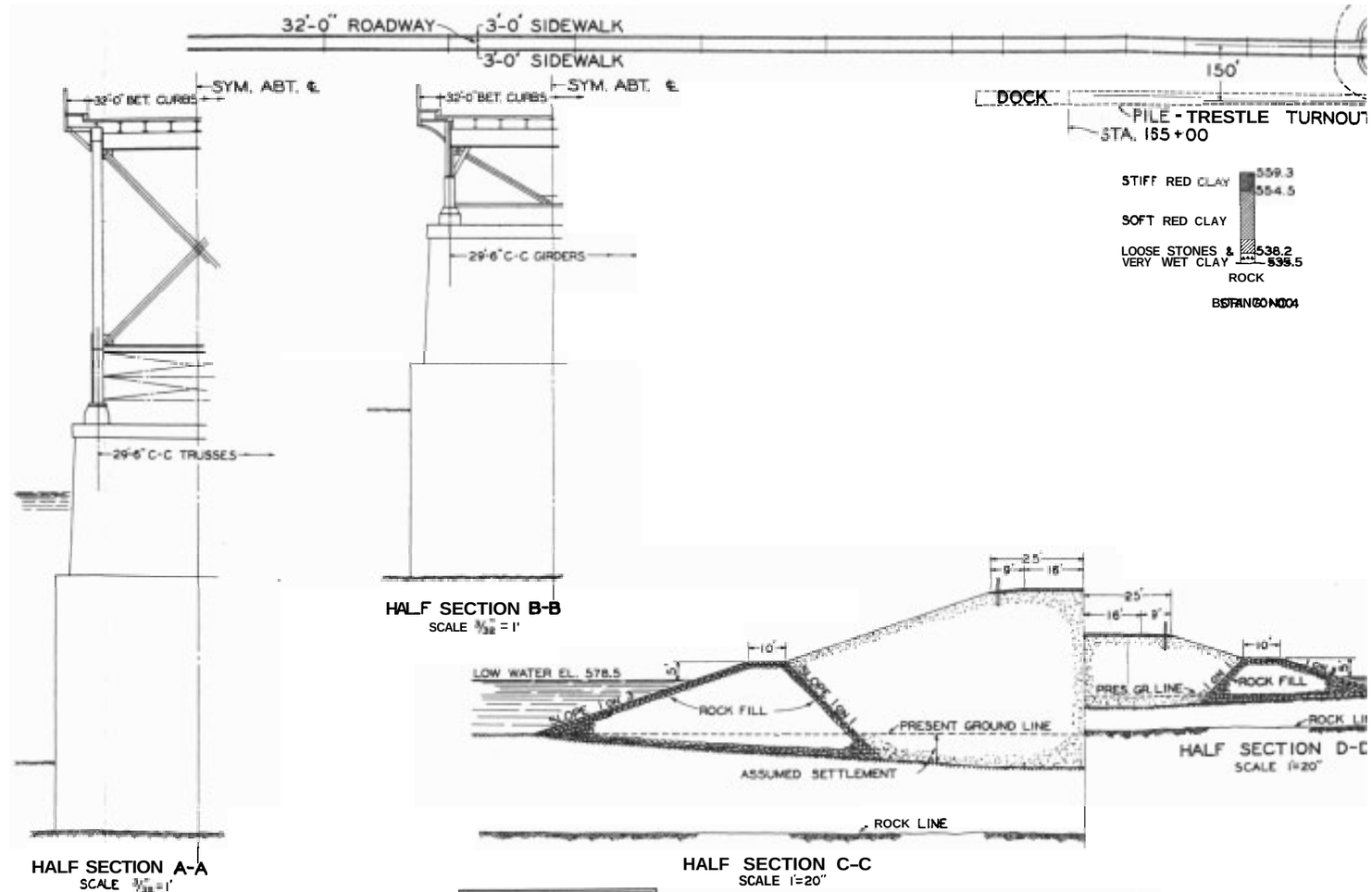
Plate No. 15

TENTATIVE PLAN FOR ST. IGNACE
APPROACH TO THE BRIDGE

Here, in detail, is the tentative plan and elevation for the St. Ignace approach to the bridge which would be used as the St. Ignace terminus of the ferry system until construction of the bridge is completed. This filled causeway would become a part of the bridge, serving as the north approach, following its completion.



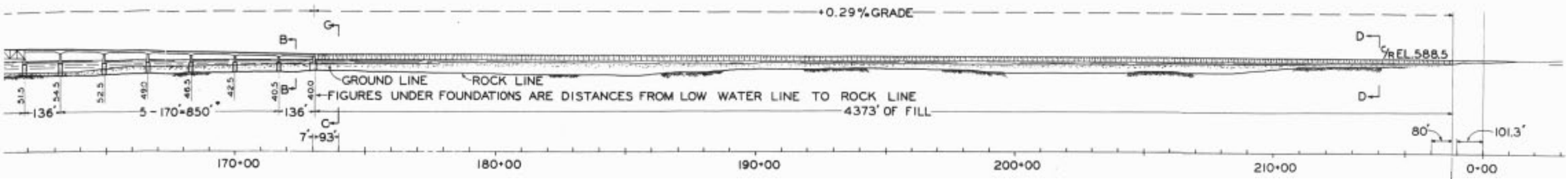
ELEVA



The MACKINAC STRAITS BRIDGE AUTHORITY of MICHIGAN

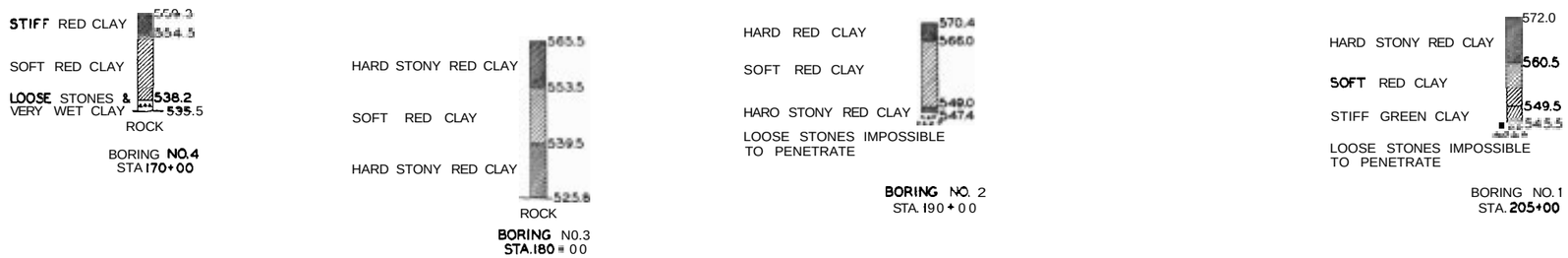
MODJESKI & MASTERS CONSULTING ENGINEERS

TENTATIVE PLA

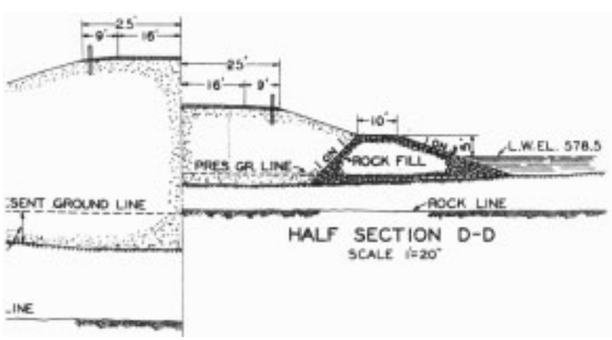


ELEVATION

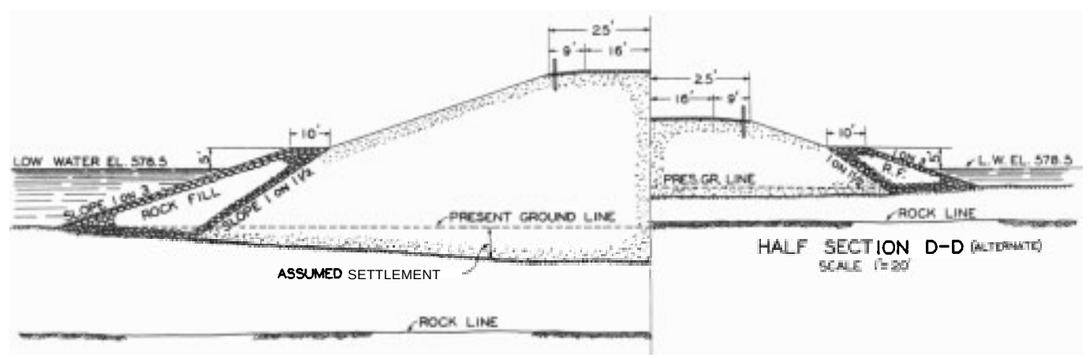
PLAN



BORING LOGS
SCALE 1"=20'



HALF SECTION D-D
SCALE 1"=20'



HALF SECTION C-C (ALTERNATE)
SCALE 1"=20'

HALF SECTION D-D (ALTERNATE)
SCALE 1"=20'

TATIVE PLAN FOR ST. IGNACE APPROACH TO THE BRIDGE

PLATE NO. 15

State of Michigan
Mackinac Bridge Authority

REPORT ON
PROPOSED MACKINAC STRAITS BRIDGE

BOARD OF ENGINEERS

O. H. Ammann
D. B. Steinman
G. B. Woodruff

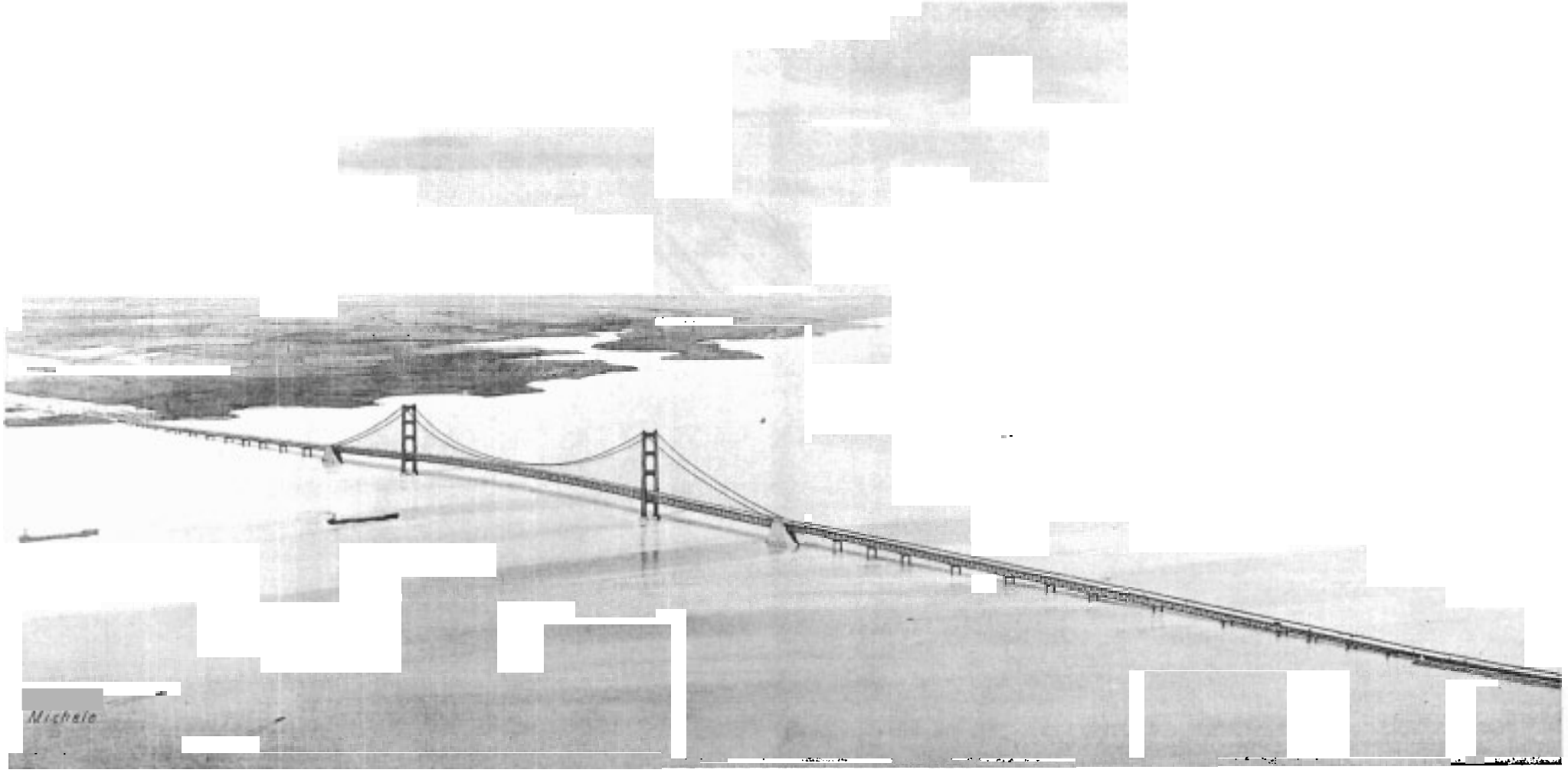
TRAFFIC CONSULTANTS

Coverdale & Colpitts

CONSULTING GEOLOGISTS

Charles P. Berkey
Sidney Paige

January 10, 1951


Michele

January 10, 1951

Mackinac Bridge Authority
Mr. Prentiss M. Brown, Chairman
Lansing, Michigan

Gentlemen:

In accordance with our assignment we present herewith a report describing our investigation of the feasibility of constructing a bridge across the Mackinac Straits, and including preliminary design plans, estimates of cost of construction, operation and maintenance and a summary of our conclusions.

This report is a summary of our more detailed investigations. Our supporting studies are submitted under separate cover.

Respectfully submitted,

O. H. Ammann
D. B. Steinman
Glenn B. Woodruff

O. H. Ammann
D. B. Steinman
Glenn B. Woodruff

Board of Engineers

INTRODUCTION

The straits of Mackinac divide the State of Michigan into the upper and lower peninsulas. The desirability of uniting these areas by a bridge or tunnel has long been apparent. In 1920 the late Horatio S. Earle, highway commissioner, suggested a submerged floating tunnel and invited discussion of its feasibility and advantages. A counter-proposal was made by Mr. C. E. Fovler, who suggested a series of causeways and bridges starting at a point near Cheboygan and proceeding via Bois Blanc Island, Round Island, and Mackinac Island to St. Ignace. In 1923 in response to the growing demand for better facilities the State inaugurated a highway ferry service.

In 1928 after some limited studies, the highway department concluded that it was feasible to build, for about $30,000,000, a highway bridge directly across the Straits from Mackinaw City to St. Ignace. Although negotiations were undertaken and partially completed for the financing of such a bridge, the project was dropped.

Early in 1934, the state legislature created the Mackinac Straits Bridge Authority of Michigan and empowered it to investigate the feasibility of constructing a bridge to connect the peninsulas and to issue and sell the necessary revenue bonds and fix and collect the necessary tolls. In April 1934, Governor Comstock appointed Messrs. S. T. Stackpole, Otto W. Lang, and Patrick H. Kane as members of the Authority.

The Authority engaged Mr. Fowler as temporary chief engineer. The plan developed by Mr. Fowler followed closely the one proposed by him in 1920. In August 1934 the plan was submitted to the Public Works Administration with a request for a loan of 70 per cent and a grant of 30 per cent of the estimated cost of the project. This application was formally disapproved by PWA on July 18, 1935.

In the meantime many objections to the proposed route had been brought to the attention of the Authority. As a result, the Authority continued its studies and ultimately reached the conclusion that a direct crossing was both feasible and preferable. Mr. Francis C. McMath was engaged to prepare such data on a direct crossing as would be necessary for a new application to PWA. Mr. James E. Cissel served as consulting engineer. A new application was submitted to PWA on September 7, 1935.

On December 23, 1935, following a request by President Roosevelt, the Chief of Engineers U. S. Army, reported on the proposed bridge i formally as foll s: The construction of the bridge on the direct line appears to be entirely feasible; it will unquestionably be of great public convenience in facilitating communication between the peninsulas; and there is a reasonable possibility that the revenue from tolls will meet the carrying charges of the loan requested. However, PWA disapproved the latest application on September 18, 1935.

In 1938, the Mackinac Straits Bridge Authority engaged Modjeski and Masters, with Leon S. Moisseiff as an associate, to make a further investigation of the project. These engineers submitted their report to the Authority on June 3, 1940 recommending the construction of a bridge "extending almost due north across the Straits from the point at which highway routes U. S. 31 and U. S. 23 converge on the south shore."

This report was submitted by the Bridge Authority to the Governor and the State Highway Commissioner on June 25, 1940. Before further steps could be taken World War II started.

The present Mackinac Bridge Authority was created by Enrolled House Bill No. 24, Extra Session of 1950 of the 65th Legislature of the State of Michigan. Section 4 of this bill provided, "The Authority shall employ three consulting engineers to be recommended by the dean of the college of engineering of the University of Michigan, who shall constitute a board of consulting engineers and

who shall determine whether a bridge can be safely and feasibly constructed across the Straits of Mackinac and the probable cost thereof."

The Authority invited the three engineers who were recommended by the dean to meet with them at the site on July 12, 1950. The investigations described herein were started on that date.

The combination of deep channels, exceptional rock formations, severe ice conditions and winds present unusual engineering problems. The extreme peaking of traffic compared to the average volume required careful consideration in establishing the capacity of the bridge.

The work of the Board of Engineers included a review of previous investigations, study of the conditions at the site - geology, currents, wind and ice formations and their effect on the structure - alternate design studies and cost estimates to determine the most appropriate type and arrangement of structure and the preparation of plans in sufficient detail to permit an adequate estimate of the required quantities and the cost of construction.

On recommendation of the board of consulting engineers the Authority also engaged the firm of Coverdale and Colpitts to undertake a traffic analysis and assist in the economic study. In view of the important and controversial question of the suitability of the rock formations under the Straits to carry the bridge foundations the Authority further engaged the advisory services of Dr. Charles P. Berkey and Dr. Sidney Paige, two of the most outstanding engineering geologists.

CONDITIONS AT THE SITE

The Straits of Mackinac are a comparatively narrow body of water joining Lakes Michigan and Huron. They also divide the State of Michigan into Upper Peninsula with its resources of minerals and the Lower Peninsula which, with Detroit as its major city, is rapidly becoming highly industrialized. The Upper

Peninsula is also noted as recreation area. The Straits and the crossing of St. Mary's River at Sault Ste. Marie form a gateway into the Province of Ontario which also provides a vast recreation area.

Geology

With its unusual brecciated formation, the geology of the area has, for over 100 years, attracted the attention of the geologist. With the agitation for a crossing of the Straits, the geology was exhaustively studied by professors Kenneth K. Landes, George M. Ehlers and George M. Stanley, under the direction of State Geologist R. A. Smith. Two features are pertinent to the planning of the bridge--the breccia formation and the hidden rock gorge. The breccia formation has been fully described by Messrs. Landes, Ehlers and Stanley. We have discussed the matter with Professors Ehlers, Landes and W. S. Housel, and with State Geologist G. E. Eddy and Mining Engineer F. G. Pardee of the State Department of Conservation, The report of Professors Berkey and Paige has been submitted to the Authority under separate cover. In addition, the Authority requested Mr. W. W. McLaughlin, Director of Testing and Research of the State Highway Department, and Professor Housel to make compression tests on samples of the material and also to make "in-place" loading tests. The borings and probings at the site in 1939 are reproduced on Plate 5.

As a result of the above data, with the sole qualification that further core borings at the site of the main piers and anchorages are a prerequisite to the final design of such construction, we have no doubt that the rock strata underlying the Straits along the recommended location are entirely capable of withstanding the moderate pressures assumed in the design.

A second geological feature of importance to the construction of the bridge is the hidden rock gorge underlying the channel between Mackinac City and St. Ignace. (Plate 1) East of the proposed crossing the gorge veers north,

makes a loop around Mackinac Island and enters Lake Huron. This gorge was eroded through the breccia at a time when the level of Lake Huron was much lower than at present. The 1939 subaqueous. explorations did not extend to depths greater than were necessary to locate the rock bed of the gorge.

currents

The average volume of water flowing through the Straits is so small that currents produced by this volume are negligible. The maximum currents result from two causes; seiches or oscillations of the lake caused by passing changes in air pressure or barometric waves or from protracted wind in any given direction.

The results of certain observations made in 1939, gave a maximum of 1.97 mph. Higher velocities may be anticipated. It is certain that no current velocities such as those experienced in the construction of the Trans-Bay, Golden Gate and Tacoma Narrows Bridges are probable and that the difficulties, from this cause, of pier construction or of lifting sections of the suspended spans from barges will be less than those experienced in the case of the bridges above listed.

Ice

A very complete report of the ice conditions at the Straits has been made by Mr. W. O. Fremont of the State Highway Department. Mr. Fremont carried his investigations to an appraisal of the forces from the ice. These observations have been supplemented by those of State Highway Commissioner Charles M. Ziegler.

We have carefully considered the data and have further investigated information on ice pressure on engineering structures. As a result of these investigations we have adopted the very severe assumptions of an ice pressure of 230,000 pounds (half of this amount for circular surfaces) per lineal foot

of pier width at the water line. The resulting forces are considerably greater than those generally assumed for engineering structures under comparable climatic conditions. We are confident that these forces are in excess of those to which the piers will ever be subjected.

Wind

The Straits of Mackinac are north of the "tornado belt" but are subjected to comparatively heavy wind. The highest recorded velocity at the site was 78 mph on November 11, 1940.

BRIDGE LOCATION

We have considered the locations shown on Plate 1 which are designated as the Fowler, Cissel and Masters locations. Neither Mr. Fowler nor Mr. Cissel had any information as to the depths to rock at the center of the "hidden gorge" With the information now available it is certain that the cost of a bridge at either of the Fowler or Cissel locations would be much greater than at the location herein recommended. Our conclusions in this respect may be summarized as follows:

1. The construction of a bridge on the recommended location is entirely feasible.

2. The recommended location fits the existing State Highway System better than any other.

3. It is possible, though not probable, that a very extensive subaqueous investigation might develop a site that would permit a slight reduction in the cost of construction. In view of the existing mole which will serve to protect the piers of the short spans at the north end of the bridge against ice, the chances of finding a more economical location are so remote that the cost of the investigation is not warranted.

vestigation it was apparent that the
feasible only by keeping the cost of con-
stent with adequate capacity, safety of
and structural details conducive to economical
and it was recognized that reasonable allowance
eds of the future.

gsis it appears probable that, immediately
e to traffic, northbound traffic may be as high
. Within the following 50 yeaxs it is possible
ripled. During the northbound peak southbound
half this volume.

provided with moveable traffic barriers or changeable traffic lights, so that the bridge could be operated with two lanes in one direction and a single lane in the opposite direction might meet these requirements except for interruptions caused by accidents or car stoppages. These interferences with smooth flow of traffic do occur, however, and may be serious enough during peak traffic to throw the operation into confusion. This is of particular importance on a bridge of such great length.

For this reason we recommend that a capacity of not less than four lanes, two in each direction, be provided. However, in accordance with instructions, we have also prepared a cost estimate for a three-lane bridge.

Consideration has been given to provision of a traffic barrier along the center line between the two roadways to avoid possible head-on Collisions by vehicles getting off the inner lanes. Modern practice with respect to the character of traffic barriers varies greatly. On some large bridges high malls have been installed preventing any crossing by vehicles. On others low curbs, raised traffic markers or even only lines

painted on the pavement are used which permit the crossing of vehicles when necessary under proper control.

Barriers of the low type, not over two feet wide, have been assumed for the Mackinac Straits Bridge for the following reasons. While it is not recommended that direction of traffic in any lane be regularly reversed, it is highly desirable, especially on a long bridge with only two lanes in each direction wide, that in the case of emergencies for vehicles to be detoured across the barrier at any point under police control and to permit more direct access by tow cars to vehicles requiring their services.

A low well marked barrier will also induce vehicles to stay closer to it than to a high mall thus justifying a somewhat narrower traffic lane next to it.

These considerations, as well as reasons of economy, have led to an overall width of roadway between curbs of 48 feet, of which not more than two feet would be occupied by the center barrier, 12 feet by each outer lane and not less than 11 feet by each inner lane

These lane widths compare favorably with those of other modern long bridges and tunnels.

No provision is considered necessary on this four mile long bridge for regular pedestrian traffic. However, footwalks on each side are essential for maintenance and operating personnel and only in emergency cases for occupants of vehicles. A width of three feet between curb and railing has been assumed for each of these two footwalks. Substantial railings are provided on the outside of the footwalks The overall width of the floor between railings is 54 feet.

Design Specifications

The specifications for materials, loads and permissible stresses which have been used as a basis for the design of the Mackinac Straits Bridge follow general practice for modern structures of this type and magnitude.

For the floor structure throughout and for the shorter main girders and trusses the current specifications of the American Association of State Highway Officials have been followed, with the basic loading of H20-S16-44 as generally applied to the design of bridges on major highways.

The latter specifications are intended to apply to bridges of ordinary type and modern spans. For the design of the stiffening trusses, cables, towers and anchorages of the suspension bridge and for the long trusses of the other spans of the main crossing, special load and stress specifications were adopted in accordance with best modern practice for structures of such magnitude.

For the four-lane bridge design a live load of 2000 lbs. per lin ft. of bridge has been adopted, representating a continuous line of heavy trucks about 50 ft. apart on each of the four lanes, a load which will probably never be obtained under actual conditions. For ordinary heavy traffic the average load will probably be less than one third of that load.

For the three-lane design the relatively somewhat larger load of 1800 lbs. per ft. has been assumed.

On account of the possibility of high winds of considerable extent and the exposed location of the bridge a static wind pressure of 50 lbs. per square foot of exposed area was assumed over the entire structure. This corresponds to a wind velocity of about 120 miles per hour as compared with the maximum recorded velocity of 78 mph observed in that vicinity.

Type of Structure and Span Arrangements

Fairly extensive borings at the proposed bridge location in connection with the report of Modjeski & Masters in 1940 made it possible to determine the most appropriate type of structure and span arrangement. Time and available funds for the present study did not permit the making of supplementary borings to explore to a greater extent the slopes of the hidden rock gorge under the main channel. However, it may be reasonably concluded from the information available that any piers located closer to the gorge than now proposed would probably become excessively deep and expensive to justify a shorter span across the gorge.

As proposed that span has a length of 3,800 feet between centers of piers. The outstandingly appropriate type of structure for a span of that length is a suspension bridge. The side spans from main piers to the anchorages were given a length of 1,500 feet, which under the given conditions is in the most appropriate ratio to the center span.

A number of alternate layouts made for the remainder of the crossing over the waterway between the south shore and the end of

the mole at the north shore led to a series of truss spans on concrete piers as the best solution. Twenty-two spans over the deeper portions of the waterway are of unusual length for a structur of this character, ranging from 560 feet to 302 feet. Four spans near each shore have spans of 160 to 200 feet. The comparatively long spans are economically necessitated because of the deep and expensive piers, which have to be designed to withstand the heavy ice pressures.

Along the mole in the St. Ignace side it was found appropriate to carry the roadway on a viaduct with short spans resting on pile fo Patio s driven through the existing bankment

Grades, Clearances and Lengths

From the end of the mole and the Mackinac City shore the bridge roadway ascends by easy grades, not exceeding 2.5 per cent, to the towers of the main bridge. Over the center span of the latter the roadway is cambered by a parabolic curve.

These grades allow a minimum clear height above mean lake level of 135 feet for a width over 3,000 feet of the main channel. The minimum clear height at the center of the span is 150 feet

The clearances under the approach viaducts range from 84 feet near the anchorages of the main bridge to a minimum of 20 feet near the south shore or the end of the mole respectively.

These clearances are believed to meet fully the requirements of navigation. They are subject, however, to the approval of the Department of the Army after a public hearing

Upon an informal inquiry sent to Lt. Colonel John D. Brister,

District Engineer of the Corps of Engineers for the Detroit District, by Mr. Fred M. Zeder, Chairman of the Engineering Committee of the Mackinac Bridge Authority, Col. Brister answered with the statement that "it appears that the indicated horizontal and vertical clearances would be generally adequate for navigation, however, this opinion must be considered an informal expression not binding in any way on the Department of the Army."

The total length of the proposed bridge and 'approaches is five miles, made up as follows:

Main Crossing		
Suspension Bridge, including Anchorages,	7,120 ft.	
South Truss Spans	6,412	
North Truss Spans	4,392	
		17,924 ft.
Approaches		
Mole Viaduct	3,420	
Mackinac City Approach	563	
St. Ignace Approach	4,278	
		8,261
Total length - Bridge and Approaches		26,185 ft.

Floor Construction

One of the controlling factors in the economical design of long span bridges is the weight of the roadway floor. Heavy concrete slabs such as are extensively and appropriately used on shorter bridges become too costly on long spans. In the case of the Mackinac Straits Bridge, in particular, it appeared essential to reduce the weight of that structural element as far as consider-

ations of usefulness and economy of maintenance would permit.

A number of different types of light flooring were considered. In the outer lanes preference was given to a solid flooring consisting of a steelgrid filled with a lightweight concrete and topped, either initially or later, with a layer of bituminous concrete. During most of the time traffic will be confined to this lane.

For the inner lanes, which will be used mainly during the exceptional peak hours, an open-grating floor is proposed. It is the lightest type commercially available at present and has for this reason been used on a number of long-span and moveable bridges on which saving in dead weight in the floor is of importance. Its weight is about one third of that of the solid flooring proposed for the outer lanes.

It is recognized that this open grating flooring has certain disadvantages, such as the somewhat annoying effect of a distinct "hum" from tires passing over the grating and the probability that on the Mackinac Straits Bridge a considerable amount of sanding or spraying with salt will be necessary during the winter season, when the surface may become coated with ice. However, these objections are not considered to be of sufficient importance to outweigh the possible saving in cost due to the lightness of the flooring.

Superstructure of Suspension Bridge

With a central span of 3,800 feet the suspension bridge across the north channel will be second only in length to the Golden Gate Bridge in San Francisco, which has a span of 4,200 feet.

In its major carrying members, the cables, towers and anchorages, the design of the Mackinac Straits Bridge follows closely the practice established by other modern long-span suspension bridges.

For the four-lane capacity each of the two cables is to be composed of 37 strands, each strand containing 398 wires of 0.192 inch diameter before galvanizing. The finished cables will be 25.6 inches in diameter. A cable sag of 350 feet, or about one eleventh of the center span, is somewhat less than in some other suspension bridges, but is conducive to gracefulness and greater stiffness of the structure.

The steel towers are of the slender flexible type with fixed base. The tower shafts are of cellular construction, with access for the cleaning and painting of all interior surfaces. They reach to a height of about 565 feet above mean lake level. Service elevators are proposed in the towers for more convenient access to all parts.

The two shafts of each tower are connected by horizontal struts, which are also of closed cellular construction. The shafts and struts form integral parts of a rigid frame designed to transmit the large lateral wind forces to the piers.

The anchorages above foundations are conceived as huge concrete blocks to resist the pull of the cables and transmit the same to the foundations. However, through proper distribution of the mass of concrete and by hollowing out as far as practicable, the weight of the anchorage block is reduced to a minimum so as to lighten the load on the deep foundations as far as possible.

The suspenders which transmit the load of the suspended structure to the cables are standard steelwire ropes. For the four-lane bridge each suspender is composed of four ropes of 1 3/4 inch diameter.

The suspended structure includes two stiffening trusses, one in the plane of each cable. They transmit the floor loads to the suspenders and stiffen the structure against excessive distortions and possible oscillations under the action of dynamic loads and wind forces.

The question of adequate resistance against aerodynamic action has received intensive attention on the part of the engineering profession since the failure of the original Tacoma Narrows Bridge in 1940 both in this country and in England and has been given prominent consideration in connection with the design of the Mackinac Straits Bridge.

This is reflected in several features of the proposed design which differ from those of some of the large suspension bridges built in the past, namely:

1. The stiffening trusses have been given a depth of 45 feet or about 1/85 of the length of the center span. The above ratio is the same as that of the recently completed new Tacoma Narrows Bridge of 2,800 feet span, which under winds of up to 60 miles per hour has not developed any noticeable oscillations. A corresponding ratio of 1/100 has been adopted, after extensive research, for the 3,600 ft. span of the proposed Severn River Bridge in England.

2. The traverse floor-beams which carry the floor and longitudinal stringers and transmit their load to the stiffening trusses are designed as open trusses in place of solid-web girders, so as to minimize wind pressure against them.

3. Double lateral trusses, one in the plane of the top chords and one in the plane of the bottom chords of the stiffening trusses, are provided. This increases very substantially the torsional rigidity of the suspended structure as compared to that provided by a single system which has been used in a number of large suspension bridges.

4. The relatively narrow floor structure and the fact that the supporting stiffening trusses and cables are located considerably beyond the floor with open spaces between render the section of the suspended structure aerodynamically more favorable than if, as in other bridges, the floor would extend the full width between trusses.

5. The tests made in connection with the redesign of the Tacoma Narrows Bridge and for the design of the Severn Bridge demonstrate the beneficial effects of openings in the floor structure. It is quite possible that the openings need not be as extensive as those proposed in our design.

We have arranged with Professor F. J. Maher for tests on a model of the proposed cross section in the wind tunnel of the Virginia Polytechnic Institute. The results of these tests have reinforced our conclusion that the suspension spans as proposed will be aerodynamically stable and safe against any dangerous or objectionable motions under wind action.

To facilitate access for, and thereby decrease the cost of maintenance of the suspended structure travelling platforms carried on tracks suspended from the floorbeams are proposed for all spans.

Superstructure of Truss Spans

Because of the great depth to rock of 170 ft. in the secondary gorge near the Mackinaw City side of the crossing, the layout recommended by Modjeski and Masters in their 1940 report, and some of the layouts studied by us included a secondary suspension bridge.

The secondary suspension bridge, however, was found to offer no economy compared to the design we now propose. Moreover, the secondary suspension bridge had the effect of detracting from the general composition and impressiveness of the bridge. Accordingly, we propose to cross the secondary gorge with continuous truss spans ranging up to 560 ft. in length. These spans are balanced by similar, though shorter, spans north of the suspension bridge where the depth to rock nowhere exceeds 60 ft.

The floor adopted for the truss spans throughout their length of almost two miles is the same as that used on the suspension spans. The center lanes of open grating flanked on each side by a lane of grating filled with light weight concrete and an open grating emergency walkway, all supported on cross beams and continuous stringers yield a light roadway and floor system resulting in maximum economy in the supporting trusses. To keep the size of the foundations to a minimum and to effect maximum economy in the floorbeams, the trusses are set 34 ft. apart and the floorbeams are cantilevered to reduce their required section.

Analysis and comparative estimates indicated that fairly long spans would be advantageous from the viewpoint of economy and decrease in hazard involved in the construction of piers to the depths required, particularly for the spans south of the main suspension spans. To reduce the number of expansion joints and at the same time to obtain simplicity and economy of detail and erection and minimum cost, the four-span continuous type of construction was adopted for the truss spans.

Maintenance travellers are proposed which can pass under the floors of all spans between the anchorages and the approaches.

Foundations

The recommended layout of the bridge involves 32 subaqueous piers Of these the largest are the two anchorages and the two main piers of the suspension spans. The six piers at the secondary gorge with depths from 100 to 170 ft., may also be considered major piers.

As a result of the investigations of the underlying rock and of the ice conditions, the substructure has been designed for the live and wind loads outlined above and for the forces arising from the severe assumption of ice four feet thick with a crushing strength of 400 pounds per square inch. The very conservative bearing pressures of 15 tons per sq. ft. for live and dead load, increased to 25 tons for combinations including wind and ice, have been adopted for the design.

In order to prepare reliable cost estimates, complete designs of all piers have been made on the basis of assumed construction methods. Open dredge caissons have been assumed for the major piers and cofferdams for the remainder of the foundations. The cofferdam for the south anchorage, 115 ft. by 180 ft. in plan and extending 140 ft. below lake level, involves a continuous seal pour of 90,000 cu. yds., eclipsing, by far, all past records.

Approaches

The approaches are naturally divided into three sections: the construction over the 3500 ft. rock faced mole constructed in 1940, the Mackinac City Approach and the St. Ignace Approach.

The rock-faced mole at the north of the Straits was built with the thought that it would be used temporarily as a ferry terminal at its south end and later to carry an earth embankment to support the bridge approach. To protect the roadway from excessive spray from waves breaking on the rock face of the mole, it has been considered advisable to place the roadway surface at a minimum of 30 ft. above lake level. The mole is too narrow to accommodate a four-lane roadway at this level with the necessary side slopes of the embankments. Moreover, tests made on the underlying clays by the State Highway Division indicate the probability of a lateral flow of these clays leading to the failure of the mole if a fill were placed to such height.

Faced with these conditions and after investigating alternate types of construction, we have concluded that the most suitable construction is a series of 29 continuous plate girder spans supporting a reinforced concrete roadway with provision for a future wearing surface of asphaltic concrete.

These girders will be supported by reinforced concrete piers which, in turn, will be supported by concrete piles driven to rock. In this connection, the question arises as to the practicability of driving piles through the rock. During the construction of the fill efforts were made to place the larger rocks at the edge of the fill. This matter has been discussed with representatives of the Highway Department who witnessed the fill construction. The consensus is that, while some difficulties may be experienced, they will not be serious.

For the Mackinac City approach the alternates of filled retaining walls, concrete rigid frames and steel girders with a concrete paving on con-

crete piers have been considered. The last has been found the most economical and is therefore recommended. The roadway on this approach will be widened to three lanes in each direction, thereby forming a traffic reservoir in order that the capacity of the bridge will not be controlled by the street intersections in Mackinac City.

The St. Ignace Approach consists of a four lane roadway, partly on embankment, partly in cut, extending northward from the mole to a junction with Highway U.S. 2. At this junction the approach splits to accommodate the traffic turning westward and that continuing northward toward Sault Ste. Marie. An alternate plan has been developed eliminating all grade crossings. This would increase the cost by over $100,000. It is not considered necessary at this time and, therefore, has not been included in the estimates of cost.

Electrical Installations

The electrical installations on the bridge may be divided into the following categories:

1. Required for safety of water and air navigation - navigation lights, radar screen, fog siren and airway beacons.

2. Required for operation of bridge -

   Administration building lighting.
   Lighting of toll plaza.
   Convenience outlets - towers and anchorages.

3. Desirable for operation of bridge -

   Tow and fire call.
   Bridge lighting.
   Traffic signals - north end connection.

A question is whether or not, in the interests of economy, roadway lighting may be eliminated. The estimates which follow are based on a complete installation. Approximately $300,000 could be deducted by omitting such provision from the initial installation.

Administration Buildings and Toll Plaza

It is proposed that tolls be collected at a plaza located on the St. Ignace Approach. With the two northbound lanes at their full capacity, approximately 3000 vehicles per hour, and half this volume in the southbound direction, 12 toll collectors will be required. We therefore have based our estimate on a total of 12 lanes through the plaza of which the center four would be reversible in direction.

Adjacent to the Toll Plaza an administration building will be required to house the operating and maintenance personnel. The layout of this building will depend largely on the organization developed for this purpose. We have made layouts of this building, based on experience at other locations, for the purpose of estimates only.

In the case of several major structures it has been found desirable to provide office space for a detail of the State Highway Patrol. Our estimates include $70,000 for this purpose.

Because of the great length of the bridge it will be found desirable to have an auxiliary maintenance building at the Mackinac City end of the bridge. Our estimates allow for this facility.

Our estimates also provide for the necessary operating and maintenance equipment.

CONSTRUCTION SCHEDULE

Because of climatic conditions and especially the ice, the working season for the foundations of the main crossing will be confined to the eight months of April to November inclusive. The erection of steelwork including the spinning of the cables could be carried on during the winter. However, such winter work might be too costly and, for the purpose of setting up the construction schedule, we have assumed a complete shut down during this period.

To minimize the interest charges during construction, it is essential

that the total construction period be reduced to a minimum. We have investigated the records on other major bridges and have discussed the program with experienced contractors. With an adequate amount of construction equipment, especially for the foundations, the assumed schedule given below is entirely practicable.

Sept. 1951	Award Foundation Contract
Season 1952	Anchorages 17 and 20 - First Stage Piers 2-8, 18, 19, 28-33 Mackinac City Approach - Foundations Mole Approach - Foundations St. Ignace Approach - Grading
Season 1952	Erection - Main Towers - Suspension Spans Anchorages - 2nd Stage Piers 9-16 and 21-27 Superstructure - Mackinac City Approach Spans Truss Spans between Piers 2 and 6 Truss Spans between Piers 28 and 30. Mole Approach Paving St. Ignace Approach
Season 1954	Spinning of Cables Superstructure - Truss Spans between Piers 6 and 16 Truss Spans between Piers 21 and 28 Administration Buildings and Toll Plaza
Season 1955	Complete project

ESTIMATED COSTS - FOUR-LANE VEHICULAR BRIDGE

Following is a general summary of our cost estimate of the project. At this critical time, when many of the building materials, more particularly the metals, are becoming scarce and fabricating plants are working at full capacity, it is very difficult to forecast unit prices. We believe, however, that if it were possible to let contracts on a competitive basis at this time and prospective bidders could be assured of a supply of materials, the cost level would be approximately as we have assumed. We believe, therefore, that our estimates

are as realistic as possible under present conditions.

Estimate of Cost

Main Bridge	- Foundations	$24,000,000
	- Superstructure, Suspension Spans	29,600,000
	- Superstructure, Truss Spans	10,600,000
Approaches	- Mole Section	2,000,000
	- Mackinac City	500,000
	- St. Ignace	500,000
Administration Buildings and Toll Plaza		500,000
Operating and Maintenance Equipment		400,000
Electrical Equipment		650,000
Borings		250,000
Engineering, Administration & Contingencies		6,900,000
Total Construction Cost		75,900,000
Real Estate		100,000
Preliminary Expenses		300,000
Total Estimated Cost of Project (before financing)		$76,300,000

We have not included an estimate of interest during construction nor other costs connected with the financing, since these will depend largely on the method of financing that the Authority may adopt.

ESTIMATED OPERATING AND MAINTENANCE COSTS--FOUR-LANE VEHICULAR BRIDGE

Pending a determination of the organization for operating the bridge, we submit no estimate in detail of operating and maintenance costs of the pro-

posed structure. Based on the experience of other major toll bridges, considering the differences in conditions from the other major bridges, and based on an estimate of 1,800,000 vehicles for the first year of operation, we believe that the costs of operation, maintenance and insurance in that year will not exceed $300,000.

With increasing traffic the above would probably increase to $350,000 for the fifth year after opening.

THREE-LANE VEHICULAR BRIDGE

For the reasons given above, we recommend that a four-lane vehicular bridge be constructed. The Authority has requested an alternate estimate on a bridge with three vehicular lanes.

We have made no detail plans for the three-lane bridge. We assume the roadway would be as proposed for the four-lane bridge with 12 ft. of grating eliminated, thereby reducing the weight of the floor by only ten per cent. The width of the suspension spans was fixed for adequate lateral rigidity. No reduction would be advisable for the three-lane bridge. The spacing of the trusses for the other spans of the main crossing could be reduced to 28 ft.

By the A.A.S.H.O. Specifications which we are following in general, a three-lane bridge is designed for 2.7 lane loads, a four-lane bridge for 3.0 lane loads. For the suspension spans the corresponding ratio for the live loads is 1800 to 2000 pounds per lineal foot of bridge. The design of the substructure is controlled to a large extent by the forces assumed for ice action.

From the foregoing it is apparent that a comparatively small saving is possible by reducing the width of the bridge from four to three lanes. Our estimate for the three-lane bridge on a price basis comparable to that used for the four-lane bridge is $70,000,000 (before financing) compared with $76,300,000 for the four-lane bridge. The difference in operating costs between a three and four-lane bridge would be negligible.

PROVISION FOR RAILWAY FACILITIES

Rail traffic across the Straits of Mackinac is presently handled by car ferries. At the request of the Authority we have investigated the feasibility of providing facilities on the proposed bridge to accommodate rail traffic in addition to the vehicular traffic.

The suspension type structure is required for the long spans over the deep rock gorge, whether the bridge is designed for railway or highway loading. The same span layout as that used for the highway bridge has been assumed for the combined four-lane highway and single track railway bridge.

A single-track railway has been assumed to be sufficient to handle the traffic which can be expected to use the proposed facility, and an E-50 loading has been adopted as adequate. A single track, located under the center of the roadway, is more advantageous than a double track, particularly for the suspension spans on account of the severe distortions of the bridge which would result from loading of one of the two tracks.

The estimated maximum grade change on the suspension span for combined highway and railway loading and temperature change gives a maximum calculated adverse railway grade of three per cent at the towers.

Our estimate of the cost of a combined highway and railway bridge has been prepared on the basis of carrying the railway between the Mackinac City Abutment and the St. Ignace abutment and does not include the cost of bringing the railway to the bridge abutments.

The estimated additional cost for provision of a single-track railway on this bridge is $60,000,000 (before financing).

STUDY OF A SUBAQUEOUS TUNNEL

We have made a study of a four-lane vehicular tunnel at the same site

as that proposed for the bridge. In this study we have had the advice and assistance of Mr. Ralph Smillie, Consulting Engineer of New York, an outstanding expert on tunnel construction.

The assumed tunnel structure would consist of 56 twin-type precast tunnel sections, each approximately 300 feet long, supported generally at the junctures by multiple steel-shell concrete-lined caissons sunk to rock or to firm material. In the gorge the caissons would have to be sunk to the unprecedented depth of about 300 feet below lake level.

The top of the precast tunnel sections would be located to provide a minimum water depth of 50 feet for a channel width of 12,300 feet, which will allow the largest type vessels to pass. As the tunnel roadways climb towards the shores the tunnel structure would be protected on each side and on top by substantial rip-rap fill.

The length of tunnel from portal to portal would be approximately 16,700 feet. Full use would be made, as in the case of the bridge, of the existing mole on the north side of the strait. Two ventilation buildings have been located approximately at the quarter points between portals, each building housing 32 ventilation fans with attendent electrical switch boards and controls. Ventilation in the tunnel will be by the transverse distributed method, similar to that used in the principal vehicular tunnels around New York City.

We estimate that the cost of the tunnel project would be approximately $141,000,000.00 (before financing).

The estimated cost of operation for the first year is approximately $1,000,000.00.

CONCLUSIONS

The conclusions from our investigations as outlined in this report may be summarized as follows:

1. The construction of a bridge across the Straits of Mackinac with construction methods which have proven successful on other large bridges in entirely feasible.

2. The location of a bridge directly northward from Mackinac Point is more suitable than other locations which had previously been proposed.

3. It has been definitely established that the rock formation underlying the Straits has much greater strength than necessary to resist the moderate pressures which would be imposed upon it by the structure, even under severest combination of ice and wind forces.

4. A bridge designed for two lanes of traffic in each direction is recommended. It will be adequate for a reasonable number of years to come. The proposed design provides for the heaviest vehicular loadings specified by the American Association of State Highway Officials. Special attention was given in the design of the long-span suspension structure to assure safe resistance against dynamic wind action.

5. The bridge can be completed, ready for traffic, within four years of the award of the first construction contract.

6. Based on prevailing prices we estimate that the bridge can be built as proposed at a sum of $76,300,000, exclusive of the cost of financing and interest during construction.

7. Operating and maintenance expenses are estimated at $300,000 during the first year.

8. A bridge with three traffic lanes would cost only about $6,300,000 less than one with four lanes and is not recommended.

9. The construction of a four-lane subaqueous tunnel is feasible, but its construction would involve unprecedented operations. Its construction cost would be much greater than for a bridge and the cost of operation would also be materially higher.

10. Provision for a single track standard railway is feasible, but it would increase the cost of the four-lane highway bridge by approximately $60,000,000 (before financing), in addition to the cost of necessary railway approaches.

11. The estimates of traffic and revenue made by Coverdale & Colpitts indicate that a four-lane bridge as proposed herein is economically justified and feasible if the saving of present costs of the ferry operation is taken into consideration.

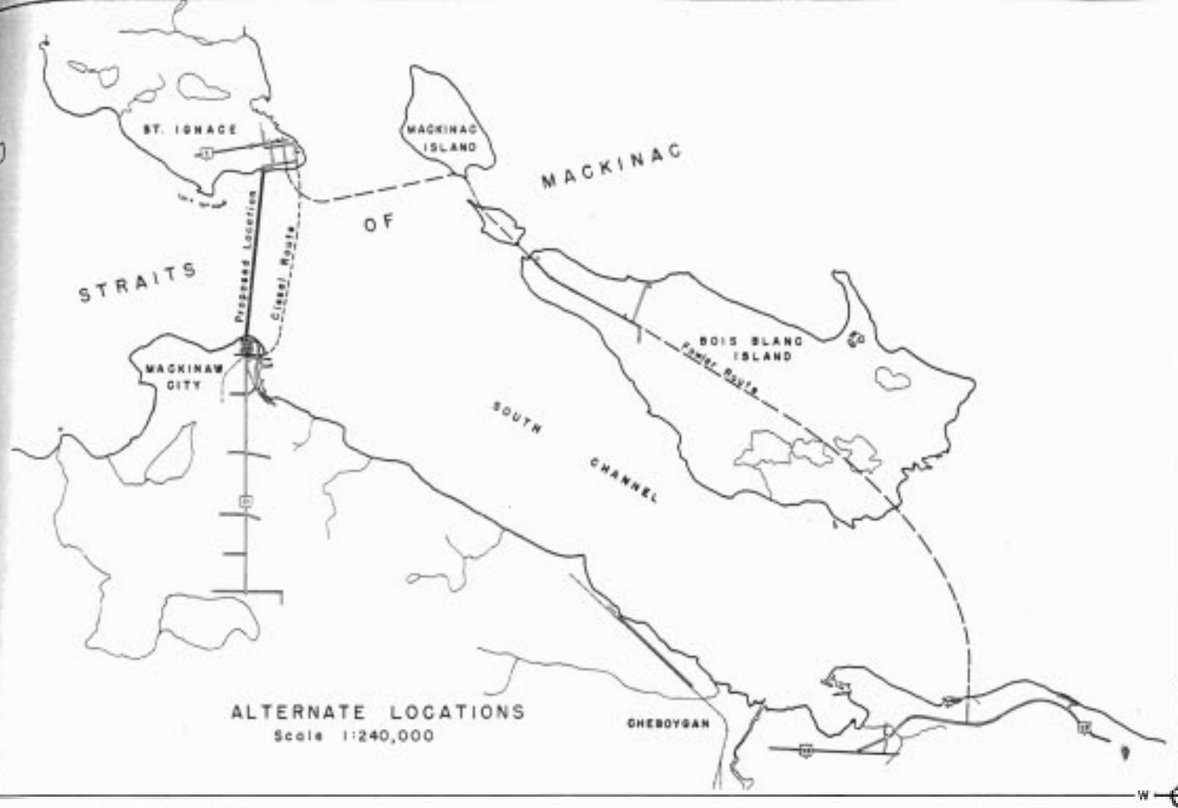
ACKNOWLEDGMENTS

We acknowledge the courtesies extended throughout our investigation by the Authority. Its Secretary, Mr. Lawrence A. Rubin, has been most helpful in securing the basic data for our investigations.

The State Highway Department has rendered valuable assistance in our studies. The advice and cooperation of State Highway Commissioner Charles M. Ziegler, Mr. George M. Foster, Bridge Engineer, Mr. W. W. McLaughlin, Director of Testing and Research, and Professor W. S. Housel have been most helpful.

In connection with our study of the geology of the site we acknowledge the aid freely given by State Geologist G. E. Eddy, Mining Engineer F. G. Pardee, and Professors K. K. Landes and G. M. Ehlers of the University of Michigan.

We have drawn freely on the previous studies for a bridge at this location, including those of Mr. C. E. Fowler, Mr. James E. Cissell and Modjeski and Masters.



ALTERNATE LOCATIONS
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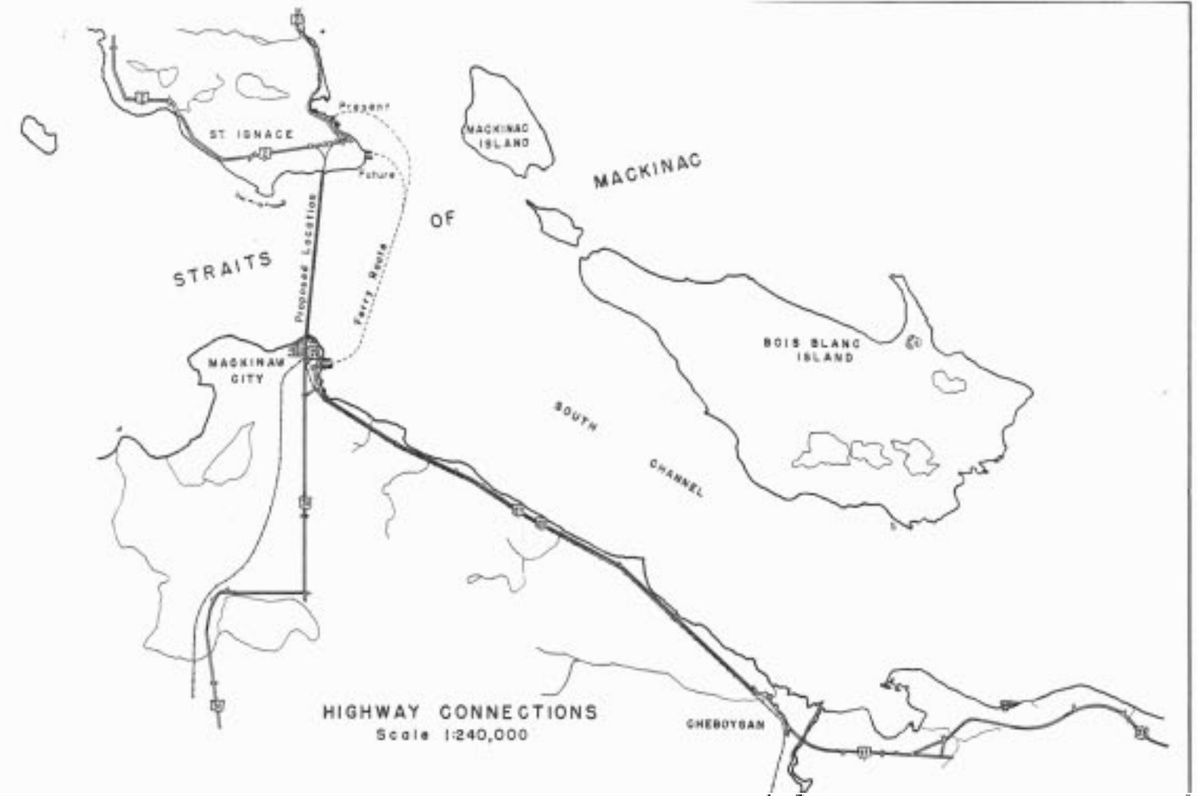

HIGHWAY CONNECTIONS
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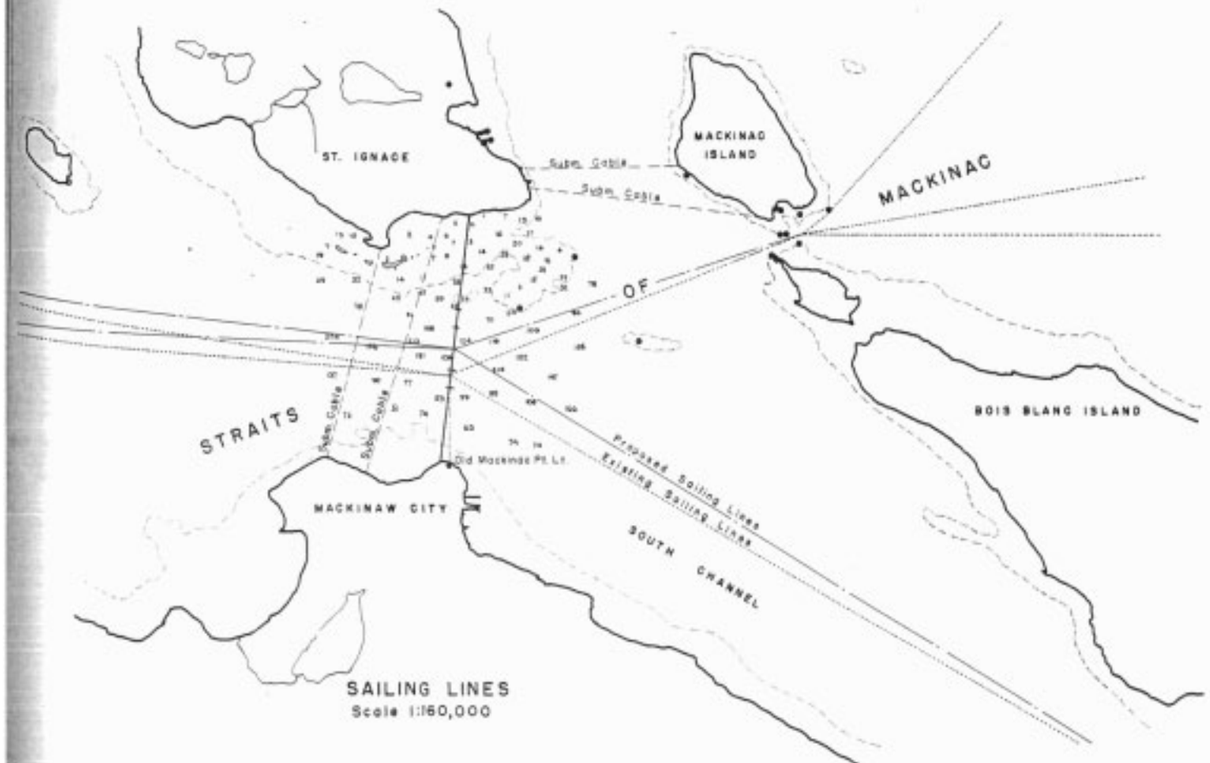

SAILING LINES
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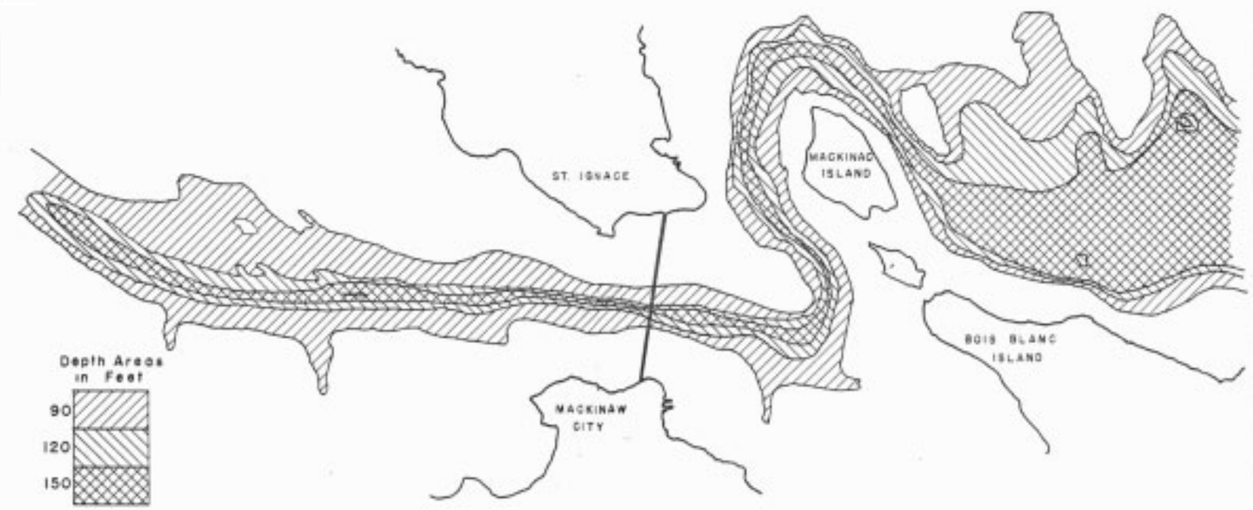

SUBMERGED VALLEY THROUGH
MACKINAC STRAITS
Scale 1:240,000

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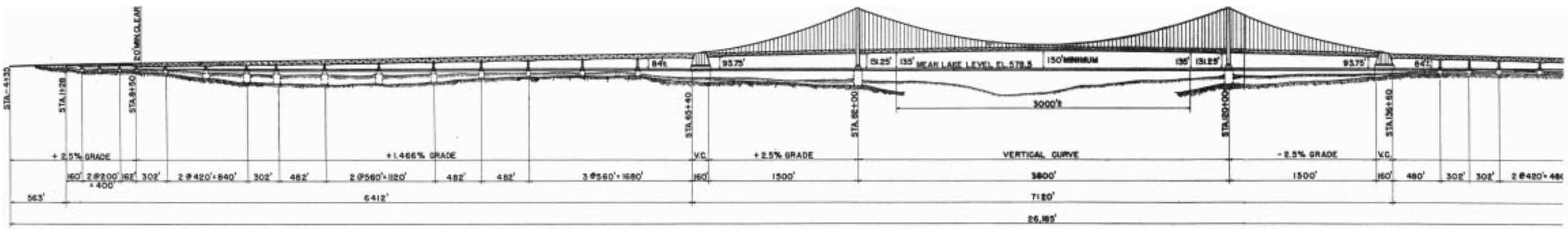
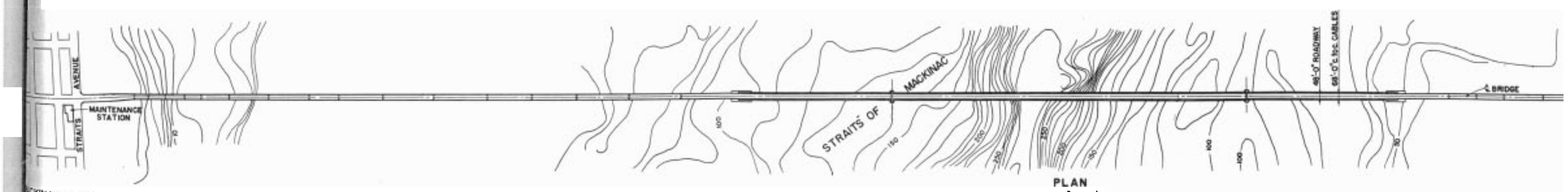
PROPOSED MACKINAC BRIDGE

LOCATION

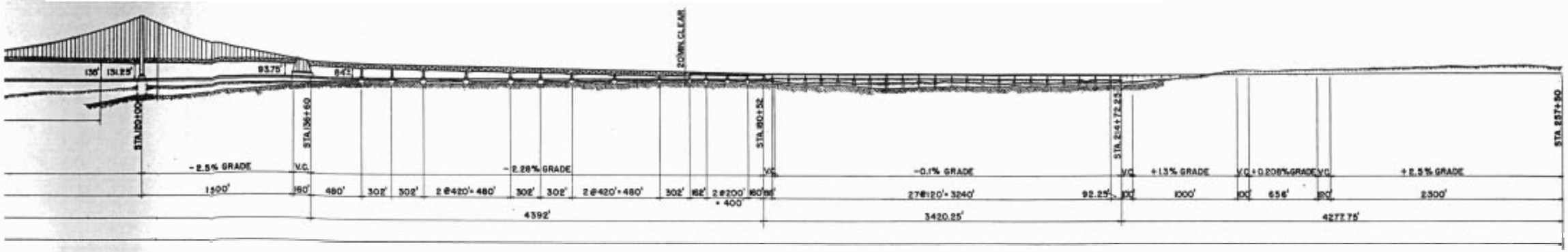
JANUARY 10, 1951
PLATE PR 1.

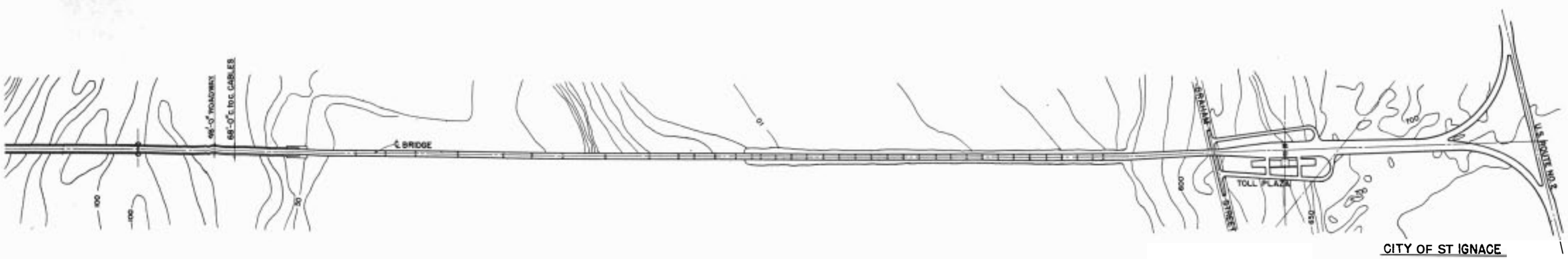


ELEVATION
Scale: 1" = 1,000'



PLAN
Scale: 1" = 1,000'





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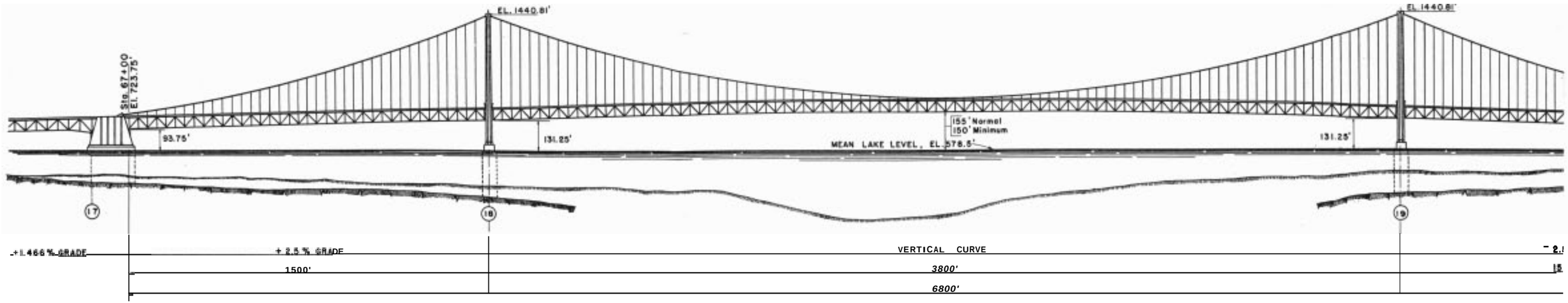
PROPOSED MACKINAC BRIDGE

GENERAL PLAN AND ELEVATION

JANUARY 10, 1951

PLATE PR 2



ELEVATION
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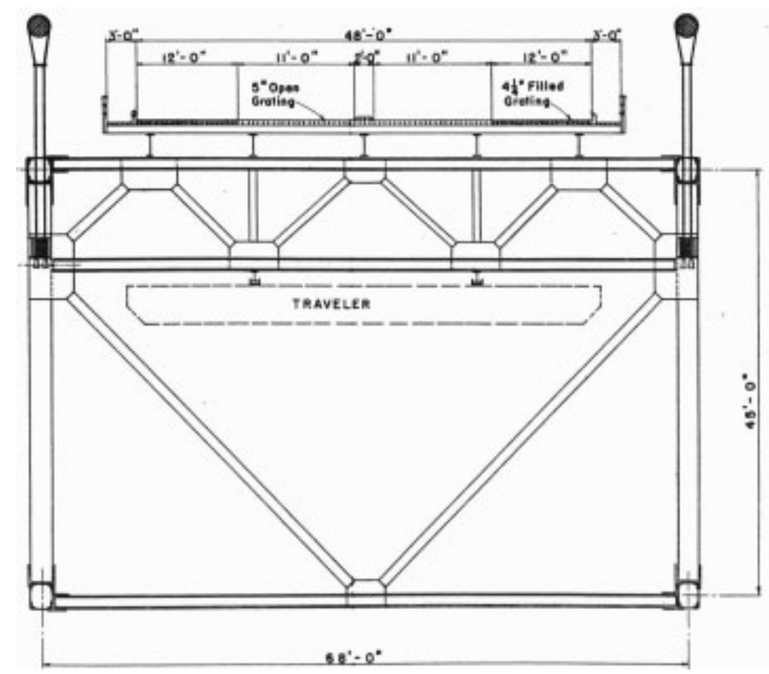

CROSS SECTION — SUSPENDED STRUCTURE
Scale: 1/8" = 1'

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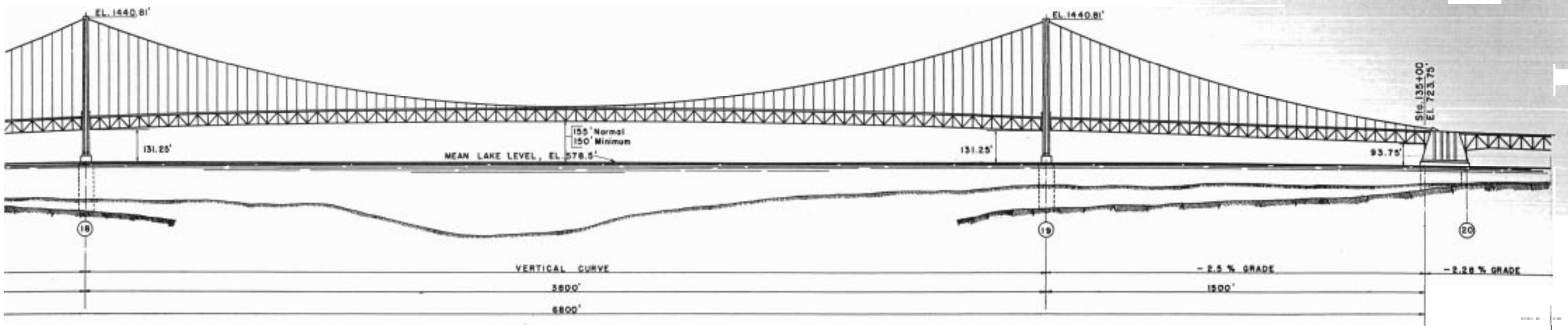

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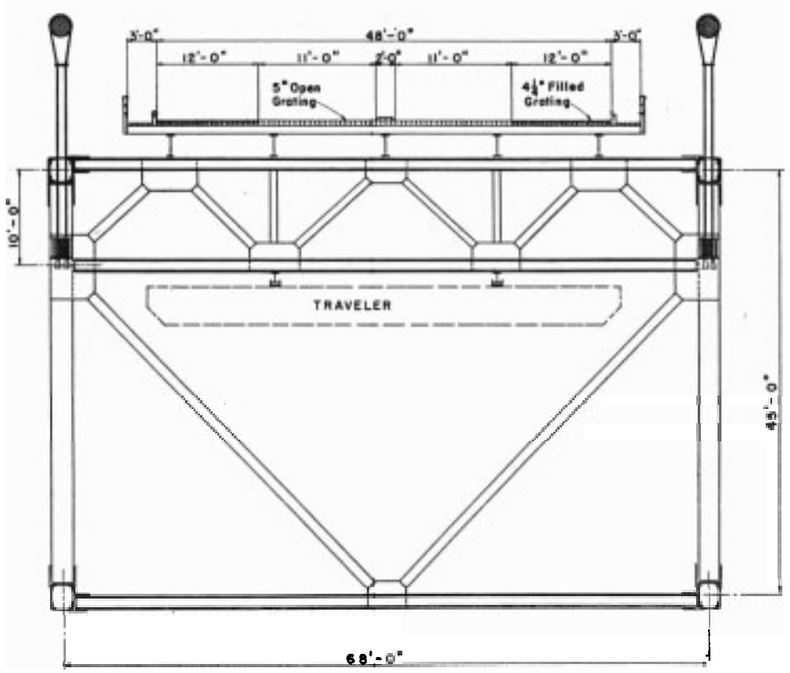

CROSS SECTION — SUSPENDED STRUCTURE
Scale: ⅛" = 1'

STATE OF MICHIGAN
MACKINAC BRIDGE AUTHORITY

PROPOSED MACKINAC BRIDGE

MAIN CROSSING — SUSPENSION SPANS

JANUARY 10, 1951
PLATE PR3

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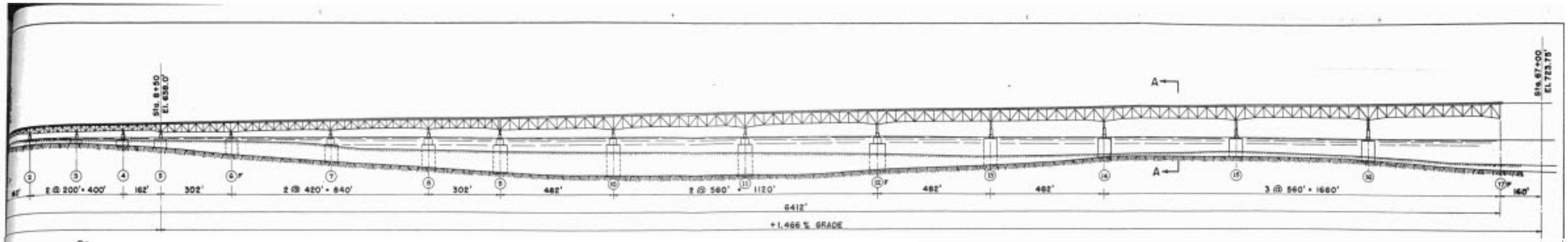
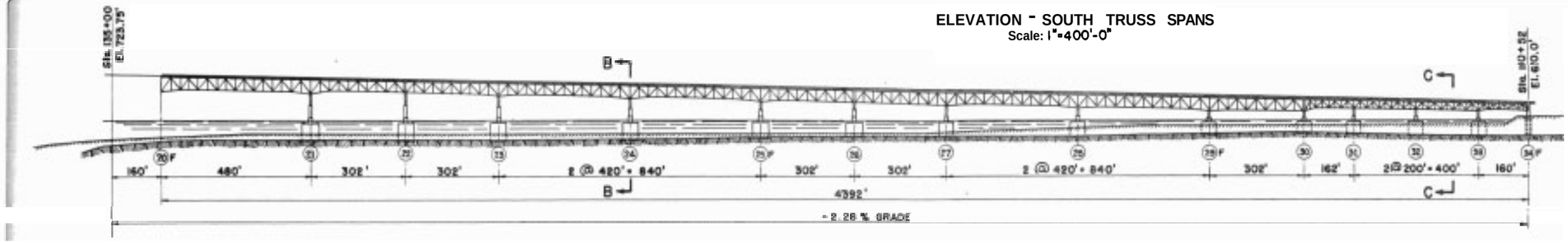


ELEVATION - SOUTH TRUSS SPANS
Scale: 1"=400'-0"



ELEVATION - NORTH TRUSS SPANS
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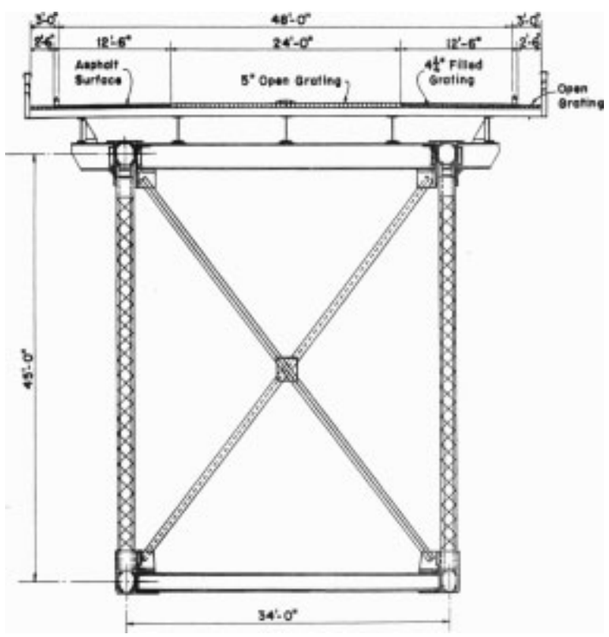

SECTION A-A
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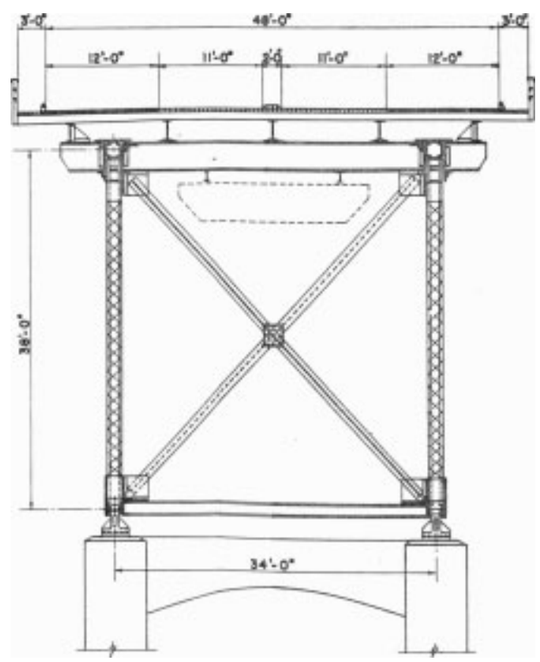

SECTION B-B
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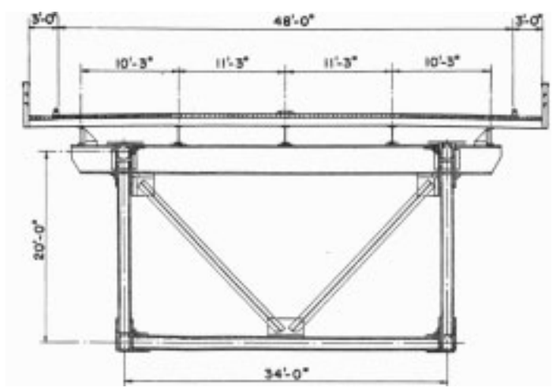

SECTION C-C
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STATE OF MICHIGAN
MACKINAC BRIDGE AUTHORITY

PROPOSED MAGKINAG BRIDGE

MAIN CROSSING — TRUSS SPANS

JANUARY 10, 1951
PLATE [illegible]

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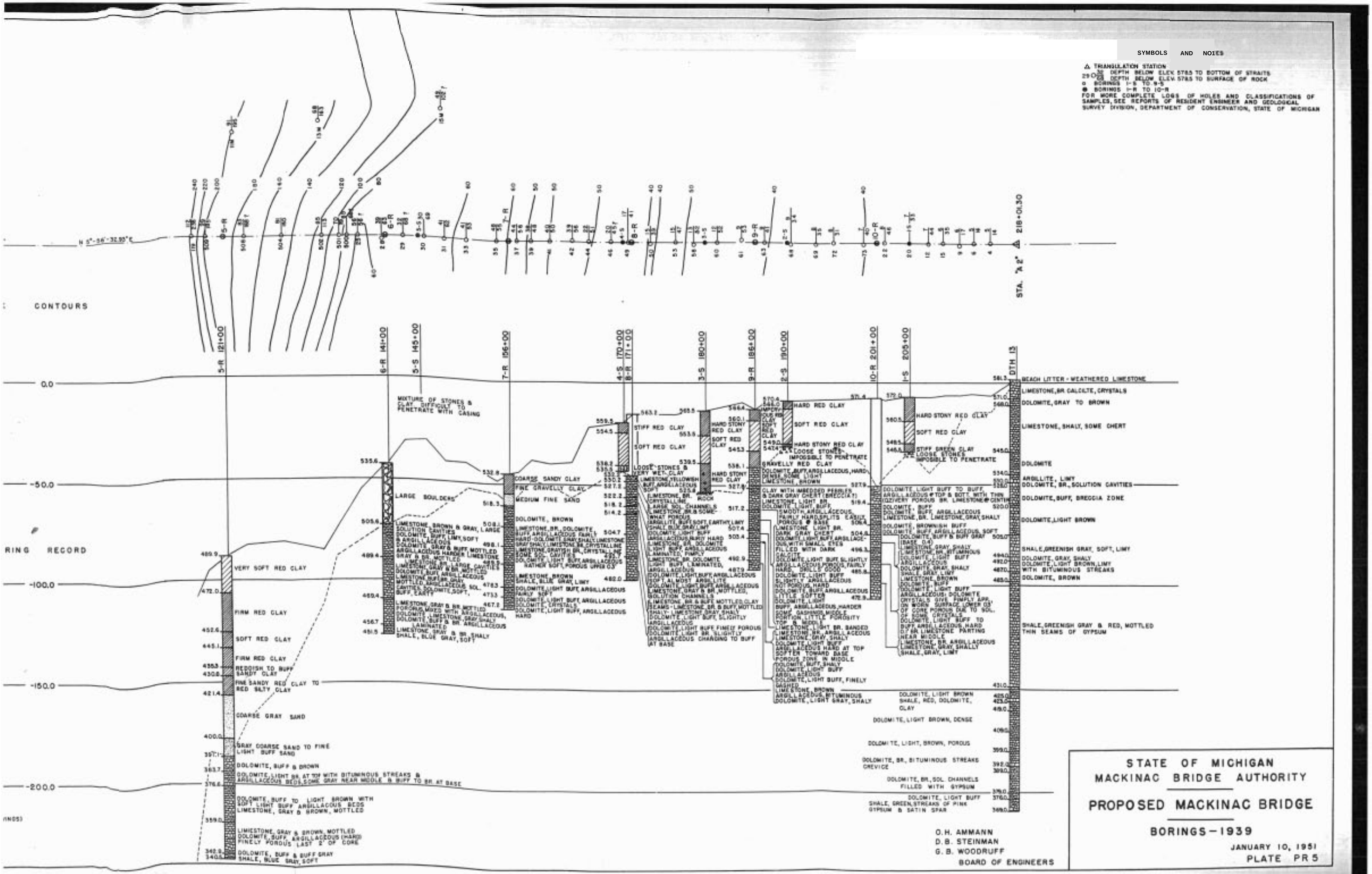
SYMBOLS AND NOTES

△ TRIANGULATION STATION
29-○$\frac{32}{68}$ DEPTH BELOW ELEV. 578.5 TO BOTTOM OF STRAITS / DEPTH BELOW ELEV. 578.5 TO SURFACE OF ROCK
○ BORINGS 1-S TO 9-S
● BORINGS 1-R TO 10-R
FOR MORE COMPLETE LOGS OF HOLES AND CLASSIFICATIONS OF SAMPLES, SEE REPORTS OF RESIDENT ENGINEER AND GEOLOGICAL SURVEY DIVISION, DEPARTMENT OF CONSERVATION, STATE OF MICHIGAN



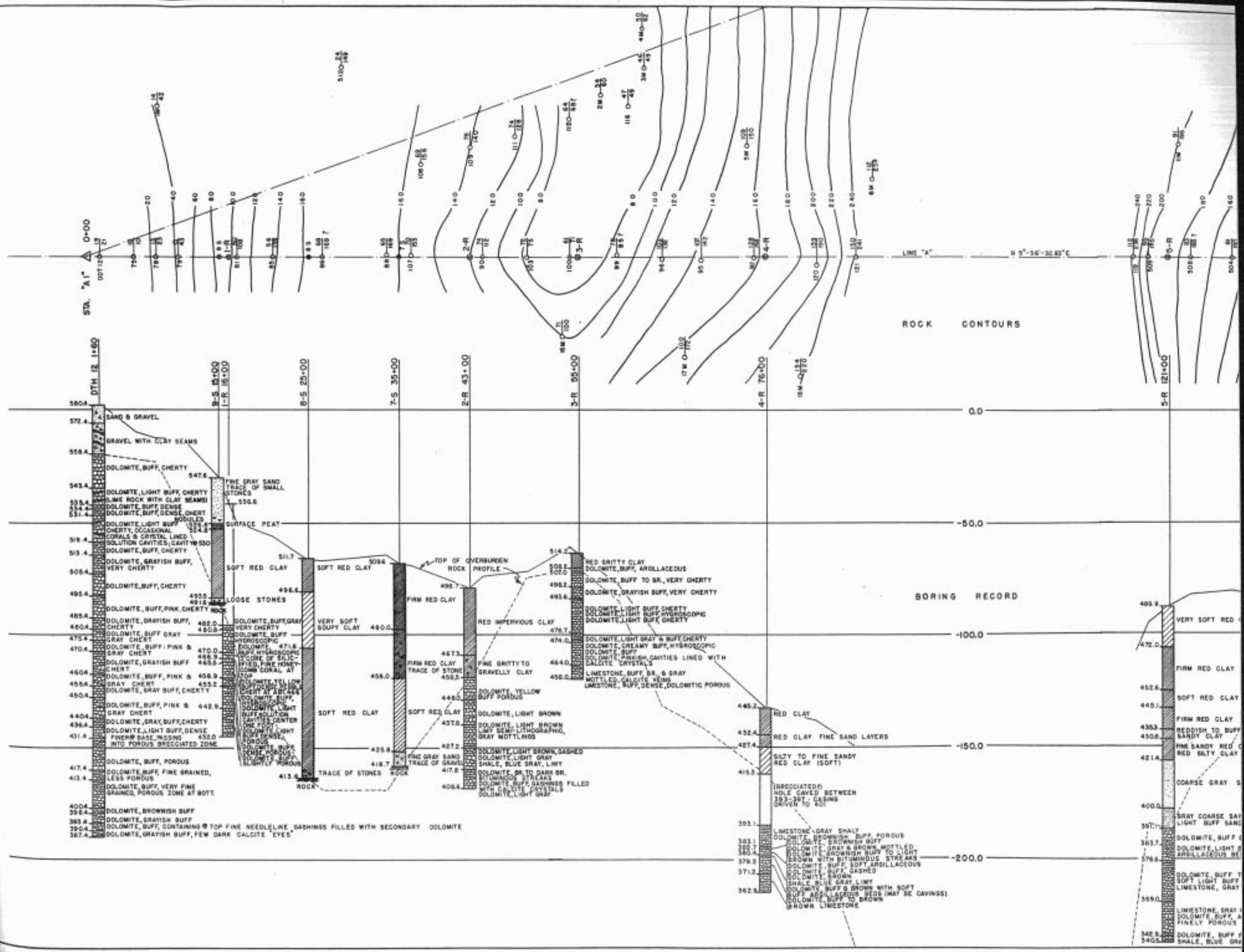
O.H. AMMANN
D.B. STEINMAN
G.B. WOODRUFF
BOARD OF ENGINEERS

STATE OF MICHIGAN
MACKINAC BRIDGE AUTHORITY

PROPOSED MACKINAC BRIDGE

BORINGS - 1939

JANUARY 10, 1951
PLATE PR 5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1-R 16+00
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3-R 55+00
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5-R 121+00
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-100.0
-150.0
-200.0
BORING RECORD
SAND & GRAVEL
GRAVEL WITH CLAY SEAMS
DOLOMITE, BUFF, CHERTY
FINE GRAY SAND TRACE OF SMALL STONES
SURFACE PEAT
SOFT RED CLAY
LOOSE STONES
ROCK
VERY SOFT SOUPY CLAY
TRACE OF STONES
TOP OF OVERBURDEN ROCK PROFILE
FIRM RED CLAY
FIRM RED CLAY TRACE OF STONE
FINE GRAY SAND TRACE OF GRAVEL
RED IMPERVIOUS CLAY
FINE GRITTY TO GRAVELLY CLAY
RED GRITTY CLAY
RED CLAY
RED CLAY FINE SAND LAYERS
SILTY TO FINE SANDY RED CLAY (SOFT)
VERY SOFT RED
FIRM RED CLAY
SOFT RED CLAY
FIRM RED CLAY
REDDISH TO BUFF SANDY CLAY
FINE SANDY RED
RED SILTY CLAY
COARSE GRAY
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LIGHT BUFF SAND
DOLOMITE, BUFF
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SOFT LIGHT BUFF
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LIMESTONE, GRAY
DOLOMITE, BUFF, A
FINELY POROUS
DOLOMITE, BUFF
SHALE, BLUE GRA

January 8, 1951

Mr. Prentiss M. Brown
Chairman of Mackinac Bridge Authority
2000 Second Avenue
Detroit 6, Michigan

Dear Sir:

In accordance with your instructions we have made a study of the probable gross and net revenues of the proposed bridge across the Straits of Mackinac between Mackinaw City on the south and St. Ignace on the north. This estimate is made on the assumption that the State-owned and operated ferry in this location will cease to operate on the completion of the proposed bridge. For the purposes of our estimate, we have assumed the bridge will open for operation on January 1, 1956.

The results of our study are shown in the following tabulations, the first of which shows the estimated traffic, gross and net revenues by years, and the rate at which a $3\frac{1}{2}$ per cent bond issue in the amount of $87,000,000 could be paid off assuming that all of the net earnings were available for debt service. The second tabulation gives similar information assuming that the operating expenses are not charged against bridge revenues, but are paid from other funds.

PROPOSED MACKINAC BRIDGE

TENTATIVE ESTIMATE OF TRAFFIC AND GROSS AND NET REVENUES AND TABULATION SHOWING RATE AT WHICH A 3-1/2 PER CENT BOND ISSUE IN THE AMOUNT OF $87,000,000 COULD BE RETIRED ASSUMING ALL NET REVENUES WERE AVAILABLE FOR DEBT SERVICE AND THE BONDS WERE RETIRED AT PAR

Year	Vehicles	Revenue	Operating Expenses	Available For Debt Service	Interest at 3-1/2%	Available for Amortization	Bonds Outstanding $87,000,000
1956	1,770,000	$3,700,000	$400,000	$3,300,000	$3,045,000	$ 255,000	$86,745,000
1957	1,858,000	3,884,000	400,000	3,484,000	3,036,000	448,000	86,297,000
1958	1,946,000	4,068,000	400,000	3,668,000	3,020,000	648,000	85,649,000
1959	2,034,000	4,252,000	400,000	3,852,000	2,998,000	854,000	84,795,000
1960	2,122,000	4,436,000	400,000	4,036,000	2,968,000	1,068,000	83,727,000
1961	2,210,000	4,620,000	425,000	4,195,000	2,930,000	1,265,000	82,462,000
1962	2,298,000	4,804,000	425,000	4,379,000	2,886,000	1,493,000	80,969,000
1963	2,386,000	4,988,000	425,000	4,563,000	2,834,000	1,729,000	79,240,000
1964	2,474,000	5,172,000	425,000	4,747,000	2,773,000	1,974,000	77,266,000
1965	2,562,000	5,356,000	425,000	4,931,000	2,704,000	2,227,000	75,039,000
1966	2,650,000	5,540,000	425,000	5,115,000	2,626,000	2,489,000	72,550,000
1967	2,738,000	5,724,000	425,000	5,299,000	2,539,000	2,760,000	69,790,000
1968	2,826,000	5,908,000	425,000	5,483,000	2,443,000	3,040,000	66,750,000
1969	2,914,000	6,092,000	425,000	5,667,000	2,336,000	3,331,000	63,419,000
1970	3,002,000	6,276,000	425,000	5,851,000	2,220,000	3,631,000	59,788,000
1971	3,090,000	6,460,000	450,000	6,010,000	2,093,000	3,917,000	55,871,000
1972	3,178,000	6,644,000	450,000	6,194,000	1,955,000	4,239,000	51,632,000
1973	3,266,000	6,828,000	450,000	6,378,000	1,807,000	4,571,000	47,061,000
1974	3,354,000	7,012,000	450,000	6,562,000	1,647,000	4,915,000	42,146,000
1975	3,442,000	7,196,000	450,000	6,746,000	1,475,000	5,271,000	36,875,000
1976	3,530,000	7,380,000	450,000	6,930,000	1,291,000	5,639,000	31,236,000
1977	3,618,000	7,564,000	450,000	7,114,000	1,093,000	6,021,000	25,215,000
1978	3,706,000	7,748,000	450,000	7,298,000	883,000	6,415,000	18,800,000
1979	3,794,000	7,932,000	450,000	7,482,000	658,000	6,824,000	11,976,000
1980	3,882,000	8,116,000	450,000	7,666,000	419,000	7,247,000	4,729,000
1981	3,970,000	8,300,000	450,000	7,850,000	166,000	7,684,000	
1982	4,058,000	8,484,000	450,000	8,034,000			
1983	4,146,000	8,668,000	450,000	8,218,000			
1984	4,234,000	8,852,000	450,000	8,402,000			
1985	4,322,000	9,036,000	450,000	8,586,000			
1986	4,410,000	9,220,000	450,000	8,770,000			

Bonds issued, say, 1952 (beginning)
Date of last maturity, 1981 (end)
Time to amortize - 30 years

Total bonds issued	$ 87,000,000	
Total interest paid	54,845,000	
Total debt service	141,845,000	100.0%
Total revenues collected	200,260,000	41.2%
Coverage over 35-year period		141.2%

PROPOSED MACKINAC BRIDGE

TENTATIVE ESTIMATE OF TRAFFIC AND REVENUES AND TABULATION SHOWING RATE AT WHICH A 3-1/2 PER CENT BOND ISSUE IN THE AMOUNT OF $87,000,000 COULD BE RETIRED ASSUMING ALL GROSS REVENUES WERE AVAILABLE FOR DEBT SERVICE AND THE BONDS WERE RETIRED AT PAR

Year	Vehicles	Revenue	Interest at 3-1/2%	Available for Amortization	Bonds Outstanding $87,000,000
1956	1,770,000	$3,700,000	$3,045,000	$ 655,000	$86,345,000
1957	1,858,000	3,884,000	3,022,000	862,000	85,483,000
1958	1,946,000	4,068,000	2,992,000	1,076,000	84,407,000
1959	2,034,000	4,252,000	2,954,000	1,298,000	83,109,000
1960	2,122,000	4,436,000	2,909,000	1,527,000	81,582,000
1961	2,210,000	4,620,000	2,855,000	1,765,000	79,817,000
1962	2,298,000	4,804,000	2,794,000	2,010,000	77,807,000
1963	2,386,000	4,988,000	2,723,000	2,265,000	75,542,000
1964	2,474,000	5,172,000	2,644,000	2,528,000	73,014,000
1965	2,562,000	5,356,000	2,555,000	2,801,000	70,213,000
1966	2,650,000	5,540,000	2,457,000	3,083,000	67,130,000
1967	2,738,000	5,724,000	2,350,000	3,374,000	63,756,000
1968	2,826,000	5,908,000	2,231,000	3,677,000	60,079,000
1969	2,914,000	6,092,000	2,103,000	3,989,000	56,090,000
1970	3,002,000	6,276,000	1,963,000	4,313,000	51,777,000
1971	3,090,000	6,460,000	1,812,000	4,648,000	47,129,000
1972	3,178,000	6,644,000	1,650,000	4,994,000	42,135,000
1973	3,266,000	6,828,000	1,475,000	5,353,000	36,782,000
1974	3,354,000	7,012,000	1,287,000	5,725,000	31,057,000
1975	3,442,000	7,196,000	1,087,000	6,109,000	24,948,000
1976	3,530,000	7,380,000	873,000	6,507,000	18,441,000
1977	3,618,000	7,564,000	645,000	6,919,000	11,522,000
1978	3,706,000	7,748,000	403,000	7,345,000	4,177,000
1979	3,794,000	7,932,000	146,000	7,786,000	
1980	3,882,000	8,116,000			
1981	3,970,000	8,300,000			
1982	4,058,000	8,484,000			
1983	4,146,000	8,668,000			
1984	4,234,000	8,852,000			
1985	4,322,000	9,036,000			
1986	4,410,000	9,220,000			

Bonds issued, say, 1952 (beginning)
Date of last maturity, 1979 (end)
Time to amortize - 28 years

Total bonds issued	$ 87,000,000	
Total interest paid	48,975,000	
Total debt service	135,975,000	100.0%
Total revenues collected	200,260,000	47.3%
Covers over 35-year period		147.3%

A bond issue in the amount of $87,000,000 has been assumed on the advice of the Consulting Engineers, who have given us this figure as a tentative estimate of the over-all cost of the project.

It is to be noted that a bond issue of the above amount can be retired from the net earnings of the bridge in 30 years and that if the bonds cover a term of 35 years the total debt service would be covered during this period 1.41 times.

The second tabulation indicates that if the bridge is relieved from the burden of operating expenses, the bond issue can be retired in 28 years with a coverage of 1.47 times.

Our estimate of bridge traffic for 1956 is arrived at as follows:

	Vehicles
Estimated ferry traffic - 1950	
(Not counting trailers as separate vehicles)	538,600
6 Years growth @ 6% (41.85%)	225,400
Total ferry traffic - 1956	764,000
Diverted from west side of Lake Michigan - 3%	22,900
Total ferry and diverted traffic	786,900
Induced traffic @ 125%	983,600
Total bridge traffic - 1956	1,770,500
Say	1,770,000

Our estimate of bridge revenue has been derived by dividing the total revenue received in 1950 by the number of vehicles carried in that year as shown above and applying this average toll to the estimated number of vehicles carried in 1956. On this basis the average toll is approximately $2.09 per vehicle.

We believe that our estimate of traffic is liberal, but considering the territory, the character of the present traffic and service rendered by the ferry, we believe it is reasonable to expect the traffic volumes and revenues shown.

As it may not be possible to finance the project from the net revenues of the bridge alone, we have assumed in our second tabulation that the State would pay the operating expenses which we have estimated at $400,000 for the first five years, $425,000 for the next ten years, and $450,000 thereafter. As the deficit from ferry operations alone, excluding any capital improvements necessary, was approximately $474,000 in 1948, $360,000 in 1949, and will be greater than the latter amount in 1950, the payment of the operating expenses by the State should not be considered a contribution as such payments would be less than the present deficits resulting from ferry operation.

In cases where it has been difficult to finance projects solely from revenues available from the project itself, States have contributed to the project in certain cases by assuming part of the construction costs; for instance, of the bridge approaches. The guaranty of the debt service by the State would, of course, result in a substantially lower interest rate, making the total overall cost less and insuring the success of the project.

We wish to express our appreciation for the courtesies extended to us by the Michigan State Highway Department and their co-operation in furnishing us with past and present ferry traffic, revenue, operating expense and other data.

Respectfully submitted,

Coverdale & Colpitts

Consulting Engineers

January 8, 1951

Mr. Prentiss M. Brown, Chairman
Mackinac Bridge Authority
2000 Second Avenue
Detroit 26, Michigan

Dear Mr. Brown:

In accordance with directions arranged through Mr. D. B. Steinman of New York, a report on the geological conditions represented at the site of the Mackinac Straits bridge has been prepared, and is presented herewith.

Because of my inability to make a personal field examination at this time, I obtained authorization to engage Mr. Sidney Paige, a competent associate in this kind of work, to make the preliminary investigations. The report is our joint product.

Very truly yours,

Charles P. Berkey

Charles P. Berkey
Consulting Geologist

Pier Foundations for a Proposed Bridge Across the Straits of Mackinac

An Engineering Geologic Report

by

Charles P. Berkey, Consulting Geologist

and

Sidney Paige, Consulting Geologist

Contents

I. Foreword

A question has been raised with respect to a proposed bridge across the Straits of Mackinac -- "Are the geological conditions such that one may with assurance assert that stable foundations can be developed for the main and subsidiary piers of the bridge?"

A widespread presence of the Mackinac breccia in the Straits area and the known presence of a relatively deep and ancient inter-glacial stream channel separating the northern and southern peninsulas have caused some questions to be raised regarding the feasibility of the bridge, particularly questions "with respect to the locations and development of firm footings for the bridge piers". It is the objective of this report to answer, insofar as it appears to us possible, these questions.

The study which we have made is based on an appraisal of the data assembled in an excellent report entitled "Geology of the Mackinac Straits Region and Subsurface Geology of Northern-Southern Peninsula" by Kenneth K. Landes, George M. Ehlers, and George M. Stanley; State of Michigan, Department of Conservation, Geological Survey Division, Lansing, Michigan, 1944; on a number of engineering reports, cross sections, and drilling records furnished by Dr. D. B. Steinman, Consulting Engineer, New York City; and on conferences by Mr. Paige with Messrs. K. K. Landes and W. S. Housel of the University of Michigan, at Ann Arbor, and with the State Geologist, Mr. G. E. Eddy and his associate, Mr. F. G. Pardee at Lansing, Michigan; and on the examination of some bulk samples of parts of the Mackinac breccia.

II. Conclusions

It is our considered opinion that a bridge such as that proposed across the Straits of Mackinac is entirely feasible, but there are precautions to be observed that must not be disregarded, as is explained in the body of this report.

The Mackinac Breccia and the elements composing it, which is the principal formation involved in this problem, has the strength required to support the proposed bridge piers with an ample margin of safety.

The collapse of ancient caverns and the primary brecciation of this formation occurred millions of years ago. The heavy loads of sediment that subsequently were deposited over the breccia have effected a consolidation of the rocks, and ample time has elapsed for re-cementation. We are not greatly concerned, therefore, with the caverns that once existed millions of years ago in Devonian time. On the other hand, the actual structural conditions are still relatively unknown at the immediate site and should be determined by a suitable program of exploratory drilling.

A question has been raised regarding the strength of the shales that are present and that may become part of the bridge foundation. Would these shales "flow" toward the valley walls under stresses induced by the load of the bridge? In our opinion no such movement will take place under the moderate stresses with which we are dealing. Furthermore, strength tests can be made on the cores recovered.

When the recommended drilling program has been carried out and its results interpreted by a geologist, we believe that suitable footings for the piers can be constructed. There is nothing unusual in our recommendation that an adequate core drilling program be carried out before construction begins. It is accepted practice and in the interest of suitable construction treatment, economy and safety on a project of such magnitude and importance.

III. Recommendations

We recommend that a program of drilling, carried out by experienced drillers, be undertaken before construction begins at each of the proposed main suspension bridge footings, consisting of four 3-inch core drill holes on each footing, each hole to penetrate rock not less than seventy five feet, the program to be directed toward the recovery of core and geologic information.

We recommend that at least one 3-inch core drill hole be drilled at each subsidiary pier footing.

We recommend that the guidance of a geologist be sought in the interpretation of the drilling, and that he in cooperation with the engineers, direct any further drilling that may prove necessary because of the unusual character of the bedrock.

We also recommend probing or drilling to bedrock in the area surrounding the pier sites to insure an adequate knowledge of the rock floor contour and the relation of the sites with reference to any possible buried channels tributary to the main stream.

IV. The Geology of The Mackinac Straits Area And Its Bearing On The Stability Of The Bridge-Pier Footings Of A Proposed Trans-Straits Bridge.

Introduction

The Southern Peninsula of Michigan with the Straits of Mackinac at its northern border, is underlain by sedimentary strata, limestones, dolomites, shales, and their intergradations with which are associated beds of salt and gypsum. Structurally the area is known as the Michigan Basin, since all the beds within its boundaries slope gently downward from all directions toward a center some one hundred seventy miles south of the Straits. This structural basin was formed by a progressive downwarp of the ocean floor on which a thick series of sediments, now present, were progressively deposited during millions of years. In the Straits area, therefore, the regional dip is gently south-

ward some twenty five to fifty feet per mile from a point north of St. Ignace Peninsula, across the Straits, southward for a long distance.

Were this the whole story, we would face a simpler engineering problem than we do in appraising the strength of the bridge footings beneath the waters of the Straits. But two episodes in the long geologic history of the region serve to complicate the situation.

One circumstance concerns the nature and formation of the Mackinac Breccia; the other is concerned with a geologically much more recent development, namely, the presence during an interglacial period of a river flowing eastward through what are now the Straits of Mackinac.

The nature and the engineering consequences of these two developments is appraised in what follows. First, the significant facts concerning the nature of the formations that are present are set forth. Next, the origin of the Mackinac Breccia is described and its engineering significance appraised.

Then follows an analysis of processes that have operated during the period when a stream flowed eastward through what are now the Straits of Mackinac, and may be of engineering importance.

Rock Formations Involved

The stratified rock formations of the Mackinac Straits region occupy a position between the Engadine dolomite of middle Silurian age at the base and the Dundee limestone of middle Devonian age at the top, a stratigraphic interval of approximately one thousand feet. Brief descriptions follow of each of the mapped formations within this interval.

Pointes Aux Chenes Formation

The Pointes aux Chenes formation underlies most of the large St. Ignace Peninsula north of the Straits of Mackinac. The formation, therefore, with parts of the St. Ignace formation would be expected to be the foundation rock for the

northerly portion of the bridge.

From the known outcrops which are scanty and from the records of a few deep wells, it is known that the formation consists of green and red shale with intercalated thin beds of dolomite and irregular masses and beds of gypsum. No beds of salt have been found in the outcrop area nor in the few deep wells of the area.

Indications from the deep wells of the region place the thickness of the Pointes aux Chenes formation at five hundred to six hundred feet on the St. Ignace Peninsula. It is probable, therefore, that these rocks are the lowermost strata that will be involved in any engineering problem connected with the construction of the bridge. The fact that these rocks, with some of those that lie stratigraphically above them, have been voilently disturbed since their deposition will be discussed further, as will also the fact that they contain gypsum.

St. Ignace Formation

The St. Ignace formation, except for the upper part, consists of even-bedded light-colored dolomite, intercalated with thin beds of bluish to greenish-gray shale. The upper part of the formation consists of thick-bedded dolomites. It is estimated that the thickness of the formation lies somewhere between two hundred and three hundred feet. In the area we are considering on the St. Ignace Peninsula voilent dislocation of parts of the formation has been observed, and the formation is mapped with the Mackinac Breccia, it not being practical to separate the "breccia complex" from disturbed blocks known to be part of the St. Ignace formation.

Garden Island Formation

According to the reports of the Michigan geologists, the Garden Island formation consists of dolomites, sandstones, and shales, and may aggregate twenty five feet in thickness. We need not discuss the formation further in this study.

The Bois Blanc Formation And The Detroit River Group

The Bois Blanc formation of lower or middle Devonian age consists chiefly

of cherty limestones and dolomites. The formation underlies the southern two-thirds of Bois Blanc Island and a narrow belt of land along the northern shores of the Southern Peninsula. Numerous large blocks of this formation are involved in the Mackinac Breccia on the St. Ignace Peninsula. The boundaries of the blocks are poorly exposed, consequently have not been mapped separately but have been included in the map unit known as the Mackinac Breccia.

The lower part of the Bois Blanc formation consists of inter-bedded chert and limestone; the middle part of limestones, and dolomitic limestones. The thickness of the formation is estimated to range from three hundred and twenty five to four hundred feet.

Since the Bois Blanc formation is the uppermost stratigraphic unit with which the engineering of the bridge is likely to have much to do, the succeeding formation of the Detroit River Group needs little comment. It occupies a wide belt of land in the northern part of the Southern Peninsula between the areas occupied by the Bois Blanc and Dundee Strata. The formation consists essentially of limestone and dolomites, some portions of which may appear in the Mackinac Breccia of the Straits area.

Dundee Limestone

The Dundee limestone overlies the Detroit River beds and lies unconformably over the Mackinac Breccia which was formed during the interval between the deposition of the Pointes aux Chenes beds and the Dundee limestone.

The Mackinac Breccia

The most prominent rock formation in the Straits area is the Mackinac Breccia which is made up largely of fragments and masses of earlier strata that range in age from Silirian to Mid-Devonian, and these are included in sediments of Mackinac age. This formation occurs on both sides of the Straits and it is the principal rock that crops out on the St. Ignace Peninsula. The rock fragments involved in the brecciation range in age from the Pointes aux Chenes formation

through the St. Ignace, Bois Blanc and Detroit River beds. The lowermost Pointe aux Chenes beds are not brecciated, nor are the Dundee limestones and younger formations lying above.

Brecciation occurs on varying scales. In places great blocks of dislocated sedimentary strata form part of the breccia. These blocks may be tilted up to 25°, and oriented entirely at random. They may be hundreds of feet long. The lateral boundaries of the blocks are marked by faults and slickensided surfaces. Their base is seldom or never seen. Some of these blocks have dropped further downward than others and appear unexpectedly. In places intra-formational breccias have been noted within displaced blocks, overlain and underlain by undeformed strata. There are in addition vertically disposed breccias that cut through the entire stratigraphic section, from the Detroit River beds to the Pointes aux Chenes formation.

Origin of the breccias is discussed at length by Landes. He sets forth a very reasonable conclusion, that deposition of salt and gypsum in the Pointe aux Chenes formation was the first step. He estimates that as much as twelve hundred feet of salt beds are contained in the formation at a point as far north as Alpena County. Landes believes that the St. Ignace Peninsula was also once underlain by salt-bearing beds which in turn were overlain by the Bois Blanc dolomites, cherts and limestones and the Detroit River dolomites and limestones of the regular series. He argues that deposition of these beds was followed by emergence of the land above sea level, and that in this time salt was leached by groundwaters from the emerged rim of the salt basin, producing a vast series of caves and caverns where the Pointes aux Chenes salt lay above the water table. Collapse followed, as the formation of large caves created instability. We need not pursue the details of this process further, but the important implications of such a process are not difficult to state.

The process of collapse was complete before the Dundee limestones were deposited. In fact, a long period of erosion must have ensued before these

latter beds were deposited. Moreover, a thick section of sedimentary strata succeeded the deposition of the Dundee bexs. All this occurred millions of years ago.

It is to be expected, therefore, that this chaotic mass of dislocated and brecciated beds has been re-consolidated by immense loading and re-cemented by circulating waters to present fair stability. It is our opinion that the formation as a whole is reasonably sound in so far as the process surrounding its first collapse is concerned.

But we know that the breccia contains fault planes, gouge, joints, breccia fragments, all of which, even if sealed, are incipient planes of weakness and may have to be taken into account in estimating the strength of footings and the desirable distribution of loads.

The Significance of An Ancient Inter-Glacial Stream Valley In The Straits of Mackinac

The history of the glacial period was a long one. Ice invaded and retreated from the region of the Straits a number of times. Consequently the shape, extent and elevation of the lakes changed greatly from time to time, depending on the position and elevation of their outlets and the position of the advancing or retreating ice sheet.

There appears to be substantial evidence that a river flowed eastward through what are now the Straits of Mackinac in recent glacial time. Soundings have defined the position of the main course of the stream and probings and drillings have developed a partial rock profile of its valley, at least between St. Ignace Peninsula and the tip of the Southern Peninsula. These facts may be of some importance, especially with respect to the contour of bedrock and the distribution of the associated glacial overburden that may be present at proposed pier footings.

The presence of a deep valley between the peninsulas, through which a river flowed, means that this entire area once stood above a sloping water

table, the lowermost point of which was the river level. Such a water table sloped upward from the river, lay beneath its valley walls and beneath the bordering uplands. Since we know that the Pointes aux Chenes formation contained limestones and beds of gypsum, it is possible that solution of these rocks, where they stood above the water table, may have been active for a long time.

Solution of this kind has taken place to some extent, and is taking place today, on the surface of Mackinac Island and on the St. Ignace Peninsula. Sink holes are present; cavities are developing, and there must be some underground water circulation with outlets to the lake. Glacial deposits now cover most of these features. Therefore, no one can predict with any degree of precision how porous or permeable the shoulders of the submerged valley walls and the uplands of the submerged hinterland may be. The ancient topography of this terrain has not been explored sufficiently to know whether sharply cut tributaries to the main stream indent its bordering upland.

All of these factors indicate that exploration by careful drilling and sampling of overburden is important, and core drilling of bedrock, especially directed toward the recovery of cores and the appraisal of geologic conditions, is even more important. At each main proposed pier at least four holes (three-inch core drills) should penetrate bedrock not less than seventy-five feet, and further drilling should be undertaken if new discoveries call for it. Probings should also be undertaken in the vicinity of the pier sites to insure at least some knowledge of the conformation of the rock surface.

Conclusion

In conclusion, it appears on every count that the value of the pier sites cannot be predicted from observation of the present exposed land surfaces

alone. Such observations as can be made, and such geologic interpretations as are reasonable, indicate that non-uniformity is to be expected in bedrock. The normal stratigraphic succession has been disturbed in an unpredictable fashion, and the effects of solution in interglacial time may be of practical importance.

Despite the complex history and unusual geological structural conditions indicated at this site, there is no good reason to condemn it as impracticable. It is absolutely necessary, however, to make suitable exploratory borings to determine the actual physical condition of the ground that has to support this great proposed structure. There is ample experience in the field of construction for the treatment of any questionable ground that may be discovered. The foundation thus treated, if necessary, in our opinion would be amply strong enough to carry the moderate loads that will be imposed upon them.

Charles P. Berkey

Charles P. Berkey
Consulting Geologist

Sidney Paige

Sidney Paige
Consulting Geologist

July 23, 1957
D.M.G.

St. Ignace-Mackinac Bridge Is 70-Year-Old Dream Come True; First Suggested Back in 1884

Editor's Note — The following story on the linking of the state's two peninsulas by the Mackinac Bridge is taken from a recent issue of "Better Roads" magazine. It is an interesting and informative narrative which brings construction close to the present date. Lawrence A. Rubin is the author.

Mackinac Bridge, now under construction, which will span the 4-mile wide Straits of Mackinac between St. Ignace and Mackinaw City and connect Michigan's upper and lower peninsulas, is a 70-year-old dream come true.

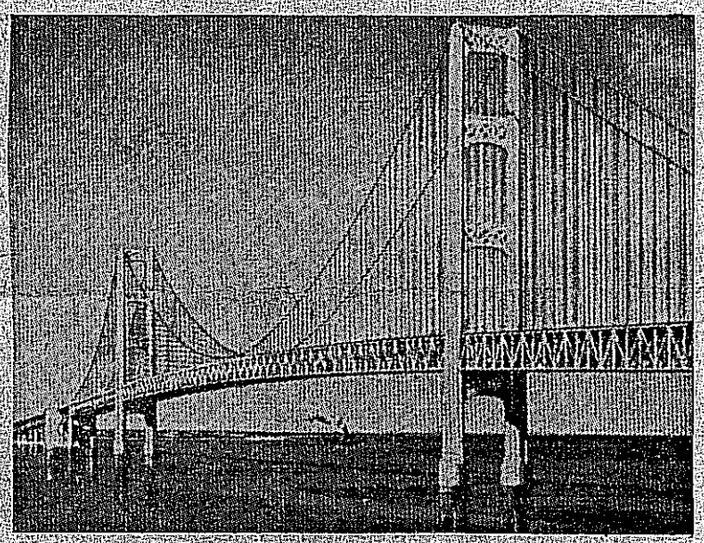
A faded editorial page of the Lansing, Mich., Republican, dated Feb. 5, 1884, reprints a story from the Grand Traverse Herald, pointing out that the experiment to provide year-round service across the straits by boat had failed and that a bridge or tunnel would be required if a great east-west route were ever to be established through Michigan. Dedication of the Brooklyn Bridge in New York city in 1883 apparently gave backers of a Mackinac bridge encouragement. A St. Ignace store owner in 1884 applied the thought to his advertising, both in the local weekly newspaper and on his store's wrapping paper. He reprinted an artist's conception of the famous New York structure and captioned it, "Proposed Bridge Across the Straits of Mackinac."

Ferries Begun in 1923

In 1923 the state legislature ordered the state highway department to establish a ferry service at the straits. Within five years, traffic became so heavy that the late Governor Fred Green ordered the same agency to study the feasibility of a bridge. The report was favorable and the cost of the bridge was estimated at $30,000,000. Some steps to get the project under way were taken but it was eventually dropped.

A Mackinac Straits Bridge Authority was created by an extra session of the legislature in 1934; the authority was empowered to investigate the feasibility of constructing a bridge and to finance the work by issuance of revenue bonds.

The authority found that a two-lane highway and one-track railway bridge could be built for not more than $32,400,000. Two attempts to obtain loans and grants from the Federal Emergency Administration of Public Works were made between 1934 and 1936, but the applications were refused. The state highway department support-



THIS IS an architect's sketch of the $100,000,000 Mackinac Bridge. Each of the main steel towers will be 552 feet above water and built on piers based on rock 195 feet below the water. The main suspension span will be 3,800 feet long. The total length of the structure is 26,195 feet.

quested the Reconstruction Finance Corp. to purchase $85,000,000 worth of bonds. While this agency was studying the request, a private investment banker became interested in the project and offered to manage a group of investment dealers who would underwrite the sale of the bonds. The authority accepted the offer.

Bond Market Weakens

While the investment group was being formed and the steps necessary for financing were being carried out, the bond market was weakening. By March, 1953, when the authority was ready to offer its bonds for sale, investors in securities of this type were simply not interested in buying.

In order to increase the marketability of the Mackinac Bridge bonds, the legislature in the spring of 1953 passed an act to provide that operating and maintenance costs of the structure would be paid out of highway department funds. Another effort to finance the bridge with this added inducement was unsuccessful in June, 1953, but toward the end of the year the market recovered and $99,800,000 worth of Mackinac Bridge bonds were bought by investors all over the country.

Contract that had been awarded contingent on financing were immediately implemented. Merritt—Chapman & Scott Corp., New York, N. Y., was awarded a $25,700,000 contract to build all the foundations, and the largest bridge-construction fleet ever assembled.

The north approach, 3,610 feet long, contains 12 deck-truss spans. The approach trusses are 34 feet wide, varying from 16 to 53 feet in depth.

The structure will carry a 48-foot roadway to accommodate four lanes of traffic with the opposing traffic separated by a raised center mall 2 feet wide. The two outer lanes will be 12 feet wide and the two inner lanes will be 11 feet wide. Two three-foot sidewalks

(Continued on Page 2)

St. Ignace

Continued From Page 1

for maintenance and emergency use will be provided. The bridge will provide a minimum clear height at the center of the main span of 148 feet, sufficient to allow passage of the largest ships plying the Great Lakes.

When it is completed the entire structure will weigh nearly 1,000,000 tons; 75 per cent of this weight will be under water. With favorable weather it is expected that the bridge will be opened to traffic ahead of the scheduled opening date of Nov. 1, 1957.

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The authority found that a two-lane highway and one-track railway bridge could be built for not more than $32,400,000. Two attempts to obtain loans and grants from the Federal Emergency Administration of Public Works were made between 1934 and 1936, but the applications were refused. The state highway department supported the project and managed to have considerable work completed, which has been of great value in constructing the present structure.

From 1936 to 1950 borings were made, a new direct route selected, and traffic, geologic, ice and water-current studies of a very comprehensive nature were completed. A mole or causeway jutting 4,200 feet into the straits from the St. Ignace side was constructed. Preliminary plans for a double suspension span were drawn and the possibility of a bridge became very real.

But the second World War halted further progress. Finally, in 1947, the legislature abolished the Mackinac Straits Bridge Authority. Then a citizens' committee was established to obtain legislation recreating a bridge authority. By 1950 the legislation was enacted but it limited the authority to determine feasibility only.

Adventures, Crises Numerous

Since the creation of the present Mackinac Bridge Authority in 1950, its history is filled with enough adventure and crises to provide material for a full-length novel. Perhaps every obstacle that could be placed in the way of a project of this kind had to be overcome by the members of the authority, their engineers and now the contractors. But just as surely as the authority overcame its greatest hurdle—selling $99,800,000 worth of bonds—so are the problems of construction now being solved as rapidly as they arise by the engineers and the contractors.

The 1950 law required the authority to consult with three of the world's foremost long-span bridge engineers for advice on physical feasibility, and with traffic analysts to determine the possibility of the structure's becoming a self-liquidating facility.

In January, 1951, the authority submitted a very favorable preliminary report, declaring that a bridge could be built and financed with revenue bonds for $86,000,000. The authority did not request powers to finance and build the structure because of the shortage of materials caused by the war in Korea. The material situation eased early in 1952 and the legislature granted the authority the power to build and finance the bridge.

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Contract that had been awarded contingent on financing were immediately implemented. Merritt—Chapman & Scott Corp., New York, N. Y., was awarded a $25,700,000 contract to build all the foundations, and the largest bridge construction fleet ever assembled was mobilized at the site. The American Bridge division of United State Steel Corp., awarded a $45,000,000 contract to build the superstructure, began its work of planning and assembly.

Center Span, 3,800 Feet Long

The over-all length of the entire structure is 26,195 ft., of which 17,918 feet is of steel construction. The structure will consist of a center-span suspension bridge 3,800-ft. long —the second longest in the world—two 1,800-foot side suspension spans and two 472-foot unloaded backstay spans. The towers will extend to a height of 552 feet above low water. They are of the conventional flexible type of cellular construction with fixed bases. The two shafts of each tower are connected at four levels by horizontal struts of open-truss construction. The height of the towers above water is equivalent to a 46-story office building. Cable anchorages will each contain about 85,000 cubic yards of concrete, and will be capable of resisting a total pull from both cables of 60,000,000 pounds.

The 5,694-foot south approach is made up of 16 deck-truss spans.

(Continued on Page 2)

St. Ignace

Continued From Page 1

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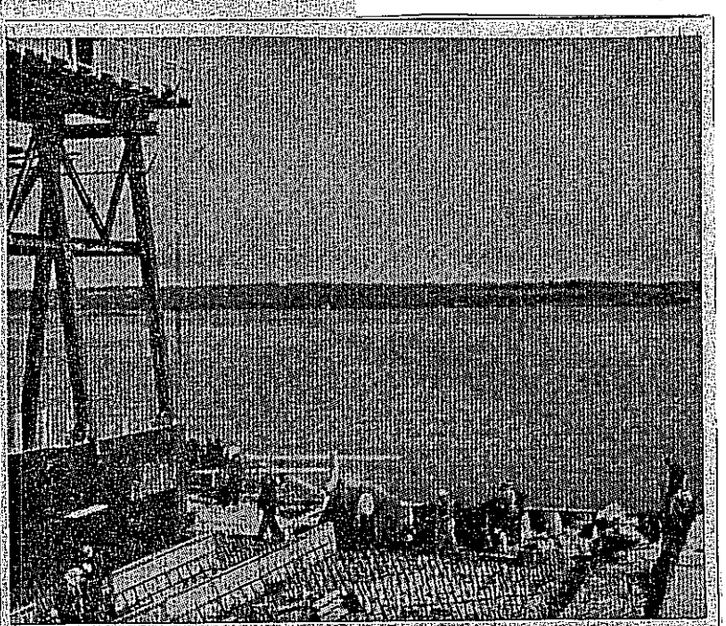


ERECTING FORMS and a trestle on the north cable anchorage foundation. A crane mounted on top of the trestle will facilitate the erection of the concrete superstructure in which the cables will be anchored. The anchorage will each contain approximately 85,000 cubic yards of concrete, capable of resisting a total pull from both cables of 60,000,000 pounds. More than 60,000 barrels of cement will be used for piers and anchorages.

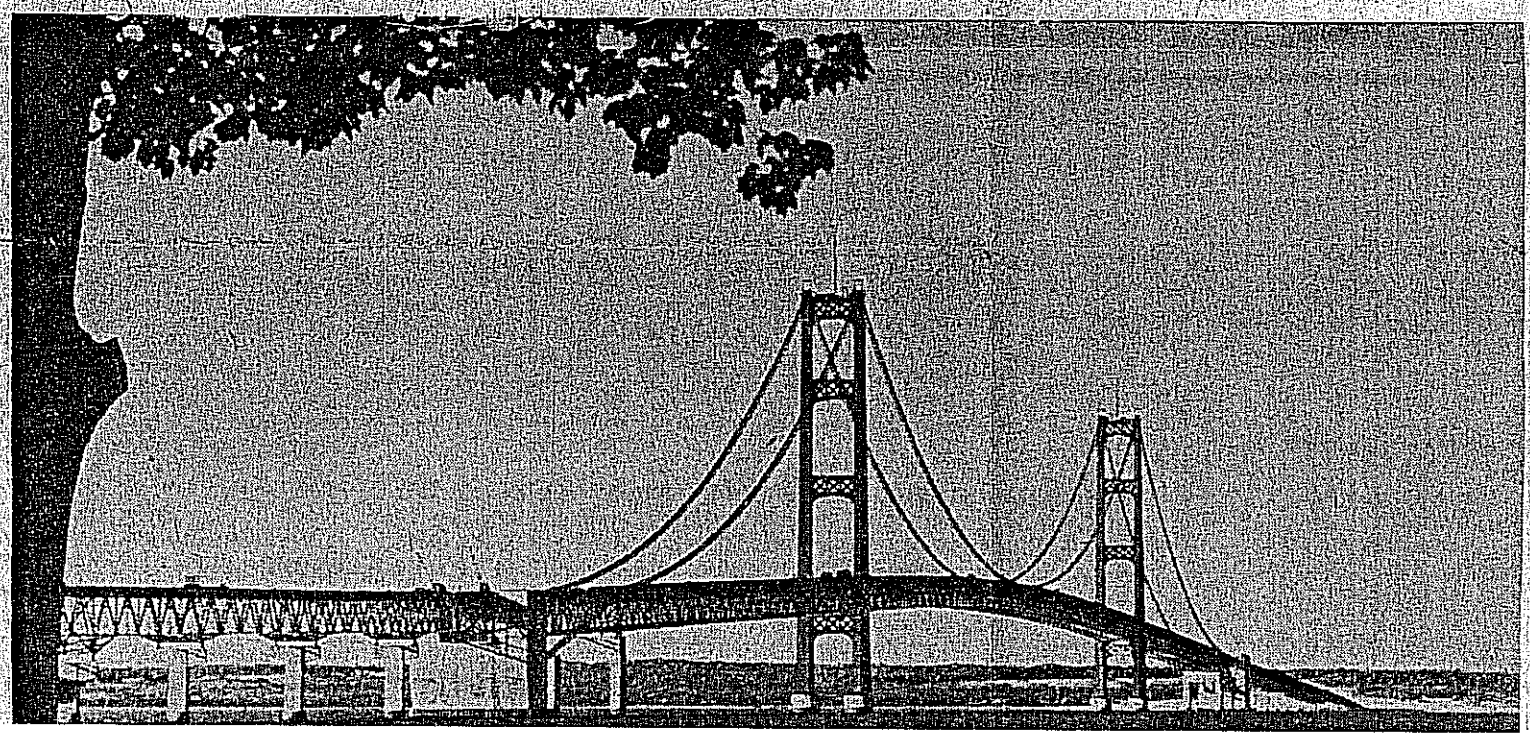
ily Mining Gazette

ME NEWSPAPER FOR MORE THAN 99 YEARS
argest Trading Area Circulation, Daily or Weekly, in the Copper Country

HOUGHTON, MICHIGAN, FRIDAY, NOVEMBER 1, 1957 TWELVE PAGES PRICE SIX CENTS

Children often hold a marriage together—by keeping the parents too busy to quarrel with each other.
—Franklin P. Jones.

Cars Now Streaming Across Straits of Mackinac Bridge



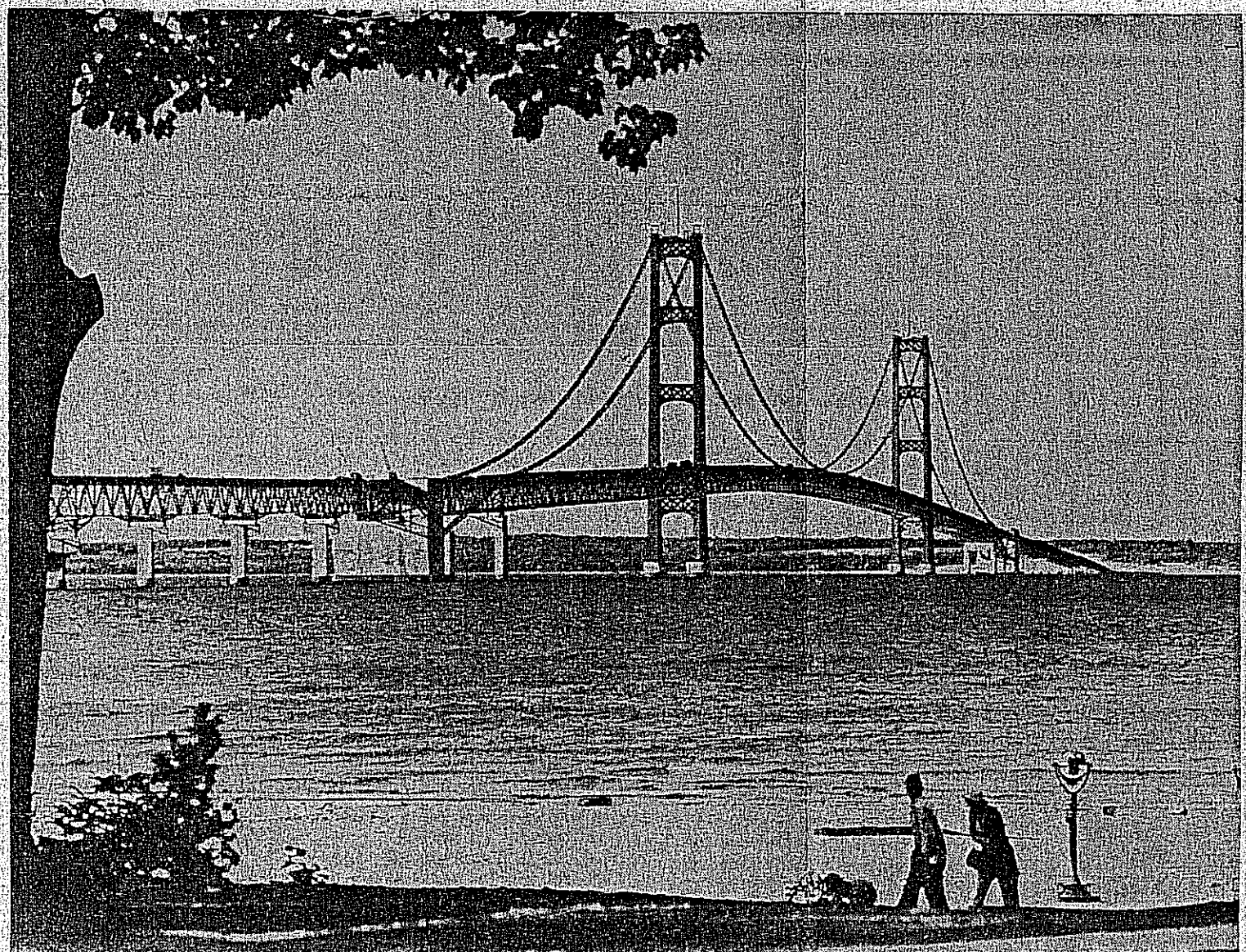
Governor Buys First $3.25 Toll Ticket

ST. IGNACE (AP)—Michigan today threw open the newest and costliest of the world's wonder bridges.

It is the Mackinac Bridge, which joins Michigan's two peninsulas for the first time since the Glacial Age.

It cost 100 million dollars and stretches five miles across the Straits of Mackinac between Lakes Michigan and Huron. Its 7,400-foot suspension span dwarfs any other and the towers that support it to reach up 552 feet—47 stories—

Cars Now Streaming Across Straits of Mackinac Bridge



THIS IS IT—Michigan's 100 million dollar Straits of Mackinac Bridge over which cars began streaming between the upper and lower peninsulas today for the first time. Rising 47 stories above the straits, the span stretches 5 miles and can be crossed by car in 10 minutes. Dedication ceremonies began this morning with Gov. Williams, state lawmakers and hundreds of guests on hand, including several former Copper Country residents now prominent in Detroit and Michigan industry. (U. S. Steel Photo)

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Gov. Williams led an opening caravan across the four-lane span in the formal opening ceremony, taking off from St. Ignace at the northern terminus around 11 a. m. for Mackinaw City at the southern end.

OPEN TO PUBLIC AT 2 P.M.

First public use was expected to begin around 2 p. m., following the caravan's return to the St. Ignace side where Williams bought the first $3.25 toll ticket to symbolize there are no passes to anyone.

Otherwise there was little ceremony and no lengthy speeches. Both these will come next June when the bridge is formally dedicated.

With opening of the bridge, financed by bonds to which tolls are pledged, service ended on the

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With opening of the bridge, financed by bonds to which tolls are pledged, service ended on the State Highway Department's auto ferries that had chugged across the straits since 1923.

BEGAN MARCH, 1954

Ferry crews threw a farewell party aboard for Williams, legislators and other dignitaries here for the opening.

Bridge construction began in March, 1954. Today's opening was on the precise day forecast for it then by its designer, Dr. D. B. Steinman of New York.

The bridge employs 53 persons, some of them from the ferries that went out of business.

Buses will carry pedestrians across the five-mile span. The trip will cost 50 cents and a bus will leave each side every hour and a half, increasing trips in the vacation season.

6,000 CARS AN HOUR

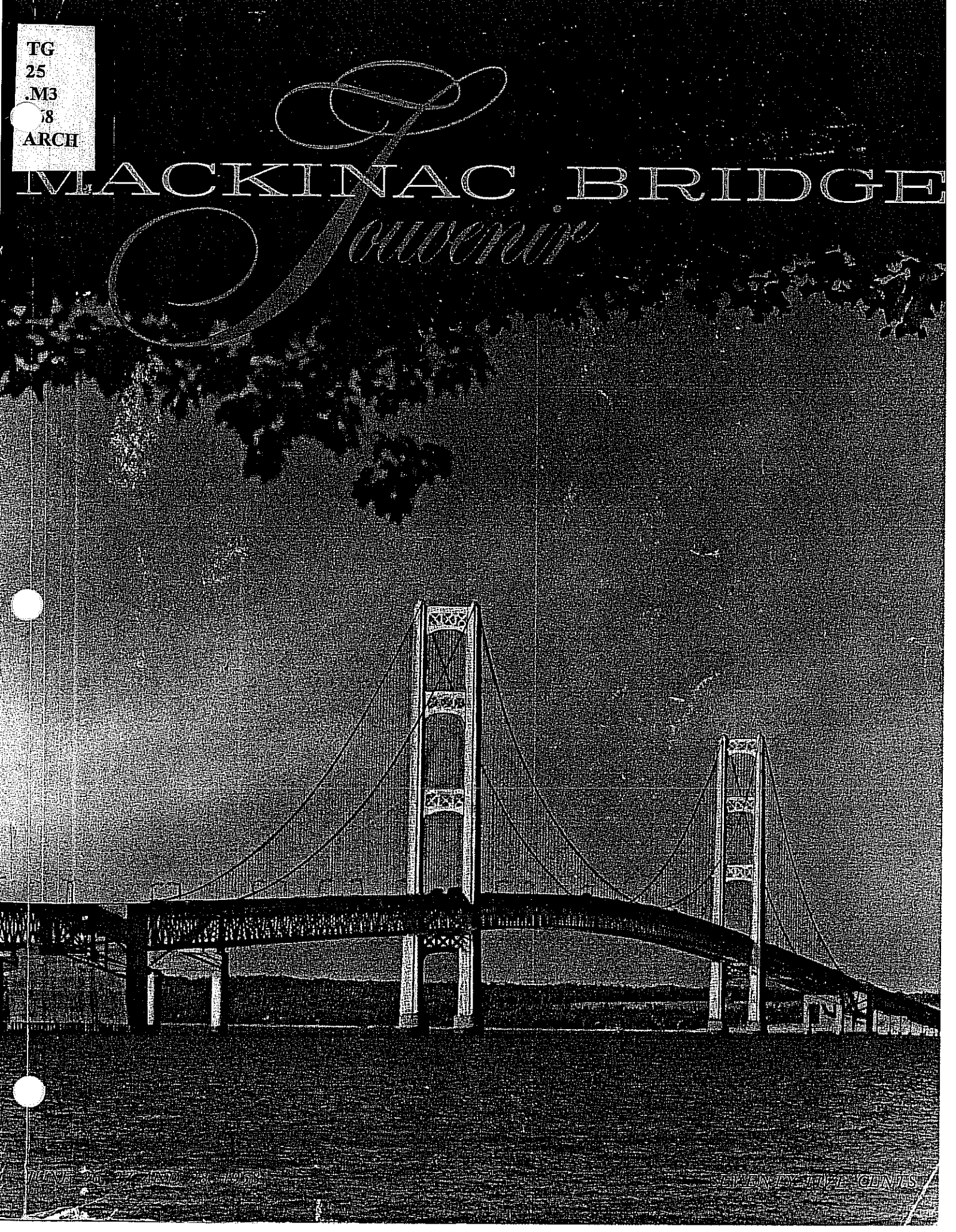
Five men lost their lives in the four-year building of the bridge, which will cut an estimated hour and a half to five hours—100 to 400 miles—off travel between the peninsulas.

It took the ferries 55 minutes to cross the straits. Lineups of automobiles waiting to get across sometimes stretched back for miles.

The ferries, loaded to capacity, could carry fewer than 500 cars each trip. The bridge can handle 6,000 cars an hour and it takes only 10 minutes to cross.

MACKINAC BRIDGE

Souvenir



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OFFICIAL
MACKINAC BRIDGE SOUVENIR BOOK
Dedication Festival June 26th, 27th, 28th, 1958

Published by Mackinac Bridge Dedication Festival Committee

DEDICATION FESTIVAL SOUVENIR BOOK COMMITTEE

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CREDITS

The thanks of the Souvenir Book Committee of the Dedication Festival are extended to all who so kindly assisted in the preparation of the editorial content of this book: Prentiss M. Brown, chairman, Mackinac Bridge Authority, Lawrence A. Rubin, executive secretary, and Herman Ellis and his assistant, Harold Bell, for bridge photographs; Eugene T. Petersen and the Michigan Historical Commission, Henry Brown and the Detroit Historical Society, Alfred H. Whittaker, M.D., of Detroit and Mackinac Island; Lynn Bartlett and the Detroit Public Library staff; and for the privilege of consulting source material in Mackinac area publications, also to the many other individuals whose help was so readily extended.

EDITORIAL FEATURES

ABOUT THE WRITERS

Heading the list of editorial features is the official welcome by Michigan's Governor Williams, followed by a message from Prentiss M. Brown, chairman, Mackinac Bridge Authority. Calling attention to a "Great Moment" in Michigan history is Walker Cisler, president of Detroit Edison Company and Dedication Festival chairman.

Warren D. "Case" Devine is a Detroit editor and writer with 30 years of experience. George W. Stark, Detroit's historiographer and famous writer for the Detroit News, needs no introduction. Dr. David B. Steinman, the bridge consulting engineer, contributes another of his excellent poems. Lawrence A. Rubin, Authority executive secretary, is most qualified to explain how the bridge operates.

Frank Davis knows tourists from his observation post as secretary manager of the East Michigan Tourist Association. G. S. McIntyre is director of the Michigan Department of Agriculture. August Scholle speaks for labor as president of the Michigan State AFL-CIO, and J. M. "Jack" Pickell for industry as publisher of the Michigan Manufacturer and Financial Record.

Price per copy: 75 cents
For small quantities and special bulk rate information, write:
Mackinac Bridge Dedication Festival Souvenir Book Committee,
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The views of the writers in this book are their own and do not necessarily reflect those of the Mackinac Bridge Authority and the Dedication Festival Committee.

MICHIGAN'S MIRACLE BRIDGE

by D. B. STEINMAN,
Consulting Engineer

In humility and reverence
we dedicate this work of faith.
And with pride we behold what
vision, courage and determination
have wrought.

A poem in steel.
A dream-span on bed-rock.
A symphony in metal and stone.
The mystical union of beauty and
strength.
A lyric pattern etched
against the blue.
God working through man to confute
the powers of evil and to add another
stanza to the hymn of creation.

This is the Song of the Bridge:
With hammer-clang on steel and rock.
I sing the song of men who build.
With strength defying storm
and shock,
I sing a hymn of dreams fulfilled.
I lift my span, I fling it wide,
And stand where wind and
wave contend.
I bear the load so men may ride
Whither they will, and to what end.
The light gleams on my
strands and bars
In glory when the sun goes down.
I spread a net to hold the stars
And wear the sunset as my crown.

With humble pride and wonder, we
look up to gaze upon the Bridge.
Outsoaring gravity and space, it
rises from the waves on shining
strands to arch across the sky
in lofty grace.
Seen from above, a battleship
appears dwarfed like a toy beneath
the vaulting span.
This is our triumph over ancient fears.
A Bridge of Peace,
wrought of the dreams of man!

Before it was built,
we envisioned the Bridge.
We saw it clearly and
clairvoyant bright:
Twin sky-piercing towers
of majestic rise.
The power-packed cables in
symmetry of parabolic arcs.
The titan uplift of the singing strands.
The lofty roadway bearing multitudes
high above the waves.
And deep beneath the waves and
tides, the massive caissons founded
upon bed-rock, enduring as
the pyramids.

There is timeless strength in those
towers and poetry in the cable-borne
span. The two are
harmoniously joined.
Between the two pierced steel
towers, framing the azure of the
sky, the arching roadway slowly
sweeps upward to meet the swift
downward sweep of the cables.
These curves and proportions
were not accidents.

It is no accident that the Mackinac
Bridge is a thrill to the beholder,
to lift the heart with pride and
the soul with thankful prayer.
It was planned that way.
A lifetime of dedicated purpose,
long years of consecrated effort,
the highest yearnings of the human
soul, went into the planning and
building of this masterwork.

85,000 Blueprints.
A million tons of concrete and steel.
Twenty-million man-hours of
sweat and toil and courage
and sacrifice.
But, above all these, the
priceless ingredient—
the Spirit of Consecration.
And that includes the qualities
of vision, devotion, inspiration
and integrity.

That is why the Mackinac Bridge
will endure.
That is why the Mackinac Bridge
is majestic.
And that is why the Mackinac Bridge
is beautiful.

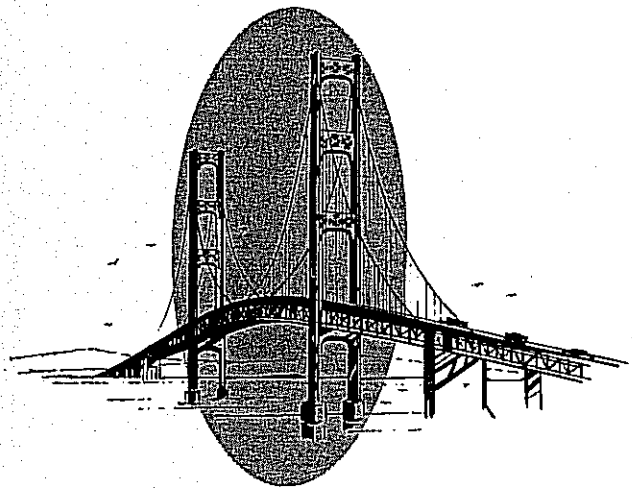
In the planning and building of
Michigan's Miracle Bridge, no effort
was spared, nothing was stinted.
The highest attainments of the
science and art of bridgebuilding
went into the design.
The best qualities of materials and
workmanship went into the
construction.
The finest qualities of honor and
loyalty and teamwork went into
the consummation of this
great project.

These are eternal verities:
There is no excellence without effort.
There is no achievement
without vision.
There is no consummation
without faith.

The Mackinac Bridge is a triumph of
science and art.
But, more than that,
the Mackinac Bridge is a monument
—an enduring monument to vision,
faith, and courage.
Without the vision, faith, and courage
of the people of Michigan—
their leaders, their statesmen,
their workers—this great Bridge
could never have been built.

This is the heroic saga
of the Mackinac Bridge:
Generations dreamed the crossing;
Doubters shook their heads in scorn.
Brave men vowed that
they would build it—
From their faith the Bridge was born.
There it spans the miles of water,
Speeding millions on their way—
Bridge of vision, hope, and courage,
Portal to a brighter day.

—D. B. Steinman



Bridge Across the Straits...
Symbol of Hope, Faith and Effort

by PRENTISS M. BROWN
Chairman, Mackinac Bridge Authority

THIS magnificent bridge which spans the Straits between Mackinaw City and St. Ignace effects at last a direct physical connection between Michigan's Upper and Lower Peninsulas. That this is so, is the realization of our fondest dreams. It stands as an appropriate symbol of the hope of Michigan people that one day the bridge might exist, their faith that it would be built and their efforts to surmount all obstacles to make it possible.

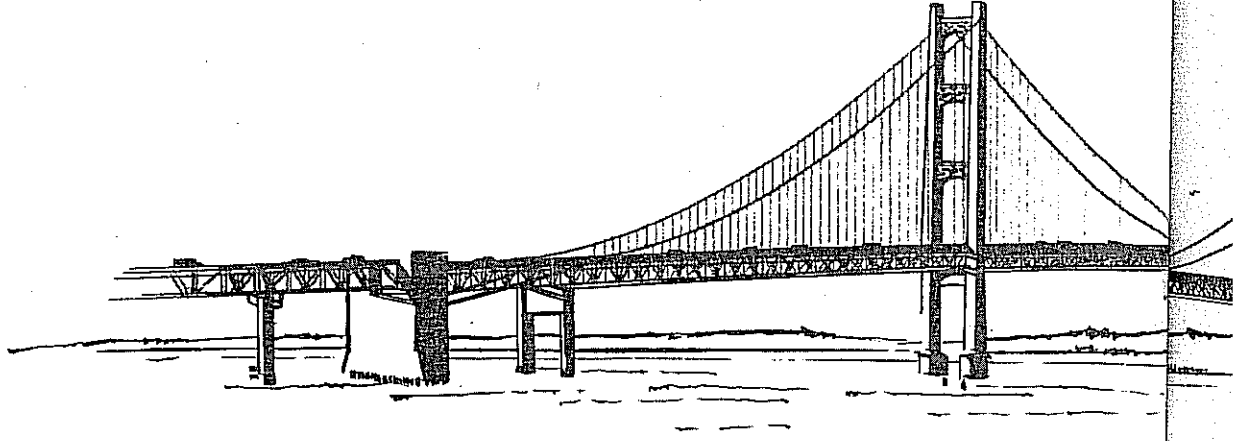
This brochure is a souvenir of the dedication of the Mackinac Bridge. May I humbly suggest that you save it and in time pass it on to your children and urge them to pass it on to their children. For beyond even them the Mackinac Bridge will still be carrying persons over the beautiful Straits of Mackinac, tying our two Peninsulas together.

However, as time goes on people will come to realize that this bridge is more than a physical link between Upper and Lower Michigan. True, we now have an all season, safe and dependable crossing. Not only have we bridged a physical barrier, but we have bridged a social barrier, and travel between the two Peninsulas is taking on a fresh, new concept in the minds of citizens on both sides of the Straits.

This is the first step. It will lead, at the outset, to more recreational travel which the bridge mainly serves. This in turn will attract more residents to the areas on both sides to serve the increased numbers of tourists. Soon this growing population will require more schools, more libraries, churches and all the other social and cultural facilities and advantages that accompany people wherever they go.

Also, in due course the cost of crossing the bridge will be decreased so that the financial barrier will be inconsequential. Mackinaw City and St. Ignace will grow and gradually they will be almost the same as a single community, as are many cities the world over connected by a bridge. This idea of the two communities being as one will spill over and spread throughout the entire Upper and Lower Peninsulas. The people of southern Michigan will learn about and become acquainted with the wondrous beauties of the North, and the residents of the North will point with pride at the industrial marvels of their state to the South.

Thus, Michigan will truly become one commonwealth — one great state, not just physically, but socially, culturally and spiritually. That process began some 75 years ago when men of vision urged a better connection at the Straits. We can consider ourselves fortunate to have seen completion in our time. But what we are now witnessing is simply another chapter in Michigan history. Many more chapters are yet to be written, and partly because of the Mackinac Bridge they will be great and good chapters.



the MACKINAC

PRENTISS M. BROWN, ***Chairman***

Born in St. Ignace, graduated 1911 Albion College, attended University of Illinois. L. L. D., University of Michigan, began practice of law in St. Ignace 1914. Mackinac County prosecutor 12 years, elected to Congress 1932 and served 10 years in the House of Representatives and the U. S. Senate. Appointed chairman of board, Detroit Edison Company May, 1944, retired July 1, 1954, but remained director. Trustee, Albion College; member, Michigan Historical Commission and other civic groups.

GEORGE A. OSBORN

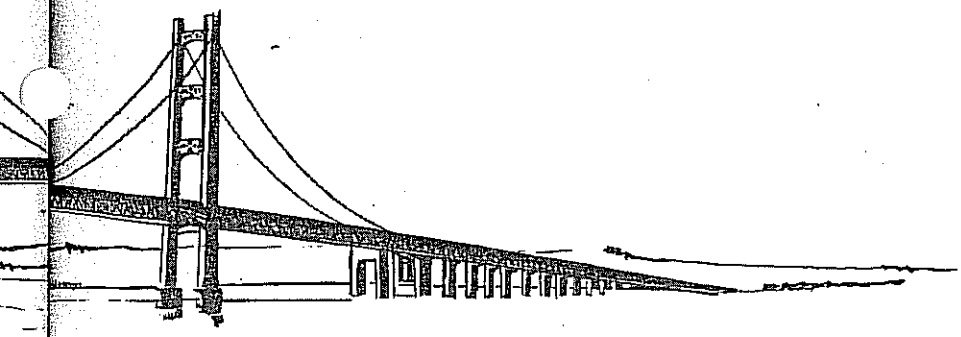
Born in Florence, Wisconsin, Editor and publisher, Sault Ste. Marie Evening News. Past president, Michigan Press Association, University Press Club of Michigan, Sault Ste. Marie Rotary Club. Chairman, Soo Locks Centennial Celebration Commission; former member Board of Control, Michigan College of Mining and Technology, member American Society of Newspaper Editors. Bachelor of Arts degree, University of Michigan.

MEAD L. BRICKER

Born in Youngstown, Ohio, pioneer automobile builder since 1904, Olds, Ford, Packard, Dodge, production manager Briggs Detroiter. Became general manager Willow Run Bomber Plant 1941. Elected Ford director 1943, vice president 1945, retired 1950. Member, Inter-Peninsula Communications Commission.

WILLIAM J. COCHRAN

Born in Hancock, Michigan, graduated University of Michigan 1947. Enlisted in Army 1942, commissioned 1943, separated as captain 1946. Director, Commercial National Bank of Iron Mountain, active in Army Reserve; member, Inter-Peninsula Communications Commission; past chairman, Iron Mountain Community Chest, Chamber of Commerce; president, Rotary Club.



BRIDGE authority

CHARLES T. FISHER, JR.*
Vice Chairman

Born in Detroit, graduated University of Detroit High School 1924, Bachelor of Science degree, Georgetown University 1928, Doctor of Laws 1939. President and Director National Bank of Detroit. Former state commissioner of banking, director Reconstruction Finance Corporation. Board member several leading business enterprises, served as director or officer on many public service groups.

**(Deceased)*

MURRAY D. VAN WAGONER

Born in Kingston, Michigan. Bachelor of Science degree in engineering University of Michigan 1921. Bridge division engineer State Highway Commission, Oakland County drain commissioner 1930-33, elected State Highway Commissioner 1933, Governor 1940. Became private consulting engineer Detroit 1943. Commissioner of Bavaria, Germany, U. S. Military Government 1948-50, delegate to International Road Congress 1938, past president American Road Builders Association.

JOHN C. MACKIE

Graduated Michigan State University 1942, civil engineering, one year-post-graduate course New York University. Enlisted Army Air Force, won commission and separated as 1st lieutenant. Established surveying business in Flint, Genesee County Surveyor prior to election 1957 as State Highway Commissioner. Member, Michigan Society of Registered Land Surveyors and Flint Exchange Club.

LAWRENCE A. RUBIN
Executive Secretary

Born in Massachusetts, graduated University of Michigan business administration. Started public relations business Detroit, then executive director Michigan Good Roads Association, Lansing. Appointed by Authority executive secretary July 1, 1950. Also secretary-treasurer International Bridge Authority for bridge at Sault Ste. Marie.

this is the MACKINAC BRIDGE

INTERESTING FACTS ABOUT THE BRIDGE

LENGTHS

Total length of bridge with approaches (5 miles)	26,444 ft.
Total length of steel superstructure	19,243 ft.
Length of suspension bridge (including anchorages)	8,614 ft.
Total length of north approach spans	7,129 ft.
Length of main span (between main towers)	3,800 ft.

HEIGHTS AND DEPTHS

Heights of main towers above water	552 ft.
Maximum depth to rock at midspan	Unknown
Maximum depth of water at midspan	295 ft.
Maximum depth of tower piers below water	210 ft.
Height of roadway above water at midspan	199 ft.
Under clearance at midspan for ships	155 ft.
Maximum depth of water at piers	142 ft.
Maximum depth of piers sunk through overburden	105 ft.

CABLES

Total length of wire in main cables	42,000 miles
Maximum tension in each cable	16,000 tons
Number of wires in each cable	12,580
Weight of cables	11,840 tons
Diameter of main cables	24½ inches
Diameter of each wire	0.196 inches

CONCRETE

Total concrete in bridge	466,300 cubic yards
Total concrete in substructure	451,000 cubic yards
Total concrete in one anchorage, No. 22	91,600 cubic yards
Total concrete in one pier, No. 19	80,600 cubic yards
Total concrete in superstructure	15,300 cubic yards

WEIGHTS

Total weight of bridge	1,024,500 tons
Total weight of concrete	931,000 tons
Total weight of substructure	919,100 tons
Total weight of two anchorages	360,380 tons
Total weight of two main piers	318,000 tons
Total weight of superstructure	104,400 tons
Total weight of structural steel	71,300 tons
Weight of steel, each main tower	6,650 tons
Total weight of cable wire	11,840 tons
Total weight of concrete roadway	6,660 tons
Total weight of reinforcing steel	3,700 tons

RIVETS AND BOLTS

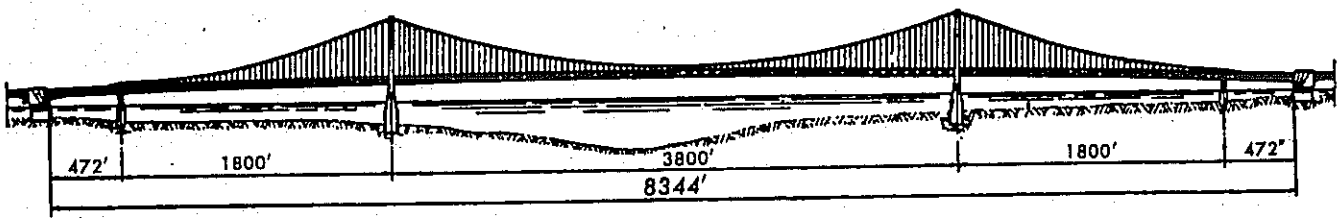
Total number of steel rivets	4,851,700
Total number of steel bolts	1,016,600

DESIGN AND DETAIL DRAWINGS

Total number of engineering drawings	4,000
Total number of blueprints	85,000

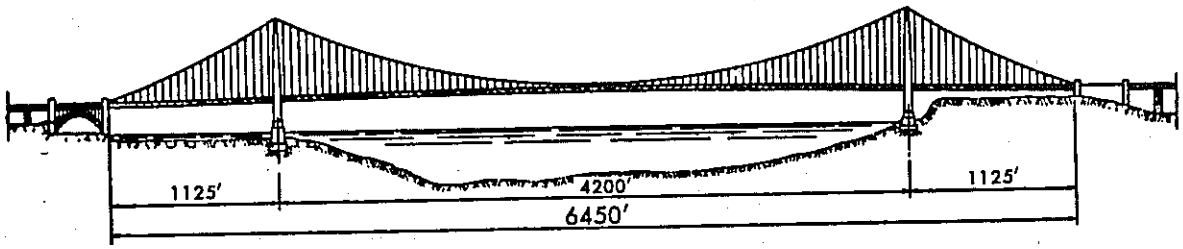
MEN EMPLOYED

Total at bridge site	3,500
At quarries, shops, mills, etc.	7,500
Total number of engineers	350

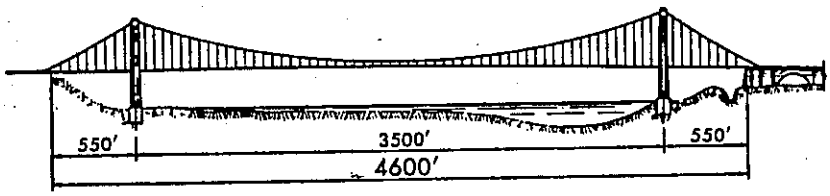


MACKINAC STRAITS BRIDGE

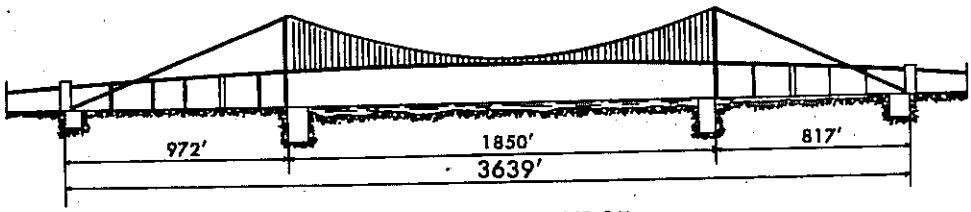
compared with other famous bridges



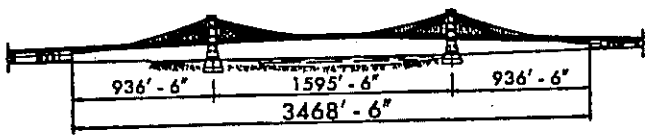
GOLDEN GATE BRIDGE



GEORGE WASHINGTON BRIDGE



AMBASSADOR BRIDGE



BROOKLYN BRIDGE

GREAT LAKES BOOKS BY WILLIAM RATIGAN

1954 — *Soo Canal!*

1955 — *Young Mister Big*

1955 — *Hiawatha and America's Mightiest Mile*

1956 — *The Adventures of Captain McCargo*

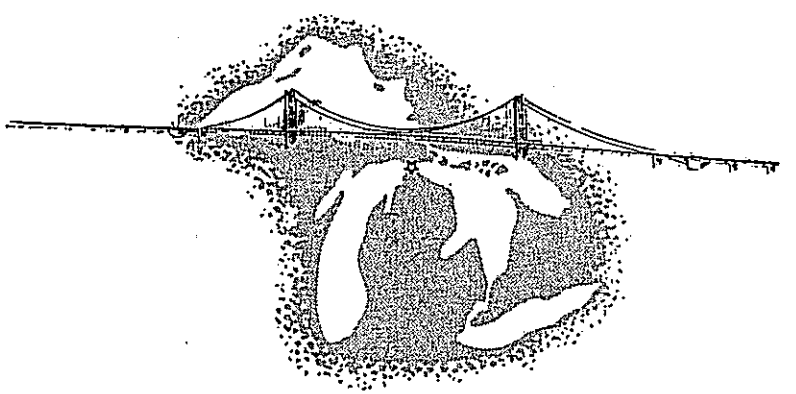
1957 — *Straits of Mackinac!*

STRAITS of MACKINAC!

CROSSROADS OF THE GREAT LAKES

by

WILLIAM RATIGAN



WM. B. EERDMANS PUBLISHING COMPANY
Grand Rapids, Michigan

STRAITS OF MACKINAC!
copyright
by William Ratigan
1957

Library of Congress
Catalog Card Number: 57-11587
First printing, June 1957
Second printing, November 1957

Once again
for
ELEANOR
PATSY and ANNE

PRINTED IN THE UNITED STATES OF AMERICA

MANITOU MICHILIMACKINAC

Who passed this way one yesterday?
Ten *voyageurs* with Pere Marquette.
Ten thousand ghost canoes and phantom sails are passing
yet.

Who passed this way another day?
Ahoy! who goes there now?
The same brigades; the Helmsman puts fresh lookouts
at the bow.

We pass this way toward yesterday.
One dark tomorrow lookouts on the bridge and stream
May fail to sight us. Did we pass, or dream?

Then tell me, *brother voyageur*,
As our paddles dip in the stream,
If no man marks the way we pass,
Did we pass, or do we dream?

W. R.

LIST OF ILLUSTRATIONS

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waters unmolested. Although all but one of the Great Lakes are divided by this international boundary, no warships patrol these waters. In this spirit of friendship and cooperation and the welcome beckoned to the vessels of all free nations to use this great international seaway, greater history is yet to be written as we continue to bend these Great Lakes to man's control.

—E. P. Forrestel
Rear Admiral U.S. Navy, Commandant,
Ninth Naval District, Great Lakes

INTRODUCTION

MACKINAC BRIDGE: CONQUERING THE IMPOSSIBLE

by

DR. DAVID B. STEINMAN

Not so long and wide the world is,
Not so rude and rough the way is.

SONG OF HIAWATHA

Both as an engineer and as a general reader who enjoys a rousing adventure classic, I admired "Soo Canal!" Therefore, I am pleased and proud to introduce the book that makes a perfect match for it, "Straits of Mackinac!" In this companion piece to "Soo Canal!" William Ratigan, who is wonderfully qualified to handle the dramatic story, celebrates the Mackinac spirit, the driving spirit of adventure that blazed trails through the wilderness and traversed wide waters to meet the challenge of long odds and to accomplish what lesser spirits deemed impossible. Just as in the past century the construction of a canal and pioneer locks at Sault Ste. Marie fell into this category, so also in this century did the building of a bridge at the broad and restless Straits of Mackinac.

The thought of connecting the two sections of the State of Michigan by a physical link across the Straits of Mackinac has challenged the imagination of engineers and the public for almost a hundred years. The difficulties, both physical and financial, appeared insurmountable. Various plans and designs were proposed from time to time during the past forty years. Some of the schemes would have been impossibly fantastic in cost. One official design for the proposed bridge would have collapsed before

completion. People (who were not engineers) said that the project was impossible.

In 1950 the present Mackinac Bridge Authority was created by the Michigan State Legislature. The Authority promptly appointed a Board of Consulting Engineers: O. H. Ammann, G. B. Woodruff, and the writer. In 1951 the three-man Board of Consultants reported that construction of the bridge was feasible.

In January 1953, the Authority selected the writer to design and supervise the construction of the bridge, and the writer engaged Glenn B. Woodruff as his Associate Consultant. However, the design of the Mackinac Bridge had been in the creative process long before this. It is the culmination of 17 years of intensive pioneering investigation by the writer of the scientific and mathematical principles involved in aerodynamic stability.

Commenced in July 1954, the construction of the bridge never once has faltered in its drive toward meeting the scheduled completion date in November of this historic and geopolitic year.

The total cost of the bridge, including the bond interest during construction, is $99,800,000. This figure establishes a new record for the magnitude and difficulty of a bridge project, and will certainly be a long-time record for a bridge carrying only four lanes of highway traffic and no railway loading.

People doubted the possibility of financing the Mackinac Bridge because it does not directly connect two large cities or population centers. But modern highway uses have enlarged our vision and our perspective. Within a radius of 500 miles from the Straits of Mackinac there resides a population of 30,000,000 people in the United States and Canada who will benefit from the construction of the Mackinac Bridge and who, in turn, insure the economic practicability of the project.

The main span at Mackinac is a suspension bridge, which is inherently the safest possible type of bridge. With

the startling destruction of the Tacoma Narrows Bridge in 1940 by cumulative catastrophic oscillations in a mild gale, the engineering profession was awakened to the importance of considering the aerodynamic problem in bridge design. The Mackinac Bridge represents a triumph of the new science of suspension bridge aerodynamics pioneered by the writer. The fundamental principles used in the design of the bridge at Mackinac will be studied as a model for all future suspension bridges designed to stand a thousand years with absolute safety. These fundamental principles include the following basic points:

1. The phenomena of aerodynamic instability are not a mystery but can be reduced to predictive scientific analysis and prevention.

2. It is more scientific (and much more economical) to eliminate the cause of aerodynamic instability by scientific design than to build up the structure, in weight and stiffness, to resist the effects of aerodynamic instability.

3. The aerodynamic characteristics of any proposed bridge section are either already known or may be predictively determined by simple model tests on a small-scale section model. Expensive, time-consuming wind-tunnel tests on a full-bridge model or on an elaborate section model are not required in predetermining the design. It is unscientific and unnecessary to spend years in haphazard, trial-and-error experimentation.

Based on fundamental conceptions of the aerodynamic forces and moments acting on a bridge section, simple modifications of the conventional bridge cross-section have been devised by the writer to eliminate instability factors. These modified sections can be easily and inexpensively tested and developed by means of simple home-made office models, suspended from light springs and exposed to the breeze from an electric fan.

The writer has operated this simple equipment since 1940. The results of these elementary tests in his own office were then confirmed by Professor F. J. Maher in the

small wind tunnel at Virginia Polytechnic Institute. The model, only 8½ inches wide and 15 inches long, was constructed by Professor Maher to represent a 120-foot section of a bridge to a scale of ⅛ inch to the foot. Open-grid sections of the bridge deck and open railings were simulated by wire screening. The total cost of the model and the tests was $500. This paved the way for the $100 million dollar Mackinac Bridge.

To put his theories on the science of bridge aerodynamics to a decisive test, the writer, early in 1954, arranged for a thorough investigation to be conducted by Professor F. B. Farquarson in the Suspension Bridge Laboratory at the University of Washington.

The dynamic model used for these elaborate wind-tunnel tests was 60.75 inches long, build to 1/50 scale, representing a 253-foot section of Mackinac Bridge, with details of shape and weight distribution reliably duplicated. The tests, which cost $15,000, were made in an open-jet wind tunnel with a wind jet 12 feet long and 4 feet high.

Professor Farquarson had to revise his test equipment when he found that this bridge had features of stability much higher than had ever been previously investigated, including studies of the Golden Gate Bridge obtained in the wind tunnel at Stanford University as well as studies of the Bronx-Whitestone, the George Washington, the New Tacoma Narrows, and other bridges tested in various foremost wind tunnels such as that in the Guggenheim Aeronautic Laboratory of the California Institute of Technology. In fact, some of the safety features in the design of the Mackinac Bridge were too high to be fully duplicated in Professor Farquarson's model.

The extensive wind-tunnel tests at the University of Washington Engineering Experiment Station showed that the Mackinac Bridge, under normal conditions, could withstand all wind velocities at all angles of attack. The model, in tests representing the worst possible condition — that is, with all roadway and sidewalk grids closed solid,

as if every opening were completely covered by ice — showed that the bridge still would be able to withstand winds up to critical velocities of 632, 942, and 966 miles per hour.

Since these velocities may be dismissed as fantastically impossible, the Mackinac Bridge must be regarded as representing the achievement of a new goal of perfect aerodynamic stability, never before attained or even closely approximated in any prior suspension-bridge design. The highway across the Straits is one hundred percent safe, even under the most adverse conditions that could conceivably occur.

The fact that the Mackinac Bridge has been designed and constructed as the ideal example of suspension-span safety combined with structural beauty is the result of the cooperative teamwork of officials, engineers, and contractors. The Mackinac Bridge Authority, under the chairmanship of Prentiss M. Brown and under the leadership of Governor G. Mennen Williams, has been outstanding for caliber, for competence, for judgment, for integrity, and for ability to put through a project despite all difficulties and obstacles.

This, truly, has been an inspiring project, this realization of the Mackinac dream. Consequently, it is a matter of pride and pleasure for me to present the introduction to "Straits of Mackinac!" because, in his rollicking enthusiasm for the North Country and the Upper Lakes, William Ratigan again has captured the irresistible spirit that, in all climes and in all ages, makes all great dreams come true.

The bridge builder and the empire builder, the voyageur and the engineer alike, must be touched with this dauntless spirit that thrives on conquering the impossible. I respect this book as the profile of a bridge, and as the portrait of a spirit mightier than all the concrete and the steel with which we have spanned the Straits. Without this compelling spirit that is always seeking a Northwest Passage of

one kind or another and forever refusing to acknowledge failure, there would be no Mackinac Bridge. In fact, there would be no United States of America or Dominion of Canada, but an unexplored wilderness still awaiting the brave arrival of adventurous men.

—D. B. Steinman
Consulting Engineer

Straits of Mackinac!

From South Anchorage, he had to cover another mile and a half before reaching shore, across twelve spans that, with the St. Ignace mole, formed the North Approach of Mackinac Bridge. There was some tight-foot walking on steel beams ahead because a small stretch of the approach was unfinished, but he made the trip in fine style and stepped ashore in St. Ignace a proud picture of a Michigander.

California has a fine *old* bridge,
The Golden Gate, they say.
We've got the biggest bridge of all
In Michigan-i-ay.
Yea, yea, yea, in Michigan-i-ay!

A hulking youth, sporting a queer haircut and city clothes, stopped to stare and snicker. But only for a moment. He scuttled away when the Watchman's eyes turned bleak as hailstones. The veteran sailor grinned and relaxed the tension in fists that always were ready to handle any trouble that came along.

Walking across the Straits had brought to mind, forcefully, the statement of a Michigan legislator on the occasion of the passage of the bill that brought the Mackinac Bridge into reality:

"The North and the South of the state have long been engaged. They now have a wedding ring."

Judging by the way his feet hurt, the Watchman, after bringing together the Lower and Upper peninsulas himself, felt as if he had been dancing his shoes off at the wedding.

3

MACKINAC MY MACKINAW

Ever thicker, thicker, thicker,
Froze the ice on lake and river,
Ever deeper, deeper, deeper
Fell the snow o'er all the landscape.

SONG OF HIAWATHA

Looking back at the "wedding bridge" across which he had "danced," the Watchman reflected it was high time the two peninsulas were united. There had been a long enough estrangement, dating back to early Michigan history when, during the so-called Toledo War, the newborn state had to surrender a strip of land to Ohio by authority of Congress, which blasted off the Upper Peninsula from an overcropping of Wisconsin Territory above the Straits of Mackinac and gave it to Michigan as a consolation. But the Lower Peninsula settlers were not consoled. Michigan's Siberia, they called the Upper Peninsula, a worthless expanse of frozen Lakes and sawed-off Rocky Mountains.

In a very few years, Iron Bay and Copper Harbor had come to stand for the mineral wealth of the treasure chest that Michigan had been awarded for loss of the thin strip of Ohio in 1837. But, until now, the water barrier at the Straits of Mackinac had kept the two peninsulas estranged.

From St. Ignace the Watchman looked back across the mighty link that finally had brought together Upper and Lower Michigan in an unbreakable connection forged with steel and stone, five miles long and 44 feet for good measure.

The Watchman knew; he had just measured it with his own shoes, from the Mackinaw shore!

It went through the Watchman's mind that, in all great creative works, a long time had to be spent in *dreaming* before the comparatively short time of *doing* began. Mackinac Bridge could be measured in space, but how far did it extend into the past? How many dreams ago?

The idea of both a bridge at the Straits and of a canal at the Soo, went far into the folklore of the Ottawas and the Ojibways. Around the Algonquin campfires in the misty past, when the pipe of peace, the *calumet*, went from hand to hand, the old chiefs told the story of Hiawatha who had been sent among the Tribes to clear their rivers, forests and fishing grounds — to *make a passage for the people, make a pathway safe and certain.*

After clearing a safe channel from Sault Ste. Marie into Lake Superior, the fabled Indian engineer came to the Straits and constructed a crossing with a bridge of stones picked up along the shore. According to the legend a great storm destroyed the bridge but remnants survive in what are now known as Bois Blanc, Round, and Mackinac Islands.

How many dreams ago did the white man vision a Soo Canal and a Mackinac Bridge?

In George Washington's last year as President, the Northwest Fur Company dug a narrow passage around the Falls of St. Marys on the Canadian side of the Sault and installed a tiny lock that was a toy forerunner of today's five giant Soo Locks. This project, more a dream than a practical reality, could accommodate only canoes or small *bateaux*, and it was destroyed by American forces in the War of 1812.

Three decades later, a half-hearted attempt at digging a canal on the American side of the Sault failed to reach the spadework point. Due to skulduggery and the difficulties of the undertaking, the private contractors welshed on their bargain with the State of Michigan.

The stage was set for Charles T. Harvey, a Connecticut Yankee in his early twenties, the teetotaler son of a Presbyterian minister, who came up the Lakes and past the Straits of Mackinac to give the world the greatest traveling-salesman story of all time, the one that begins:

"Have you heard the story about the traveling salesman who came to Sault Ste. Marie for a rest cure and stayed to build the Soo Canal?"

What impressed the Watchman on Mackinac Bridge most of all in the Harvey saga was that his only experience to qualify him for the most important construction project of the nineteenth century went back to the time when, as a boy of twelve, he had built a play bridge across a little creek running through the family back yard. In the sunset of his career, a white-bearded man full of honors, Harvey, in lecturing to a group of Canadian engineering students, had spoken with pride, not of the Soo Canal, but of the backyard bridge that had carried the hopes and plans of a boy.

How many dreams ago?

Perhaps, where the Watchman stood on the St. Ignace shore, Charles Thompson Harvey had stood a century in the past and *dreamed* the bridge that now united the two mainlands of Michigan.

Down through the years, there were different versions of the Mackinac Dream. After the *Grand Traverse Herald* first stated, in 1884, that there must be a sure and permanent crossing at the Straits, a definite trend toward realizing the dream seemed to develop, but there was no agreement on ways and means.

One Michigan official suggested a floating tunnel at the Straits. Someone else favored a series of causeways and bridges leading from Cheboygan on the mainland across to Bois Blanc and Round, and then over the west tip of Mackinac Island for a last leap across the channel to St. Ignace. This version of the dream may have been inspired by Hiawatha's mythical bridge.

Prentiss Brown, driving force of the Mackinac Bridge Authority and a true Mackinac man, born and bred in the Straits area, devoted twenty years of a crowded life toward bringing about the day of a direct crossing between Mackinaw City and St. Ignace. Through the setbacks of the Depression and of World War II, through a gale of opposition, he held the helm on a steady course and finally brought the Mackinac Dream into port.

Meanwhile, what did the calamity howlers say? Their chorus had changed little since the days when they were bent on discouraging Charles Harvey from building the Soo Canal. They said: "You might as well try to build a bridge on the moon. The Straits area is a hundred miles from nowhere. There isn't enough traffic to justify the cost. How do you expect a backwoods bridge to pay for itself?"

Actual traffic checks revealed that the holiday and hunting movement across the Straits was approaching a stampede. Car drivers in the rush seasons had waited as long as nineteen hours in a line that stretched back along the highway twenty miles from the ferry docks. And traffic was increasing more than fifteen percent a year. Experts figured that a Mackinac Bridge would pay for itself within eighteen years, and then become toll free.

The calamity howlers said: "You can't build a bridge at the Straits. There's a glacial canyon right under the place where your main suspension span would have to be. There are huge caverns in the rock bed of the Straits. As soon as you put heavy foundations on that rock, the roof of the caverns will collapse and bring your bridge down in ruins!"

Geologists made test borings all over the place. Their investigations turned up the cheerful fact that the caverns had collapsed several thousand years ago into solid rock. In fact, so solid was the weakest rock tested at the Straits that it would support more than four times the full load placed on it by the bridge foundations.

The calamity howlers said: "Even if you *can* build a bridge, you can't build it to stay through a hard winter. There's no such thing as a calm day at the Straits of Mackinac. The wind up there invented perpetual motion! Even in a fresh breeze, let alone a gale, the waves will pile up across 120 miles of open water and explode like bombs against your bridge towers, dashing fifty feet high in spray that will freeze as fast as it hits. Wait until the ice grinds down from Lake Superior, and around from Huron, and up from Michigan, and the whole mass gets moving together behind a heavy wind, pile driving through the Straits in ice floes banked thirty feet high, smashing a road anywhere, through anything, same as the irresistible force of a glacier, only more in a hurry! Wait until a real winter comes along, or maybe just one of those big winds that always leaves a calling card at Mackinac in March or August or November, and your pretty bridge will be nothing but a busted toy!"

The distinguished consulting engineer, David B. Steinman, 20th-century counterpart of Charles T. Harvey, an older man than the canal builder but with the same youthful enthusiasm and new-idea approach to the problem, had to answer the calamity howlers. Selected by the Mackinac Bridge Authority to design the bridge and then to supervise its construction, it was up to him to solve the problems of ice and wind pressure.

To this job that so often had been called impossible, Dr. Steinman brought considerable more experience and reputation than Charles Harvey had brought to the Sault. He had designed and built 300 bridges on five continents, and he had received eight awards for the most beautiful bridges in America. A president of the New York Academy of Sciences, he had also received the highest scientific honors and awards for his technical inventions and improvements in bridge design and construction. When he came to the Straits, his bridge building engagements extended as far as Baghdad in Iraq. So many people had told him his

bridges were poems that he took up poetry as a spare-time hobby and promptly began to win prizes in that field. A life-member and trustee of the Poetry Society of America and President of the Wisconsin Poetry Foundation, this engineering architect of what has been called frozen music put his heart and soul into a new poem of steel and concrete at the Straits of Mackinac, a bridge that later inspired him to write a real poem, which also was destined to win a national award in addition to the international honors accorded his record-breaking suspension span.

On paper, the designer bent to his calculations and plans. He figured the maximum ice pressure possible, and then designed the bridge piers to be safe at five times the maximum pressure. The foundations of the two main piers upholding the towers were designed to go more than two hundred feet below the water level, with South Tower Pier 19 carrying down through 140 feet of water and 70 feet of overburden (glacial till) at the bottom of the Straits, and North Tower Pier 20 carrying down through 100 feet of water and 105 feet of overburden.

By taking precautions against the maximum ice pressure possible, multiplied by five, and by planning pier foundations on rock that could stand more than four times the maximum load, David Steinman was designing a bridge twenty times as strong as any ice pressure that could be brought against it. As a final safeguard against ice damage, his plans specified armor plate for the concrete of the piers.

To protect the bridge against the violent storms that may rage across the Straits at any season, he checked the greatest wind velocity ever recorded in the area: 78 miles per hour. In his designs, he guarded against a wind many times that pressure.

"On paper!" the calamity howlers said. "Wait and see what happens in fact!"

It was in 1853 that Charles Harvey turned the first spadeful to begin the big ditch at the Sault. Exactly one

hundred years later, financial arrangements for Mackinac Bridge were being completed. During the 1953 season of navigation, the Great Lakes ore carriers, as if determined to make sure there would be enough steel on hand to build the bridge no matter what happened at home or abroad, hauled an all-time record of 95 million 844 thousand and 449 tons of iron ore from the Lake Superior ranges to the steel mills on the Lower Lakes. In the spring of 1954, ground-breaking ceremonies for the bridge were held, and, across 101 years, came the voice of Charles T. Harvey in a mood that must have found an echo in the heart of David B. Steinman:

Gangway! We're coming through! Gangway for tomorrow!

From Mackinaw City to St. Ignace and back again, the echoing past spoke to the present, as the present in its turn would send sound waves into the future, to carry on the Mackinac spirit that laughed at calamity howlers and challenged the impossible.

Who passed this way one yesterday?

Charles T. Harvey and his canal gangs!

Ahoy! Who goes there now?

Prentiss M. Brown, David B. Steinman, and the bridge workers!

From the start of the project, the Watchman on Mackinac Bridge had been, so to speak, on deck. He had watched the deep-water divers go out to blast the pier foundations down to bedrock. He had watched the caisson and cofferdam crews take off across the treacherous Straits with their floating equipment to set the forms and establish a world's record for under-water concrete placement. He had watched the mother-duck tugs shoulder the steel superstructure spans into position. He had watched the twin towers rise in lonesome grandeur and he had seen the spider threads of the parallel catwalks venture high out over the Straits between the North and South Anchorages in a daring passage so that men could spin the suspension bridge

cables to follow — an operation he compared with a housewife stringing clothesline back and forth between the hooks of two posts.

"Some strapping housewife!" the Watchman always grinned as he thought of his comparison. "She could hang out quite a washing! With her clothesline posts more than a mile and a half apart, and the clothesline itself stretching higher in the middle than any skyscraper in Detroit!"

He had watched the tiny figures, daring as tightrope walkers, higher than sea gulls, as they pulled down the wire from the spinning wheels that travelled between the banks of reels on the anchorages, pulled down wire thick as a lead pencil and fastened it strand by strand into the two Mackinac Bridge cables, enough wire to go around the equator once and then two-thirds of the way on a second trip, or to travel one-sixth of the distance to the moon.

His own hands itching to help, the Watchman had a kindred feeling for the bridge workers. Drawn from record-breaking construction jobs all over America, a dam in Oregon, a skyscraper in New York, a railroad tunnel through the Canadian Rockies, they had come to Michigan to build the world-champion bridge. Wherever they hailed from, whatever their size, they all had the look of a Great Lakes sailor born in November, the look that said: "I'm a hard man to kill!"

Suddenly the Watchman chuckled and broke into a ditty he had made up himself because the bridge men, although the best in the business, had been no better, when they first arrived, at pronouncing the name of the bridge they were building, than the average out-of-state tourists who came to act as "sidewalk superintendents" of the job. Let this be a lesson to all of them!

There are Mackinac men and Mackinaw boats,
Mackinaw trousers and Mackinaw coats,
Mackinaw City, Mackinac Straits,
Michilimackinac souvenir plates!

Holy Old Mackinaw! lumberjacks yell,
How in the Blazes can anyone spell?
Mackinac Island and Mackinaw trout,
Always two hen-tracks for writing it out,
First with a wubbleyou, then with a kay,
But when you pronounce it, there's only one way:

Mackinac's Mackinaw here at the Straits,
And everywhere else in the fresh-water States;
Spell it with kay or spell it with wubbleyou,
Say *Mackinaw*, Mack, and don't let it trouble you!

To real construction workers and to holiday sidewalk superintendents alike, the Watchman on Mackinac Bridge had been singing his home-made ditty since the start of the project. He would sing it out at the top of his lungs, at the drop of a hat, or, to speak more plainly, at any time he heard Mackinac pronounced the way it looked. If the culprit were aboard a departing ferry or work tug and likely to pass out of vocal range before the entire song could lecture him, the Watchman would hurl a quick bit of doggerel that he had composed for such emergencies:

Mackinac
Is off the track;
It's Mackinaw,
And that's the law!

The picture of a retired Lake captain making himself ridiculous over the proper pronunciation of Mackinac sometimes struck the Watchman's funny-bone until he could not keep from laughing at himself. However, it was a serious point with him, and no matter what people might say about his "Mackinac My Mackinaw" song, the words were in tune with the truth even when his voice hit a false note.

But there was one song the Watchman on Mackinac Bridge grew to hate more with every passing day, the song of the calamity howlers who chanted in endless refrain: "The bridge was built on paper. Let's see what happens

in fact. The first winter will wipe out what the first season of construction accomplishes. Remember, we warned you, we told you so. Wait and see!"

The Watchman waited, and he saw. During the first season of construction, 1954, 750 hard-driving men of Merritt-Chapman & Scott began work around the clock on the substructure of the bridge, the foundations, piers, and anchorages. When winter forced a halt after six and a half months of full-tilt operations, these substructure experts had proved themselves Mackinac men from the word *go*. They were well on their way toward using more than 600 thousand barrels of cement, placing 440 thousand cubic yards of concrete in 33 water piers, and setting at least two world records in doing so. The men worked as if they could keep one step ahead of winter if they hustled fast enough, but there was nothing slipshod about the job they did, even in blizzards and near-zero weather. When January slammed the door on them in the Straits, the solid blue ice went eighteen inches thick, and the big floes from three Great Lakes piled up on top of that to go grinding through the Mackinac channels. The substructure of the bridge met all the pressure winter could bring to bear, and never budged!

The calamity howlers had an answer: "1954-55 was just an average winter. Wait'll we get a real crusher with some wind behind it. Wait and see!"

During the second season of work, 1955, the tireless men who were responsible for placing the substructure completed the concrete piers and anchorages while the raw-boned superstructure team from the American Bridge Division of United States Steel erected the two skyscraper towers and mounted a pair of 30-ton saddles atop them to cradle the suspension cables still to come. Upwards of a thousand Mackinac men won their titles as such by battling an early winter that swept into the Straits on November 10, when huge masses of windrowed ice piled up along the south shore. Fighting time and maneuvering vital spans into

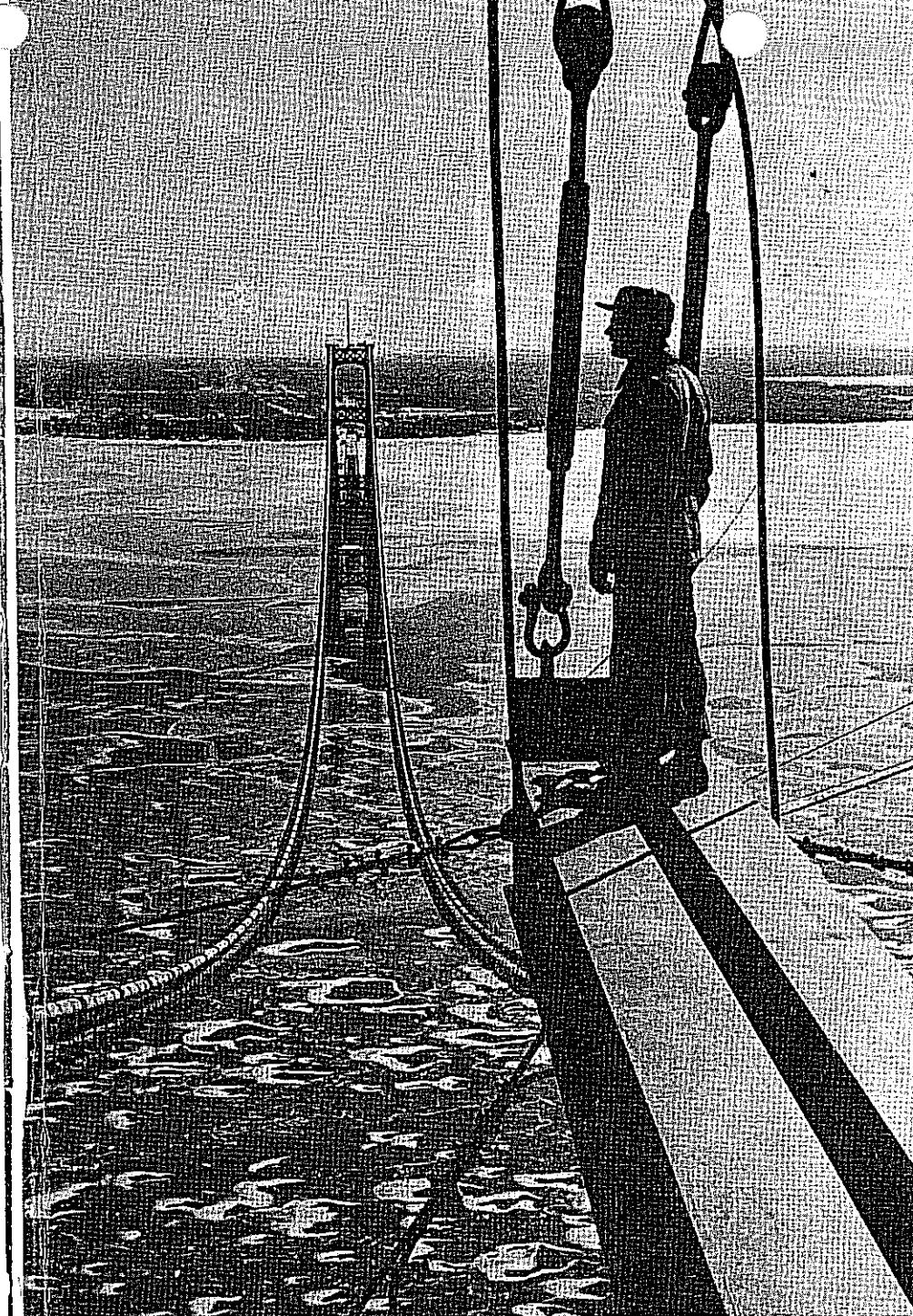
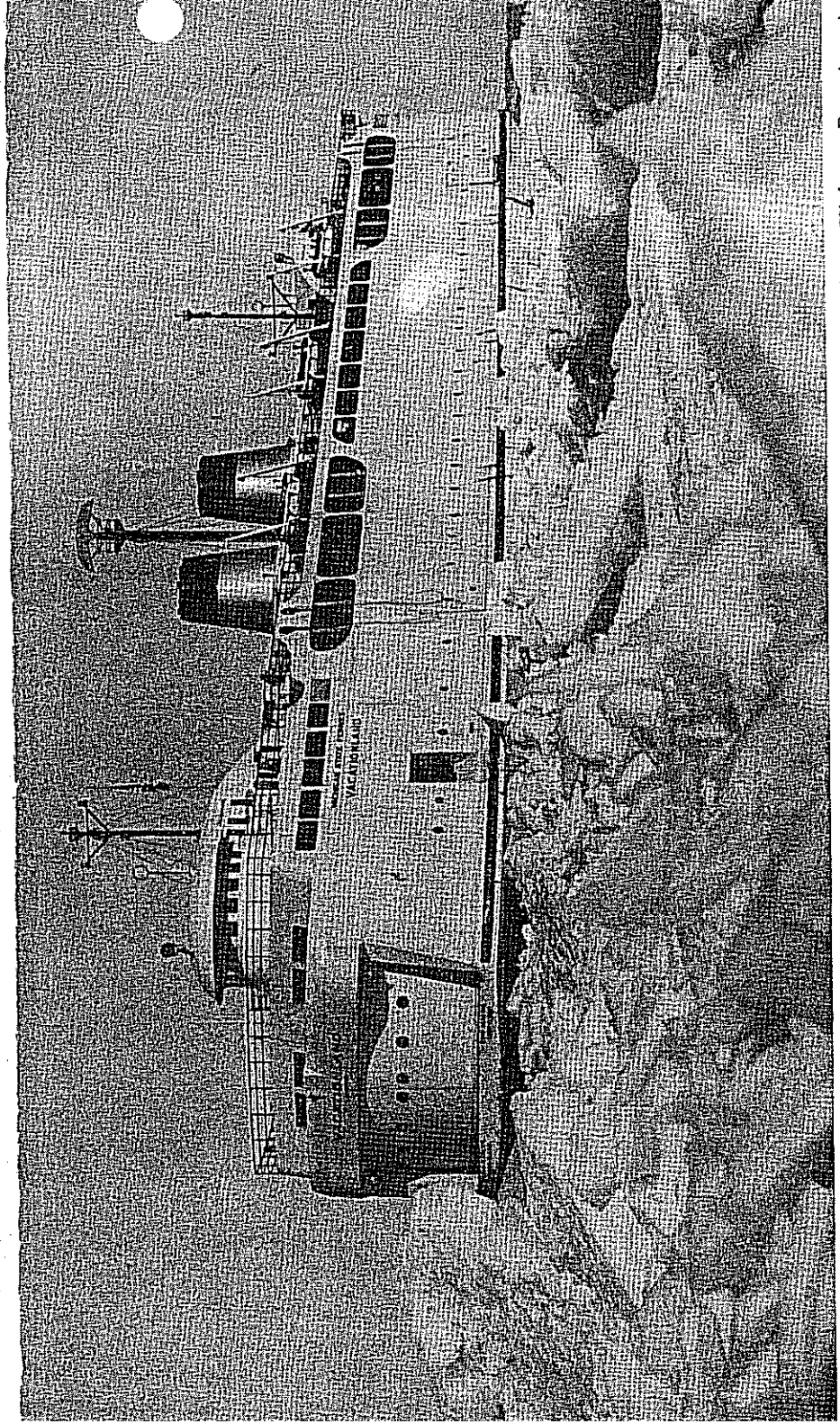


Photo by H. D. Ellis *Courtesy of Mackinac Bridge Authorit*

The Bridge: late winter view to the south from the top of the north tower.



Courtesy of Michigan State Highway Department

Straits of Mackinac ferry *Vacationland*, second in power on the Great Lakes only to the Coast Guard icebreaker *Mackina* meets winter head-on.

place across heavy seas and through increasingly severe weather, the bridge men refused to call quits until December 19, when winter locked the Straits and threw away the key until spring.

This was a winter that came early and stayed late. The tall bridge towers weathered the lengthy siege despite the fact that they lacked about half of the 220 thousand rivets necessary to each of them for maximum reinforcement. Even at half strength in this detail, they easily could withstand an icy gale of 76 miles an hour, only two miles an hour less than the highest wind ever recorded in the Straits area. Painstaking tests of the remainder of the bridge, both substructure and superstructure, showed that not a fraction of an inch had been yielded to the shock troops and assault columns of winter.

The calamity howlers made one last howl: "Okay, we admit the 1955-56 winter was rough, but it wasn't one of the worst Northern Michigan winters, the killing *carcajou* kind that rips and claws like a wild animal gone mad. Wait until a *wolverine* winter smashes into the bridge and tosses the broken parts into Canada or Wisconsin. Wait and see!"

Throughout the construction season of 1956, there were 850 men on the job, all of them hustling to win the race against time and the weather. As great shelves of ice moved in and out of the Straits, intrepid bridge men hung navigation lights on the two towers well in advance of the shipping season. Unable to work in the Straits, shore crews chopped tons of ice from tug boats, barges, and derricks, in preparation for daily journeys across the water to their bridge stations, the good part of an hour away for many of them.

By the middle of April, despite the hazard of ice floes in the Straits, the bridge crews went out from shore and construction began. Tug captains and barge skippers had to keep a weather eye peeled on the shifting ice floes that, with a change in wind, might pack together and seal the

Straits up tight. It was an uneasy April, and the shivering, frost-bitten summer that followed held out a cold foretaste of the wolverine winter in store for Mackinac Bridge.

Early in the season the substructure crews finished all the foundation work necessary for cable spinning and erection of the superstructure. From July 18 to October 10, spinning around the clock toward another world record, a 300-man crew strung back and forth across the Straits the 25,160 individual wires that were bulged into a pair of suspension bridge cables more than two feet in diameter.

It was when the catwalks were illuminated that the Watchman on Mackinac Bridge saw, in the graceful outlines stretched against the night sky, the gleaming promise of a majestic bridge destined to span the Straits, no matter what the calamity howlers predicted, or what the worst winter in history could do.

Despite strikes that closed steel mills, the superstructure crews, as if they sensed what kind of winter lay ahead, completed erection of 26 of the bridge's 28 approach spans and had partially completed the other two when weather forced a halt in December. At the end of the third season of construction, Mackinac Bridge was ahead of schedule on all counts. Three-fourths of the Big Job was over and done.

Then came winter, not just a bad winter, but the champion of bad winters, a winter out to break as many records as the bridge crews and Mackinac Bridge itself. *The Great White Cold Walked Abroad!* Relentless blizzards drove across the Straits, smothering the world. Icebergs raced through the Mackinac channels, smashing against bridge piers. Geysers of spray erupted four office stories high on the main towers and froze into fantastic shapes that looked as if they might have been sculptured by a berserk giant. Countless tons of ice coated and burdened the 34 bridge piers that marched across the Siberia of the Straits, and countless other tons jostled and jammed and glaciered against the foundations.

Snow crackled underfoot. Dog sleds *mushed* across the ice from St. Ignace to Mackinac Island. Two hundred thousand cars stalled downstate in one storm. Winter blasts picked up pine trees in one county and planted them in another. Hunters disappeared in the woods.

South of Mackinac, 361 balmy miles, new lows for winter temperatures were set on the Chicago calendar, one shattering a 76 year record of sub-zero readings. Other Lake ports, Milwaukee, Detroit, Cleveland, Buffalo, all of them hundreds of miles south of Mackinac, wrote new record-breaking readings on their calendars. The Detroit Street Department used up the snow clearance fund before the half-way mark of winter!

Fifty miles north of Mackinac, a Sault Ste. Marie weather report on one occasion contented itself with the following forecast: "Too cold to snow much the next few days." Later in the winter, when it became downright chilly, one of the citizens happened to talk by "ham" radio relay to a meteorologist, formerly of the Sault Weather Bureau, but now with the Antarctic expedition. They traded temperature reports. It was warmer at the Antarctic Pole than at the Soo Canal.

Old-timers in the Straits area, including the Watchman on Mackinac Bridge, never bothered with weather reports during a hard winter. They tested the temperature by spitting. If the spittle froze after it hit the ground, then it was a normal ten-below day, but if the spittle turned to ice on the way down, then the mercury must be around forty minus, and a thin-blooded man who felt the cold easy ought to go back inside and put on long-johns before he went anywhere.

At St. Ignace, this carcajou winter of 1956-57, a 60-man shore crew stayed on the job to put together stiffening trusses and to complete the assembly of a bridge span that covered the length of two football fields and a basketball court for good measure. These hardy workers watched one another carefully so as to give quick warning if nose

or ear tips turned white in signal of frostbite. They also took pains not to touch steel beams with their bare hands because in the sub-zero cold the skin would stick to the metal and have to be peeled off in agonizing strips.

Out in the Straits the ice piled up until even the ponderous car ferries became trapped and had to be set free by the Coast Guard icebreaker *Mackinaw*, which could plow along at four miles an hour while smashing a path through solid blue ice more than four feet thick.

Two infallible signs of spring on the Upper Lakes — the counterpart on water of the first robins on land — heralded the arrival of April as the ferry *Emerald Isle* plowed through broken ice from the Michigan mainland to Beaver Island, and Captain Ed McCann cleared the cement carrier *John L. A. Galster*, from Harbor Springs and Petoskey, bound down for Chicago with the first cargo of the season. These regular harbingers of spring were able to celebrate the opening of navigation, thanks to the Coast Guard's Ice-Breaking Task Force headed by the most powerful vessel on the Great Lakes, the *Mackinaw*, and including the sturdy CG Cutters *Sundew*, *Woodbine*, *Acacia*, *Mesquite*, and the railroad ferry *St. Marie*. The sea-going "Robin Redbreasts" of the Upper Lakes had a fleet of icebreakers to run interference for them, clear a path, and provide safe escort.

Events were soon to prove that Great Lakes shipping in the springtide of 1957 needed all the help it could get.

On April 4, a savage northeaster with winds up to 70 miles an hour snarled across the Straits of Mackinac as the 5 million dollar ferry *Vacationland*, with the second most powerful engines on the Great Lakes, attempted a crossing from St. Ignace to Mackinaw City. The raging blizzard and ponderous ice floes forced the giant ferry into a frozen trap some hundreds of yards offshore where the ice was 25 feet thick and frozen clear to the bottom of the Straits. The 91 persons aboard, including women and children, had to spend a full night and day on the stricken vessel before

the tireless Coast Guard could possibly complete a rescue in the blinding weather.

As late as April 13, with the first ore and grain carriers of the season trying to get through from Lake Superior, a giant ice field trapped 35 freighters in Whitefish Bay and in the St. Marys River. Described by veteran Great Lakes shipping captains as the worst in their memory, the ice field was estimated at 63 miles long, 30 to 60 miles wide, three feet thick in places, and with windrows up to 25 feet high. Coast Guard Captain Iver Kerr's *Mighty Mac* finally made a dent in the vast white jagged field to rescue freighters caught in the jam, but even the *Great White Lady* of the Upper Lakes could move the trapped vessels only a ship-length at a time as the ice piled up to 20 and 30 feet high in front of her crushing prow.

No wonder, reflected the Watchman on Mackinac Bridge, that Great Lakes sailors called the spring of 1957 the worst in history. He himself could not remember a more savage last gasp of winter.

But the spring break-up finally came. Sped by *chinook* winds the ice thundered loose in Lake Superior, roared down the St. Marys River past the Soo Canal to join forces with Lake Huron's free-wheeling ice pack and bulge into the Straits of Mackinac to meet the oncoming Lake Michigan ice pack in headlong collision. In the middle of this grinding white pandemonium, the Mackinac Bridge stood. And it *stood!* Despite all the unscientific pessimism, the dark gossip, the ugly rumors, the ominous warnings of busybodies who talked too much and did too little, Mackinac Bridge had withstood the gales and glaciers of an old-fashioned Michigan winter, and old-timers agreed that there could be no better test of indestructibility than that.

According to wind-tunnel tests, the Mackinac Bridge had been pronounced able to resist any wind velocity at any angle of attack, except when all openings in the deck

might — by stretching imagination to the limit — be pictured as completely closed by ice. Even in this unlikely condition, the bridge could stand the fantastic wind velocity of 632 miles an hour. In comparsion, wind-tunnel tests on the George Washington Bridge across the Hudson River between New York and New Jersey showed that its critical wind velocity was reached at only 55 miles an hour, while the critical stage for the Golden Gate Bridge was even less, 40 miles an hour.

In other words, while any of his giant brothers might run into trouble in the 70-mile gales he already had laughed at as child's play, the mighty Mackinac could stand up against any wind imaginable, even the frightful wind blasts of a super hydrogen bomb, and, covered with ice, he could still laugh at anything up to supersonic range.

David B. Steinman's "paper" bridge, proven one hundred percent safe, aerodynamically, in wind-tunnel tests at the University of Washington, had gone on to meet the tests at the real proving grounds, the Straits of Mackinac, under the toughest conditions possible — an old-fashioned Michigan winter.

What did the calamity howlers say? They started talking about something else. "Go find another project to haunt," the Watchman told an imaginary group of them. "Go over to Wisconsin and hoot down architect Frank Lloyd Wright's blueprints for a mile-high skyscraper in Chicago. The faster you talk it down, chances are, the faster it'll go up, because he's an old Mackinac man — he designed a house right around the Straits from here on Lake Michigan — and the speciality of Mackinac men is doing what calamity howlers say can't be done!"

Which is why, the Watchman mused, a retired Great Lakes captain could walk dry-shod across the Straits with no more worry on his mind than how to teach newcomers the correct pronunciation of a name that deserved respectful treatment because of the generations of *men,* from the

voyageurs to the engineers, who had worn it as a title of honor and a badge of courage:

There are Mackinac men and Mackinaw boats,
Mackinaw trousers and Mackinaw coats,
And the greatest bridge you ever saw
Is at the Straits of Mackinac!
My Mack-i-naw!

BEFORE THE BRIDGE

BEFORE THE BRIDGE

A History and a Directory of

ST. IGNACE

and

NEARBY LOCALITIES

Published by the Kiwanis Club of St. Ignace, Mich., Inc.
1957

Commemorating the Opening of the Mackinac Bridge

CONTENTS

CONTENTS (Continued)

INTRODUCTION

AS WE APPROACH the day when traffic will roll over the Mackinac Straits water, pondering the effect that the bridge will have on the future of this area; it is appropriate that we record for future generations some of the history of our locality. There is a glorious story to be told, interesting and intriguing, of a wonderful country which invited the adventurer, the missionary, the explorer, the pioneer and settler through the past several hundreds of years. After many months of research and organization of facts, a substantial part of this story is presented herewith. The finished product is, in effect, the compilation of many individual memories, family records, and acceptable material already in print. Elsewhere is given a list of persons who have been unusually helpful, but many others have also cooperated to make this publication the first history of this community to be written.

Obviously, the long, rich history of this area cannot by any means be related in detail in this one volume, which is, we hope, only the first step in assembling and preserving local history and family records. From the storehouse of information already assembled, and from the memories of some who will be stimulated, plus other facts which are sure to come to light as time passes, it is probable that one or more supplemental issues will be printed in the future.

The 1957 directory in this publication is historical as well as useful today. It will inform future generations of facts about the individuals and families, the businesses and organizations, which were here before the bridge, the completion of which will perhaps be recorded by future historians as the most important event of the community's history. In keeping with the desire to make this publication of more general interest, historically and individually, the names of women prior to marriage are given in the directory, thereby identifying them with their own families, who, in many instances, were pioneers here.

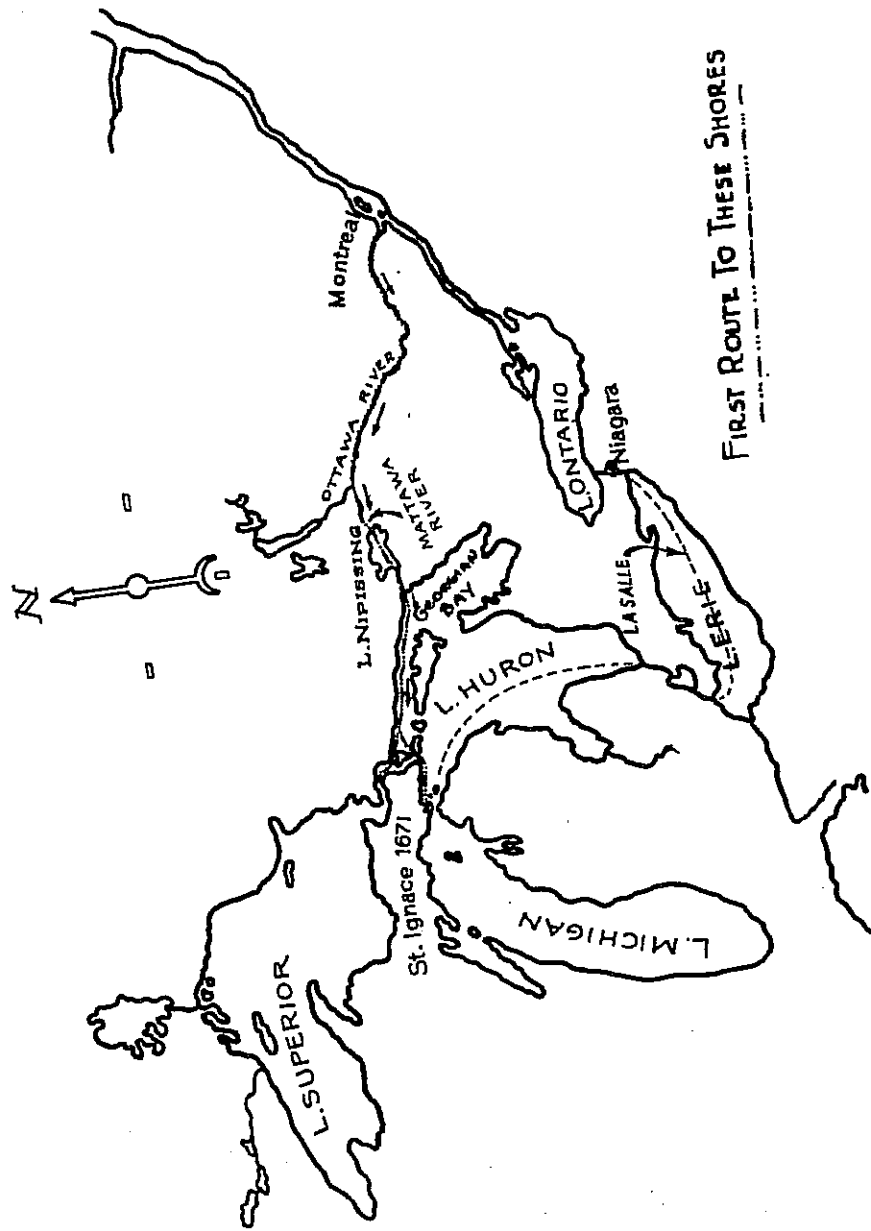
Because *Before the Bridge* is a commemorative issue, timed to appear about the time the Mackinac Bridge is open to traffic, it is our hope that each family will place a copy of the book among their treasures in order that future sons and daughters may have an opportunity to become better acquainted with the past.

The KIWANIS CLUB of St. Ignace, Mich.

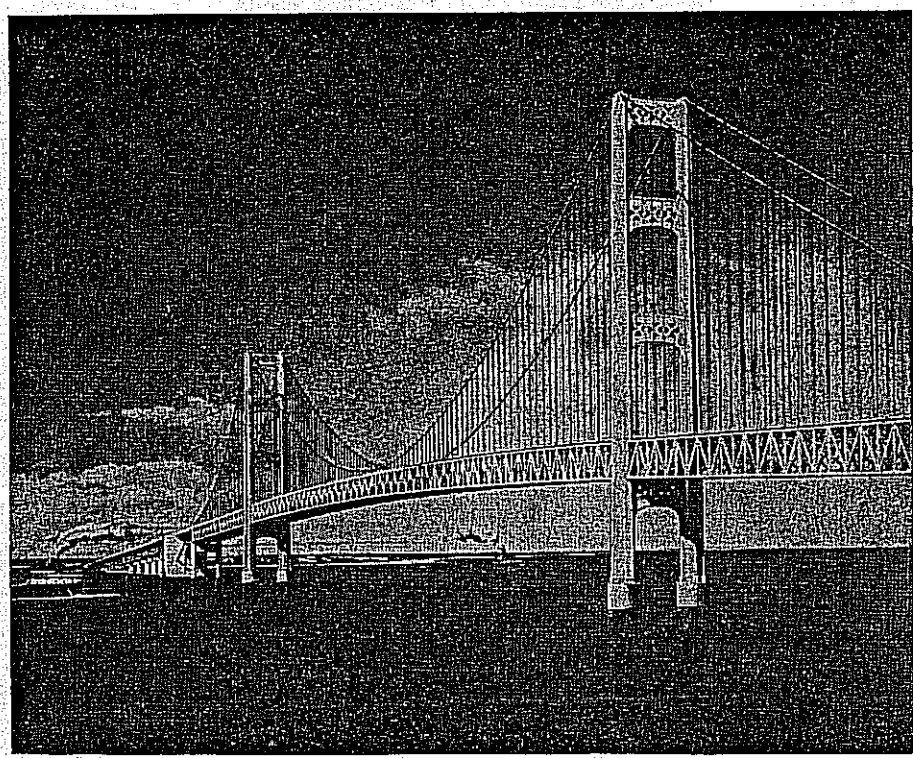
EMERSON R. SMITH,
History Project Chairman

This book is dedicated to the youth of St. Ignace and nearby localities. May they become better acquainted with the history of this area, through this book, and be benefitted by the proceeds from its sale.

TRANSPORTATION OVER THE YEARS



A DREAM COMES TRUE



THE MACKINAC BRIDGE

• • •

PRENTISS M. BROWN

Prentiss Brown married Marion Walker in 1916, who is a descendant of two of the city's best known pioneer families, the Malletts and the Walkers. The children are Mariana (Rudolph), Ruth (Evashevski), Barbara (Laing), Patricia (Watson), James J., Prentiss M., Jr., and Paul. Today there are twenty-two grandchildren of this union. James J. (named for his grandfather) now County prosecutor, and Prentiss M. Jr., are the third generation to carry on the Brown law practice in St. Ignace.

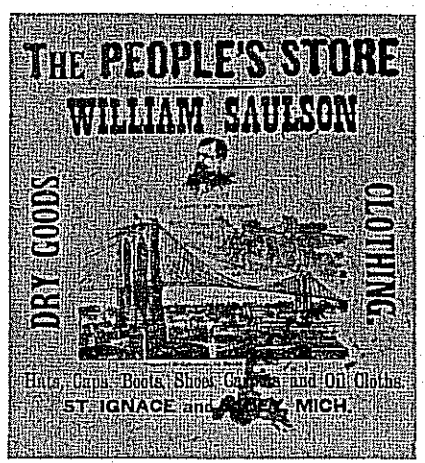
IT IS FITTING that a home town boy has been the chief figure in the long struggle to finance and erect a bridge across the Straits, which will undoubtedly mean much to the place of his birth as well as to the Upper Peninsula, and serve to unite the great state of Michigan. Prentiss M. Brown was born in St. Ignace on June 18, 1889 and received his public school education here, graduating from LaSalle High School in 1906. His education was largely augmented by the tutoring given him by his father, James J. Brown, who was county prosecuting attorney at the time of his son's birth and who conducted a successful law office in St. Ignace for many years. His able parent also served as city attorney of Detroit before being lured to this great North Country, coming here in the lumbering days of the early 1880s when it appeared that St. Ignace had a greater future than the struggling Detroit community. He was one of the pioneers who helped develop the city of St. Ignace from a village. His son became a modern pioneer, as well as the city's most distinguished citizen of all time.

After a normal boyhood here, when he played on the city's baseball team, starred on the school debating team, and entered into all the healthy activities of his day, he studied at Albion College and the University of Illinois. Returning to St. Ignace, he engaged in law practice with considerable success and embarked upon a political career. He served as county prosecuting attorney and repeatedly as chairman of the Michigan Democratic State Convention, and then in 1932 was elected to Congress from the Eleventh District — the first Democrat ever to represent this rock-ribbed Republican area. In 1936 he became United States Senator; then in 1943 was appointed Director of the Office of Price Administration; and in 1944 he became chairman of the board of the Detroit Edison Company, which he headed until his retirement in 1954. He has been given many honorary posts in various fields of business, education and cultural pursuits, among them membership on the Michigan Historical Commission on which he continues to serve.

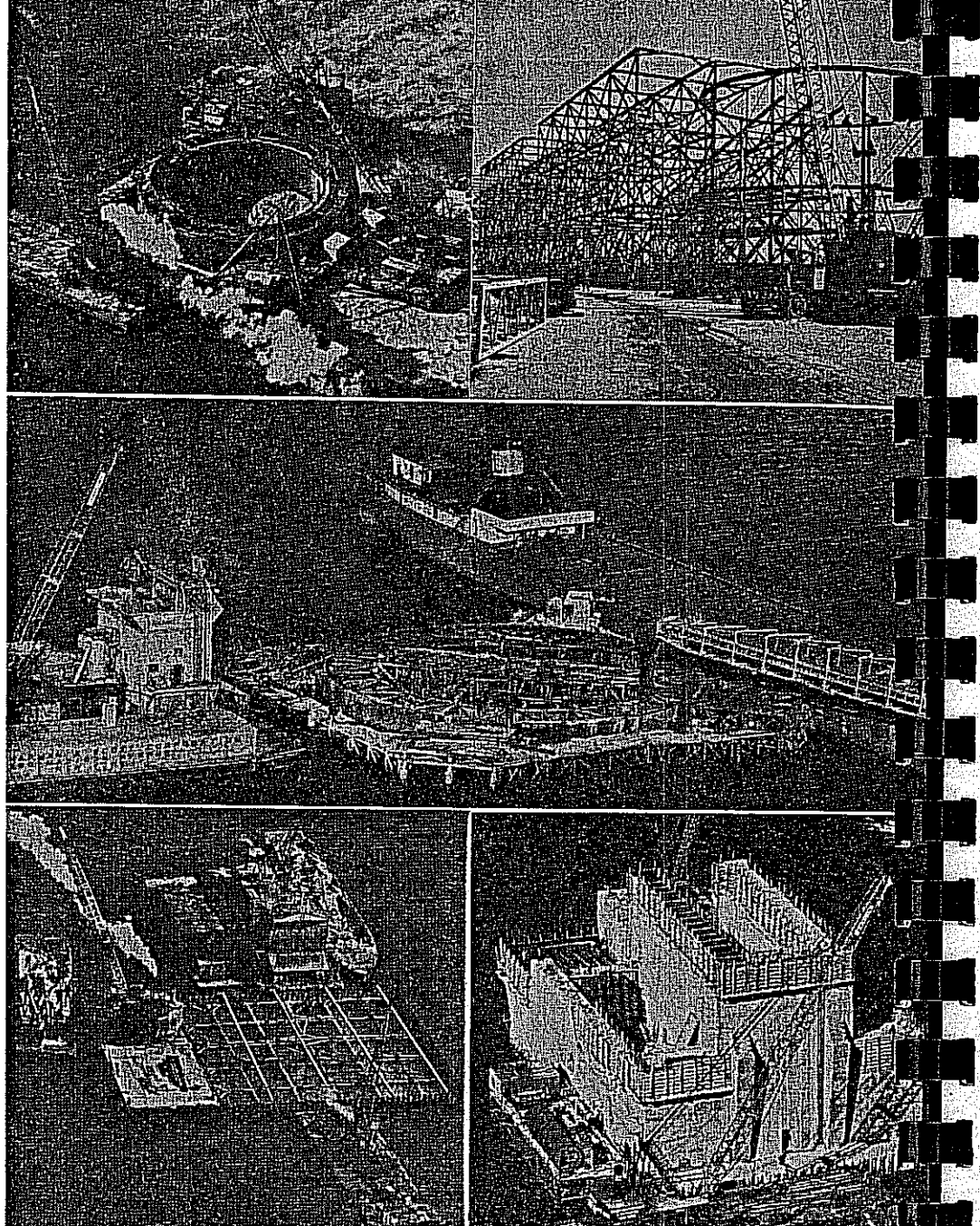
As a schoolboy Prentiss M. Brown dreamt the dream of connecting the two peninsulas with a bridge or a tunnel. He heard it described as "utter nonsense" many times, but the same "dream" was voiced many times during the horse and buggy days. When the project finally became possible and deserving of serious consideration, in later days, the dreamers and the optimists were greatly outweighted by the doubters, the pessimists and the obstructionists.

Overcoming such opposition is without doubt the monumental achievement of his career. No one can deny that without his efforts it would have been many years before this modern wonder of the world had been built, if ever. He is rightfully regarded as "Mr. Bridge," and St. Ignace pays him a just honor for his part in the building of the Mackinac Bridge — an accomplishment which will make the period of *after the bridge* as important historically as *before the bridge.*

Accompanying his story which follows, are a number of pictures presented through the courtesy of Herman D. Ellis, photographer of the Mackinac Bridge Authority. They help to give some idea of the gigantic construction task involved in spanning the Straits with this great steel structure.



Ad which appeared in the St. Ignace weekly newspaper in 1884, picturing a solution to the problem of crossing the Straits. At the time, the ice-crushers had not come into being, and St. Ignace was usually marooned for two or three months in the winter time.



(Upper) **Dredging caisson for North Main Tower Pier**

(Upper) **Frame for cable anchoring pier being assembled at St. Ignace.**

(Center) **S. S. Clymer unloading stone into Caisson 20.**

(Lower) **Connecting cable anchorage foundation.**

(Lower) **Pier 22. North anchorage from the southwest.**

A DREAM COMES TRUE

by

PRENTISS M. BROWN

WITH THE last season of the Mackinac Bridge construction underway, the day approaches when a great water obstacle will be conquered — the culmination of more than seventy years of dreams.

In 1884 William Saulson, an enterprising operator of a department store on our own State Street, printed a picture of a suspension bridge in his advertising space, suggesting — or hinting, at least — that one might be built across the Mackinac Straits. Presumably he had taken the idea from one of the state's newspapers, which told of a great, and marvellous, engineering accomplishment of 1883 when the Brooklyn Bridge was completed.

The development of the suspension idea in the erection of the Brooklyn Bridge had fired the imagination of the entire country. That a structure hung from steel cables could span a great distance without intermediate supports was advanced thinking. Of course Saulson, like all his fellow citizens, felt that such a project over a long distance such as would be required to connect the two peninsulas was but a dream. Even though no one believed that it would ever materialize, the idea served to attract attention to the fact that Saulson was selling merchandise at "unbelievably low prices," (certainly unbelievable when compared with prices today!).

Periodically, this dream was brought forth by those with visionary minds to stir the thinking of the people here, who for many years were busy trimming their kerosene lamps, and who later were to behold so many inventions and mechanical processes come to pass. Every child who grew up following Saulson's time heard that some day there might be a bridge to the land across the Straits. In some cases the child had never seen the land, except from a distance on clear days, and, like the rocket-to-the-moon stories of today, each person, young and old, discounted these fanciful tales as beyond the realm of man's accomplishment.

The fact is that, up until a comparatively few years ago, the building of a bridge across the Straits was not practical, granted that it were possible from an engineering standpoint. The financing of this bridge could be done only with the growth in motor travel which has taken place during the last thirty years, to say nothing of the development of mechanical and power processes needed to build such a tremendous project.

As the automobile traffic continued to increase, and as early as the year 1933, serious agitation for a bridge developed. Commissions were established to investigate, and the feasibility of the bridge from an engineering standpoint was carefully examined. Various engineers — Modjeski and Masters of Harrisburg, Pennsylvania; Leon Moissieff, a noted Russian engineering consultant; Professor James H. Cissel of the University of Michigan, and others in the 1930s and the years immediately following — were engaged in the work.

Out of these efforts gradually developed a general opinion on the part of engineers and the general public of the state that the bridge from an engineering standpoint was feasible. In 1950, under the leadership of Governor G. Mennen Williams, aided by many citizens throughout the state and a favorable legislature, there was established the present Mackinac Bridge Authority. Preceding bridge authorities had done excellent preliminary work; it was the task of this Authority to retain engineers and secure definite written assurances that engineering-wise, the bridge could be built. The Authority is comprised of six men appointed by Governor Williams and the legislature added the state highway commissioner as a member. (Charles M. Ziegler served until June 30, 1957, and was succeeded by John C. Mackie). The appointed members are Charles T. Fisher, Jr., Vice-Chairman; William J. Cochran, George A. Osborn, Murray D. Van Wagoner, Mead L. Bricker who is serving in the place of Fred M. Zeder, now deceased, and myself as chairman.

This Authority immediately hired Messrs. Othmar H. Ammann, David B. Steinman and Glenn B. Woodruff, unquestionably leaders in the bridge engineering world. After a thorough examination, they reported favorably to the Authority on the feasibility of the bridge, stating that while the project contained many problems, it could be built. Traffic engineers Coverdale and Colpitts of New York were hired to report on the financial probabilities.

In the meantime, public sentiment had to be aroused in the heavily populated parts of the state to favor the expenditure of a huge sum of money in this sparsely settled area. No large cities were located near the bridgeheads. The traffic is seasonal to a large extent. Advocates of the ferry system were opposed. A new boat was under construction. Ice, wind, alleged bad rock conditions, deep water, currents, and other adverse factors were cited. The trend of the time was against public expenditures. Nearby financial institutions, such as some of the Midwest insurance companies, were skeptical. The bonds were not eligible for Michigan bank investment. Interest rates were on an upward trend. Two separate efforts to finance the bridge resulted in discouraging failure. Still another attempt was made. After three years of effort a bond issue of $99,800,000 was floated and the Authority was authorized to proceed.

The bonds are revenue bonds, to be paid for solely from earnings expected from the bridge. The State Ferry system had been losing large sums. The last year before the bonds were issued the operating loss alone, without interest or depreciation charges on the State's investment was about three quarters of a million dollars. It was pointed out that the sale of the bonds would be helped if the State undertook to pay the operating cost of the bridge. Since this was estimated to be about half of the losses suffered by the ferries, the State legislature, after some considerable effort on the part of those interested in the project, agreed to pay operating and maintenance costs up to the amount of $417,000 per year. This greatly aided in the sale of the bonds.

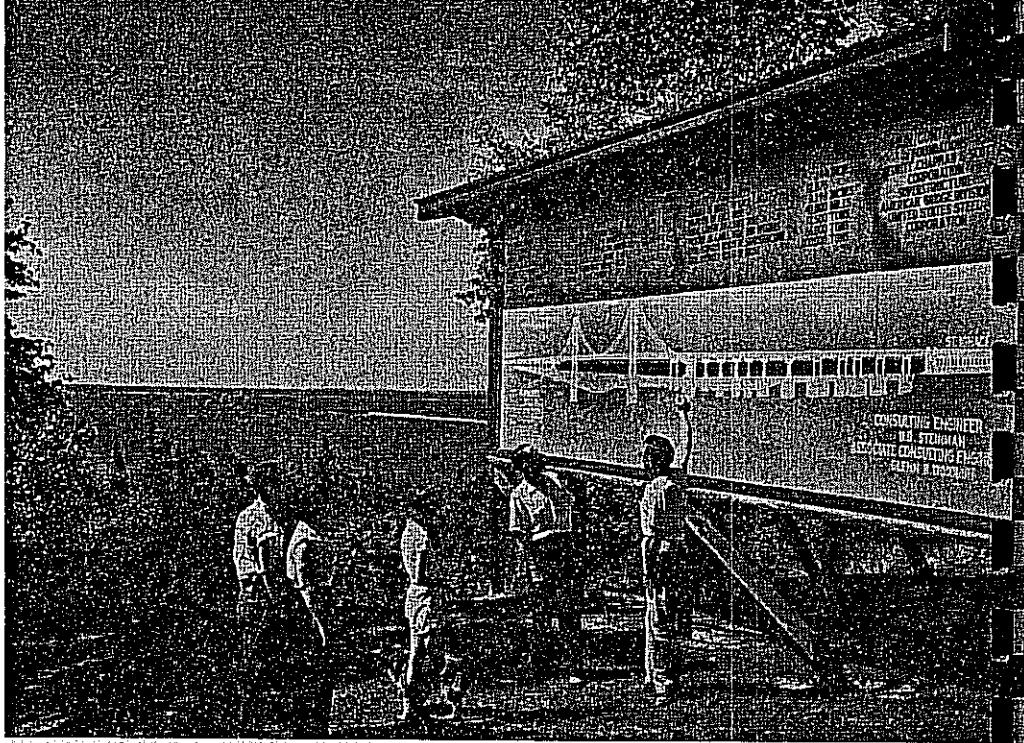
The bonds are divided into two classes: $79,800,000 first lien bonds bearing interest at 4 per cent, and $20,000,000 of second lien bonds at 5¼ per cent, which averages 4.26 per cent interest charge. The increase in traffic at the Straits indicates that sufficient funds will be collected for both interest and principal debt service to retire the bonds. The tolls are expected to average slightly less than the ferry charges. Optimistic estimates are that the bonds can be paid in about 24 years. Actually, they have a 40-year maturity date. Marketwise, the 4 per cent bonds are practically at par, while the 5¼s have generally been from $5 to $7 above par. Well informed and substantial revenue bond bankers consider them to be a reasonably safe investment. The tax-exempt status of the bonds makes them desirable from that standpoint.

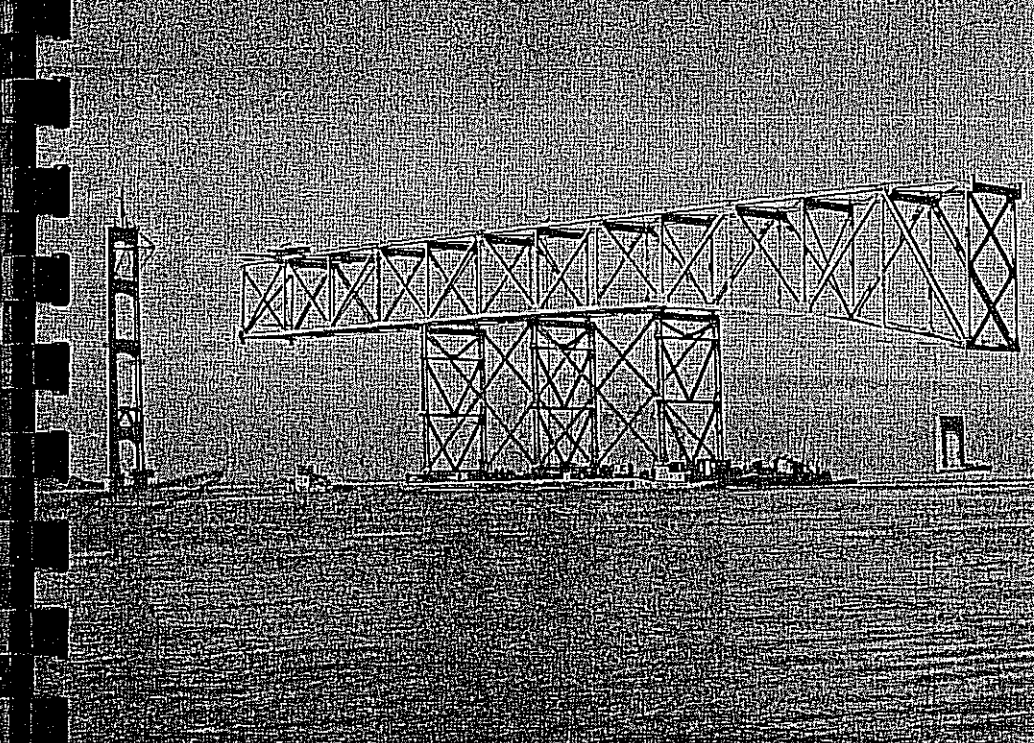
Prior to the sale of the bonds it was necessary that firm contracts for the construction of the bridge be negotiated. The bankers had to know that the job could be done for the amount of money raised. Contracts for the substructure were negotiated with the nationwide known firm of Merritt-Chapman & Scott Corporation at a lump-sum price of $25,735,600. The superstructure contract went to the American Bridge Division of United States Steel Corporation for the sum of $44,532,900. The Authority insisted on, and paid a slightly higher price for, firm contracts without escalation in price. In other words, any increase in the price of material or any increase in the price of labor or any other factor, would not increase the contract price, except in the case of the superstructure contract wherein the actual amount of material used would have to be paid for. Actually, the engineers' estimates of steel requirements turned out to be quite accurate. Several smaller contracts have been entered into, and unexpended funds are largely invested in government securities. Interest on the obligation during construction, of course, had to be provided by the original borrowing as there is no revenue during the period of construction.

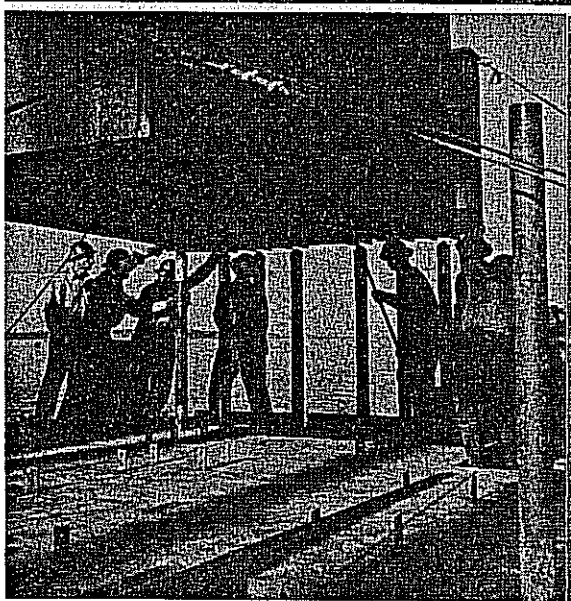
The bridge project is 44 feet more than five miles in length. Its northerly shore has a causeway 4,200 feet long running out to approximately 18 feet of water. It was built in 1941 by the then highway commissioner, G. Donald Kennedy, under the administration of Governor Van Wagoner. The purpose was to use it as a dock and shorten the run across the Straits while a then-proposed bridge was under construction. However, it was not so used. It has saved considerable in providing a portion of the north approach to the bridge.

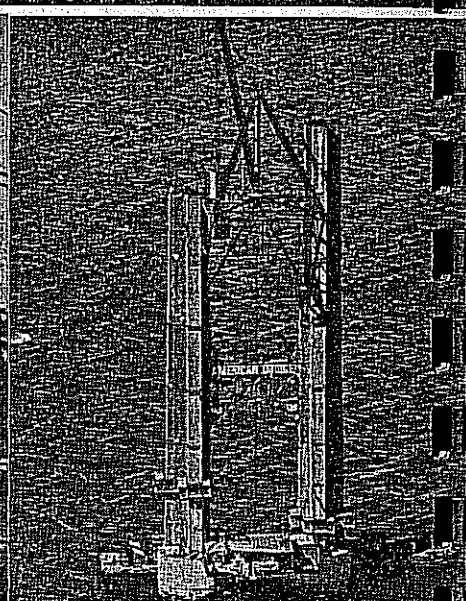
From the end of the causeway on the north to the shore on the south, a series of concrete foundations, 34 in number, are spanned by steel girders rising to the gigantic anchor blocks on each side. Six of these foundations supporting the suspension span are of tremendous size. The anchor blocks are in deep water, some 85 feet to bedrock, 115 feet wide and 135 feet long, and weigh 175,000 tons each.

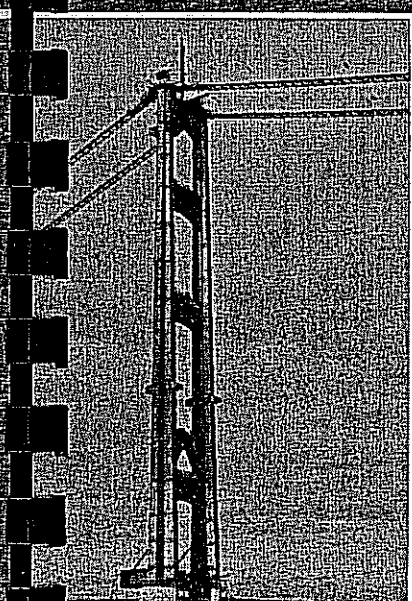
From these anchor blocks rise the cables to a height of 552 feet at the two main towers, which are placed on concrete foundations extending 200 feet below the surface of the water to bedrock. These towers form two concrete-and-steel spires extending 752 feet from bedrock to peak. The building of these foundations and towers over a mile from shore in 200 feet of water was probably the most courageous piece of construction work in all bridge history.











(Upper) **Tourists at State Park St. Ignace, Viewing Site.**

(Left) **North Tower. Setting first vertical section on west pedestal.**

(Right) **South Tower at about one-half eventual height.**

(Upper) **North Backstay Span under tow to site.**

(Left) **South Tower during cable spinning operation.**

(Right) **South approach spans connecting piers I-10, from the northeast.**

The following statistics list the proportions of the structure:

Length of Suspension Bridge (including anchorages) ...	8,614	feet
Length of Main Span	3,800	"
Total length of Steel Superstructure	17,918	"
Length of North Approach (including mole)	7,791	"
Length of South Approach	486	"
Total length of Bridge and Approaches	26,444	"
Height of Main Towers above water	552	"
Depth of Tower Piers below water .....Pier 19	210	"
Depth of Tower Piers below water .....Pier 20	205	"
Number of Main Cables	2	
Diameter of Main Cables	24¼	in.
Number of wires in each Cable	12,876	
Diameter of each Wire	0.196	in.
Total length of Cable Wire	41,000	miles
Weight of Cable, Wire and Fittings	12,500	tons
Total estimated weight of Superstructure	66,000	tons
Estimated total weight of Foundations and Superstructure..	1,000,000	tons

From more standpoints than any other, this bridge is entitled to the accolade, *The World's Greatest Bridge*. From anchor block to anchor block as shown above, it is almost 2,000 feet longer than the great Golden Gate Bridge at San Francisco, California. All six of its major suspension bridge foundations are in deep, turbulent water which at times has seas that throw spray as high as 40 feet above the surface. They are subjected to heavy ice pressure, sometimes flowing in great masses from four to eight miles an hour, propelled by wind and current. Winds at the Straits have been measured as high as 76 miles an hour. The engineers are satisfied that the great 24-inch cables will withstand the most severe wind velocity.

The highway itself rests on top of the bridge framework, approximately 180 feet above the surface of the water at the center. The clearance for vessels is 148 feet, ample to exceed the height of any mast on salt or fresh water ships. The passageway is 3,800 feet in width and almost in the center of the Straits. In the suspension portion of the bridge, the two center lanes of the four-lane highway are of steel grating to provide for disposition of snow and ice and relief of wind pressures, either up or down.

Many people contributed to the success of this project. Fred Zeder, an original member of the Authority, has passed on. He was an enthusiast for the bridge from the beginning and a mighty factor in its success. He was succeeded by Mead Bricker, who ably took his place. These two outstanding men from the automobile industry lent valuable effort to the undertaking. George Osborn handled publicity, his Sault Ste. Marie *Evening News* and Radio Station WSOO covering much of the northern area. Bill Cochran spoke extensively throughout the Upper Peninsula. Governor Van Wagoner in his administration advanced the cause and watched the interests of the Authority in contract negotiations. His experience in highway contracting was vital in these decisions. Highway Commissioner Ziegler and his aide, George Foster, who usually sat for the commissioner, gave counsel and supplied statistics for the traffic and bridge engineers. Finally Charles T. Fisher, Jr., through his work on the finance committee and as vice-chairman, based on his extensive financial contacts, opened the doors for the Authority in the money mazes of Wall Street. His standing and prestige and his devotion to the task were major factors in the final success of the project.

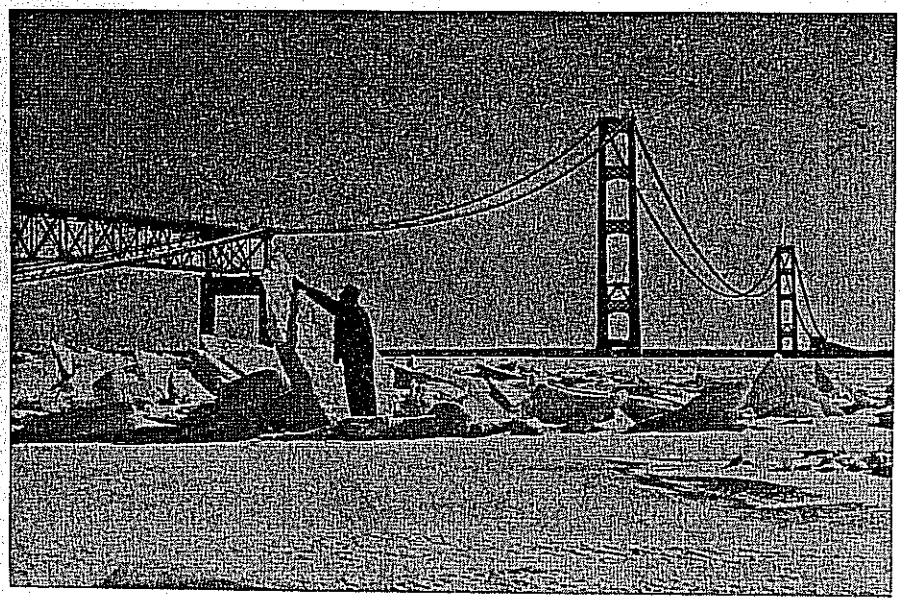
The engineer-designer of the bridge, Dr. David B. Steinman, is among the world's greatest, and with his staff has been a major factor in all phases, not only in design and construction but in financing and publicity. He has been ably aided by Glenn B. Woodruff, his associate.

The Authority's executive secretary, Lawrence A. Rubin, gave invaluable assistance in his work with the legislature, the sale of the bonds and in the contract negotiations.

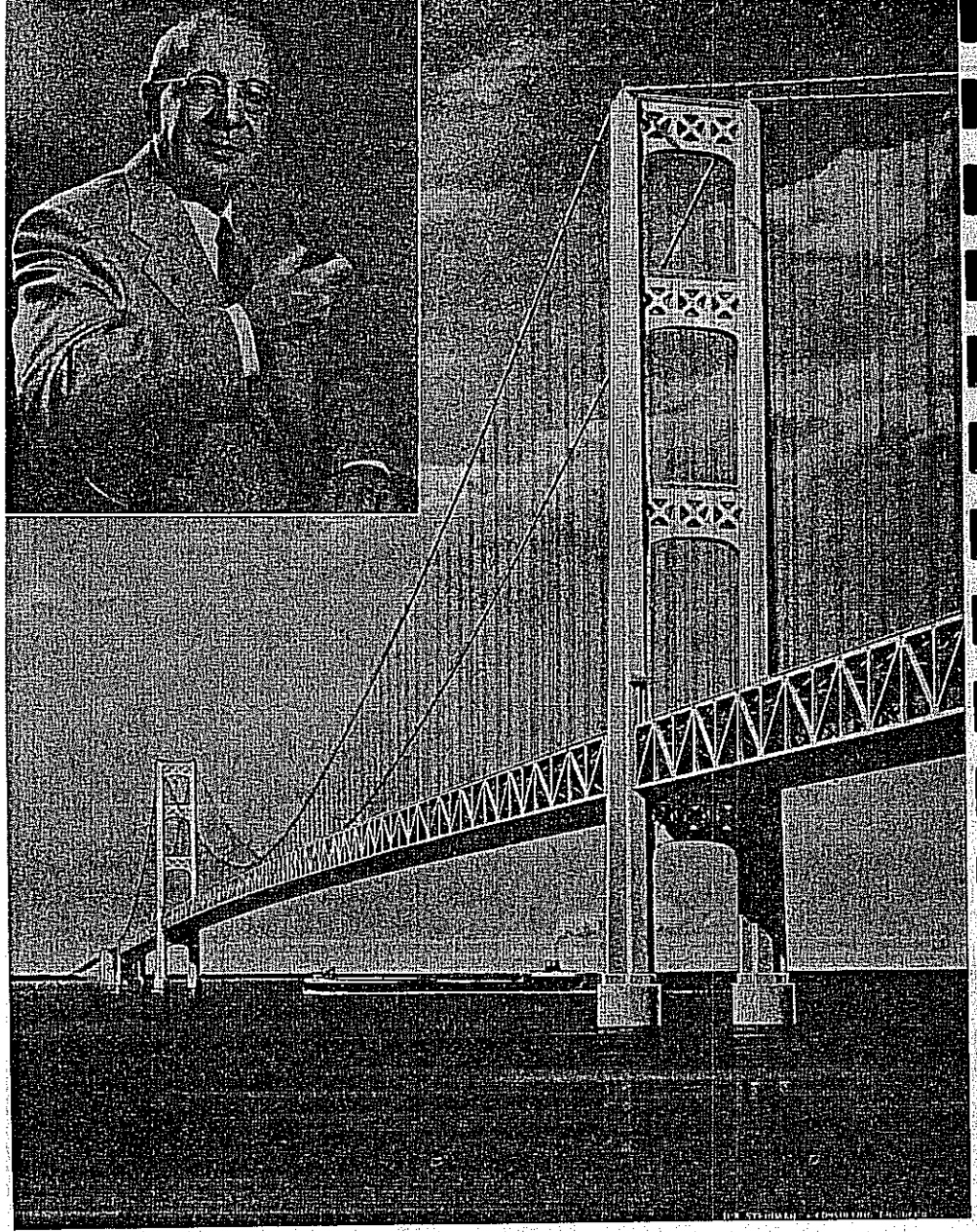
Three Michigan corporations, the National Bank of Detroit, the Chrysler Corporation and the Detroit Edison Company, loaned their facilities, and top men in these companies devoted much time to the effort. They joined in building the bridge model, shown throughout the state, and aided much in arousing pro-bridge sentiment.

Governor Williams promised the people to do something about the bridge. He created the Inter-Peninsula Communications Commission and constantly urged action. His leadership has been a major factor in the final success. The legislators who gave the project nonpartisan approval deserve commendation. The list is too long to give due credit to all who made major contributions to this long and ardous effort, but their pride in its accomplishment is a rewarding satisfaction.

The graceful structure of the Mackinac Bridge which now spans the Straits of Mackinac, forming a physical connection between the Upper and Lower Peninsulas of our State, is a fitting realization of our finest dreams.



J. S. Cortopassi, D.B.S. Engineer, observing winter ice conditions.



MACKINAC BRIDGE

designed by

D. B. STEINMAN

117 Liberty Street

New York 6, New York

THE BRIDGE AT MACKINAC*

By D. B. Steinman

In the land of Hiawatha,
Where the white man gazed with awe
At a paradise divided
By the straits of Mackinac —

Men are dredging, drilling, blasting,
Battling tides around the clock,
Through the depths of icy water,
Driving caissons down to rock.

Fleets of freighters bring their cargoes
From the forges and the kilns;
Stone and steel — ten thousand barge-loads —
From the quarries, mines, and mills.

Now the towers, mounting skyward,
Reach the heights of airy space.
Hear the rivet-hammers ringing,
Joining steel in strength and grace.

High above the swirling currents,
Parabolic strands are strung;
From the cables, packed with power,
Wonder-spans of steel are hung.

Generations dreamed the crossing;
Doubters shook their heads in scorn.
Brave men vowed that they would built it —
From their faith a bridge was born.

There it spans the miles of water,
Speeding millions on their way —
Bridge of vision, hope, and courage,
Portal to a brighter day.

* *Pronounced "Mackinaw"*

Aerial view of Mackinac Bridge, looking toward the southwest.

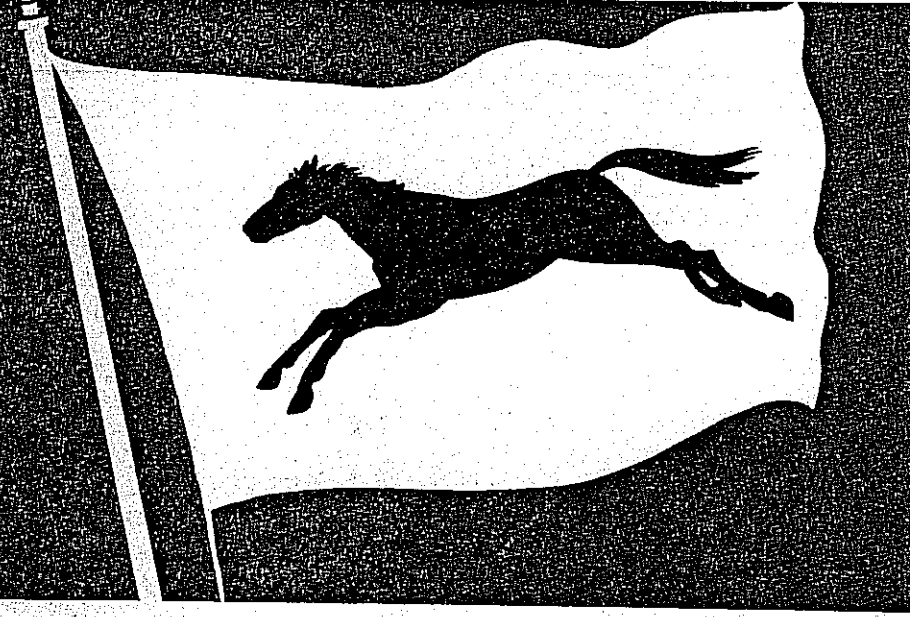
THE MACKINAC BRIDGE

This bridge is magnificent enough to speak for itself. So let us simply say that we are awfully proud to have been selected to fabricate and erect it. And we are equally honored to have worked with such versatile men as Prentiss M. Brown and David B. Steinman who possessed, among other talents, the ability to materialize what was merely a dream of previous generations.

AMERICAN BRIDGE DIVISION

UNITED STATES STEEL

USS



CONGRATULATIONS

ON THIS NEW MILESTONE OF PROGRESS

THE MACKINAC BRIDGE

As builders of the substructure for the Mackinac Bridge under the auspices of the Mackinac Bridge Authority, we are proud to have contributed to a project which will be an important factor in the further economic development of the State of Michigan and the entire area.

To all those who shared in this historic project, we express our sincere thanks for the splendid spirit of team work that helped so considerably in speeding it to completion.

Your Confidence Is Justified Where This Flag Flies

MERRITT-CHAPMAN & SCOTT
CORPORATION

Founded in 1860

CONSTRUCTION DEPARTMENT

Construction of Every Type

MARINE • HEAVY • HIGHWAY • CHEMICAL • INDUSTRIAL • BUILDING

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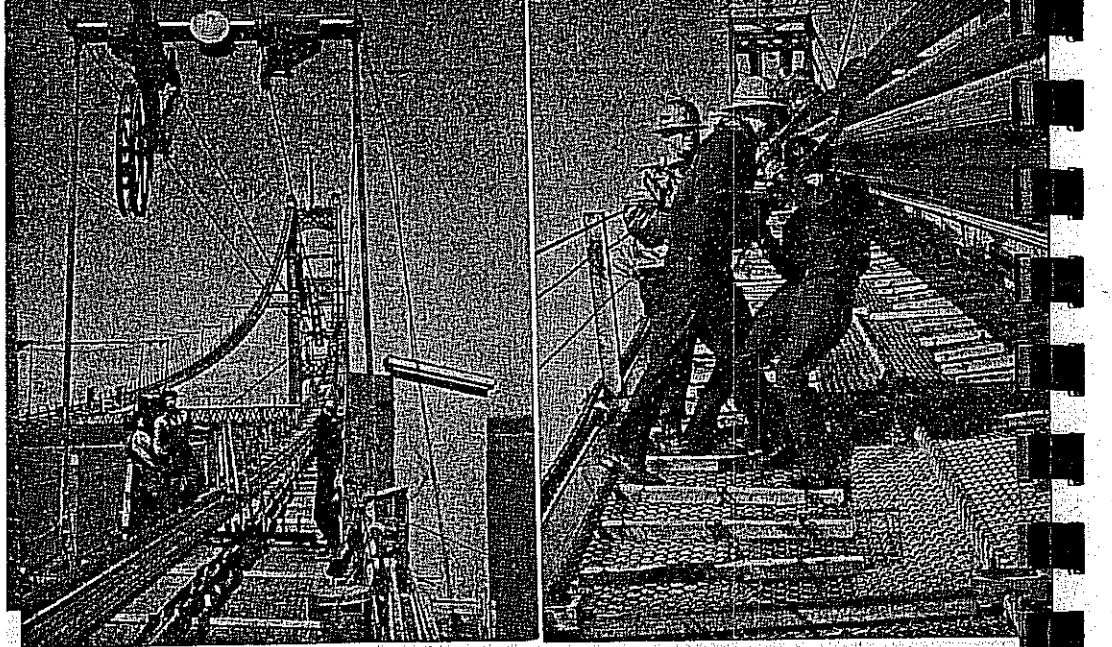


(Top Left) **Two spinning wheels meeting at center of span during cable-spinning operation.**

(Top Right) **Placing temporary bands on strands of west cable, near top of north tower.**

(Lower) **Checking diameter of east cable during compacting, near top of south tower.**

1957

DIRECTORY

OF ST. IGNACE AND NEARBY LOCALITIES

(From Rabbits Back to Pointe Aux Chenes)

Families

*(With Special List of Individuals with **, who attain age 80 or more in 1957)*

Organizations

Businesses

DIRECTORY SYMBOLS

c, child or children—*gc*, grand child or children—*emp*, employment—*w*, wife

The Magazine of Michigan

Life.

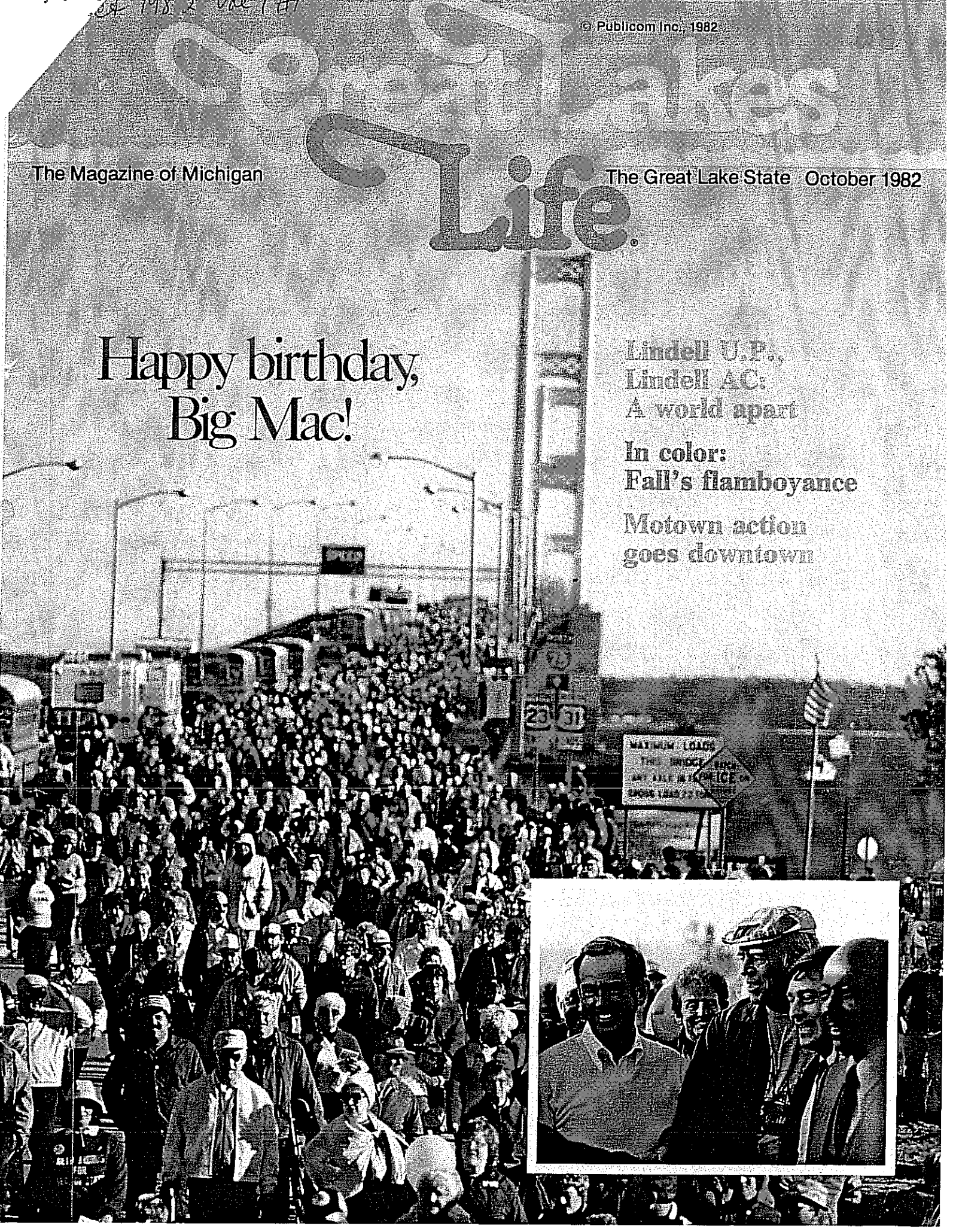
The Great Lake State October 1982

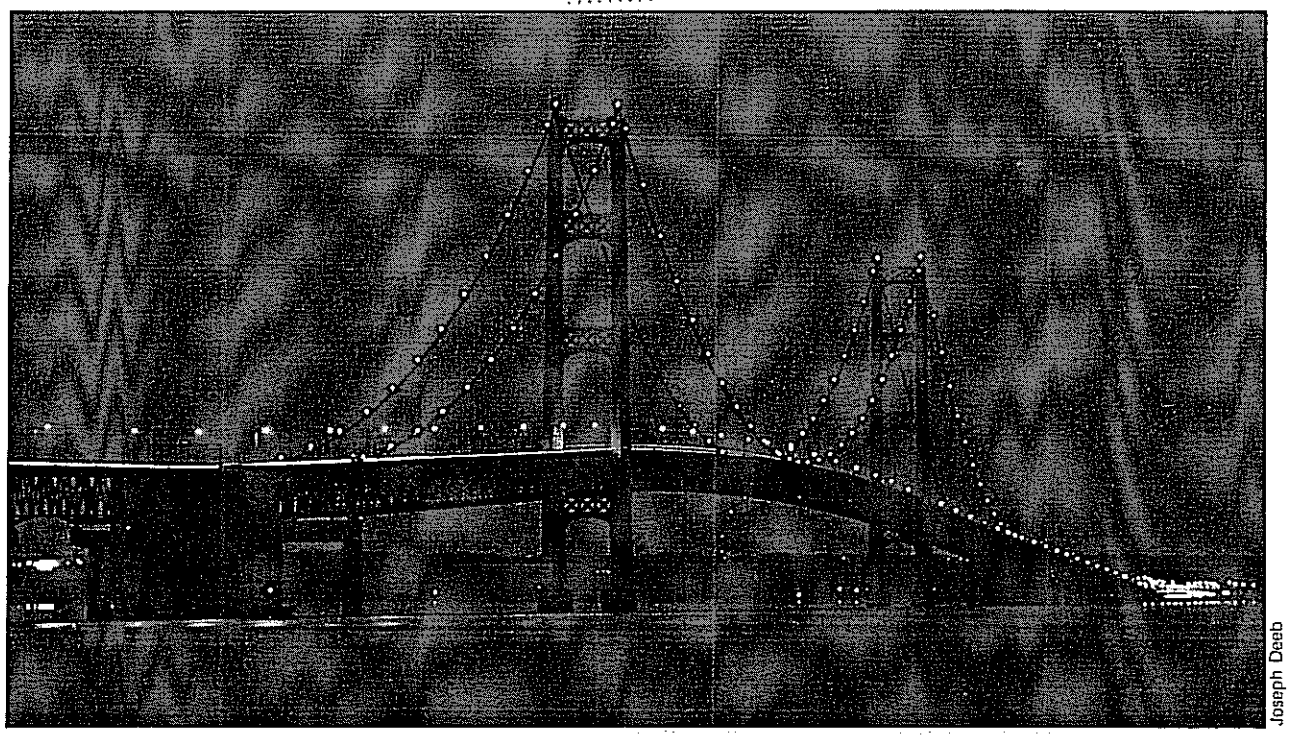
Happy birthday, Big Mac!

Lindell U.P., Lindell A.C.: A world apart

In color: Fall's flamboyance

Motown action goes downtown





Joseph Deeb

The Mackinac Bridge and its "necklace of diamonds."

Happy birthday, Big Mac!

By Maisie Brown

Michigan's mighty Mackinac Bridge is 25 this year, and the state is celebrating.

The silver anniversary party, kicked off by a champagne breakfast, will continue with a banquet in Cheboygan Oct. 30 and peak with a full-fledged re-enactment of the opening press tour Nov. 1.

A dream since Michigan's two peninsulas were declared a state on Jan. 26, 1837, the bridge spanning the Straits of Mackinac was more than a century reaching reality. Final building plans were interrupted by World War II, and it was not until Nov. 1, 1957, that the $100 million dollar bridge — almost four years in construction — felt its first wheels.

By Nov. 1 this year, 45 million vehicles will have crossed "Big Mac," according to Lawrence A. Rubin, executive secretary of the Mackinac Bridge Authority.

Designed by David B. Steinman, a bridge engineer described as having "the soul of a poet," the five-mile span can handle 6,000 vehicles an hour. Capacity of the ferries formerly used to carry traffic across the straits was 460 vehicles an hour — when weather permitted. Many deer hunters remember waiting for hours in cold cars and trucks to board a ferry.

A prime mover in favor of the bridge was W. Stewart Woodfill, manager of the Grand Hotel on Mackinac Island. At the end of the 1949 summer season, he closed the hotel, went to Lansing and, throughout the 1949-50 legislative season, worked to convince the state that a bridge connecting Michigan's upper and lower peninsulas would be an economic asset for both.

The Mackinac Bridge Authority was established in 1950. On Dec. 17, 1953, bids were accepted for bonds. The following February, bonds were delivered and cash received. Initial construction contracts were awarded soon after, and work on the bridge began in July, 1954.

One of the most glamorous phases of construction — spinning the cables — took place in 1956 and resulted in the present "necklace of diamonds" worn by the bridge at night. Lights strung for the night crews were so attractive the bridge authority made them permanent.

A symphony of sound was created by the bridge construction terms — cable bents, storm guys, drift pins, Georgia Buggy, pump crete, falsework — terms that could mystify and lent romance to the magnificence of the men who built the bridge.

Projects of such proportion are not completed without tragedy, however. Five men lost their lives during construction.

In the years since the bridge opened to traffic, there have been some unusual crossings, and Rubin said one of the most unusual took place the past summer.

"On Aug. 16, we put the cart before the horse," he recalled, smiling. 'We had a caravan of six wagons and 34 animals — 22 mules and 12 horses. Because only motorized traffic is allowed, the animals were conveyed in trailers, and the wagons were pulled by trucks!"

G. Mennen Williams, who was governor of Michigan while the bridge was being built, has written: "... The Mackinac Bridge is the manifestation, in steel and concrete, of the spirit of Michigan ... the spirit of a people for whom no task is too difficult, no job too big."

Williams joined Gov. William Milliken for this year's Labor Day bridge walk, spearheading the state's salute as Big Mac heads into its second quarter century.

LAWRENCE A. RUBIN

BRIDGING the STRAITS

The Story of Mighty Mac

WAYNE STATE UNIVERSITY PRESS DETROIT 1985

Library of Congress Cataloging in Publication Data

Rubin, Lawrence A.
Bridging the Straits.

Includes index.
1. Mackinac Bridge (Mich.) 2. Michigan—Politics and government—1951– . I. Title.
HE376.M3R83 1985 388.1'32'0977488 85–11475
ISBN 0–8143–1789–8

To the men who lost their lives
during the construction of the
Mackinac Bridge

Frank Pepper
James R. LeSarge
Albert B. Abbott
Jack C. Baker
Robert Koppen

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Came the Day!

Came the Day! November 1, 1957. The deadline was met as it was precisely scheduled by Steinman, carried out by the contractors, and overseen by the Authority. The media had a field day. The press lavished praise. It was refreshing to read front-page upbeat headlines and news stories. If any dark thoughts surfaced, they may have been due to petty jealousies aroused by someone getting a little more ink or credit than deserved. But meeting this deadline was not easy and two problems did arise—or more accurately, one problem and one big question.

The public did not realize that the bridge might not have been opened for traffic on November 1, 1957. During the fall of that year the American Bridge Division had to weld hundreds of sections of the steel grid surface of the main span to the supporting crossbeams of the deck. It was a labor-intensive, tedious, time-consuming job requiring literally tens of thousands of spot welds by scores of welders. Bad weather during September and October had limited working hours and the deck installation had fallen behind schedule. The contractors informed us that they might not be able to complete the grid deck and that the opening of the

bridge might have to be delayed. I knew they were asking for time because they did not want to increase their payroll to hire extra help or pay for overtime by their current work force.

I explained to them that the invitations for the bridge opening on November 1 had already been printed; that the media had been alerted; that VIPs had been scheduled to appear; and that the bridge opening would take place on November 1, with or without the grid. If we had to raid every lumber yard around to lay wooden planks on the cross-beams, we would do it.

With that the meeting broke up. I can only imagine what went on among the superstructure contractor's personnel: was I bluffing about the planks? If not, it certainly would be embarrassing to answer media questions about a wooden deck where there should have been steel. How much was involved in overtime or additional personnel to meet the target date? I daresay some long distance calls were made between St. Ignace and company headquarters in Pittsburgh. But when November 1 came around, the deck was done. How? A little overtime, a little more help, and an improvement in the weather.

Then came the question of the opening ceremonies.

November normally is not conducive to such outdoor events as dedications or parades. Football and hunting are fine, but standing around at the Straits of Mackinac or out on the bridge listening to speeches could be a bit much. So the Authority accepted my suggestion that the opening ceremonies be confined to a press or media tour with invitations also sent to state officers and legislators, engineers, contractors, and other persons directly concerned with the project. Then, in June of the following year when the Straits area is usually blessed with sunshine and flowers, a gala four-day celebration could be conducted, climaxed by the dedication of the bridge.

November 1, 1957, was as fickle as November 12, 13, and 14, 1952, when the underwriters were trying to impress

possible bond purchasers with the long lineup of hunter traffic only to be betrayed by one of the mildest Indian summers in memory, which made it possible for the ferries sailing on the glassy Straits to keep up with the traffic. Five years later, we again were surprised by mild weather, which was delightful for the opening day ceremonies. But this caused another problem: persons from the Straits area who normally would not have left their homes for an outdoor event in November came flocking to the Straits by the hundreds to participate in the opening of the Mackinac Bridge. The residents of Mackinaw City had graciously laid out a buffet for the three hundred invited guests. More than double showed up. But Mackinaw City hosts and hostesses made do. After the last person at that luncheon was served, there was not a cold cut or loaf of bread to be found anywhere in the Lower Peninsula within fifteen miles of the Straits.

The press busses drove out onto the center of the bridge at 10:00 A.M. as scheduled. The Authority members occupied a custom-built Chrysler open parade car, which I drove. We were followed by the VIPs and the not-so-important people, some of whom took enraged exception with me for my not having sent them invitations. The monumental importance of the occasion, however, quickly dissipated any confrontations, and all who came were welcome.

There were no speeches. Governor Williams made some informal remarks addressed primarily to the media people. He presented cuff links adorned with the state seal to members of the Authority and a few others. He also distributed souvenir ceramic plates and ashtrays. I got the ceramics, not the cuff links. Dr. Steinman also spoke briefly and mentioned again the aerodynamic stability of the bridge, one of his favorite features of the design. The press never accurately explained what he meant. Steinman described in detail the wind tunnel tests he had made of a scaled-down section of the Mackinac Bridge at the University of Oregon Engineering Laboratory. Since the collapse of the Tacoma Narrows Bridge in 1940, extensive research had been conducted to de-

termine the cause of its failure. The laboratory tested the proposed designs for new structures to determine their aerodynamic stability.

The Tacoma Narrows Bridge succumbed to winds with a velocity of only 42 miles per hour, which is relatively mild and just a little above normal at the Straits during the fall of the year. The reason for the failure was inherent in the design. The stiffening trusses or vertical beams on each side of the deck were solid and eight feet in height. When struck by wind from a certain direction, they reacted like the leading edge of an airplane wing, causing the solid surface deck to rise and fall. Gradually, the structure absorbed energy from the wind. In doing so, the distortion of the deck increased, as did its rising and falling, until the bridge twisted itself to destruction.

The researchers at the laboratory tested Steinman's section and by extrapolation concluded that it showed no aerodynamic instability no matter what the velocity of the wind. Theoretically, it would not twist itself to destruction because of its inherent design, even in winds of infinite velocity. Steinman tried to explain this in simple terms. He was careful to point out that the steel trusses were designed to withstand pressure of 50 pounds per square foot, or a wind velocity of 125 miles per hour. But most reporters seized upon the "infinite velocity" expression to dramatize Steinman's statement. They wrote that the Mackinac Bridge could withstand whatever winds might blow.

That must have raised some eyebrows in engineering and meteorological circles. Anybody who has ever witnessed or been in a tornado, which means winds of 200 to 250 miles per hour, knows that nothing stays put. Fortunately, the Straits of Mackinac is not in tornado country, but if there were winds of "infinite velocity" blowing through the Straits, the bridge would be somewhere around Mackinac Island, but who knows where Mackinac Island would be?

There was no wind at all at the Straits on November 1, 1957, until about four o'clock in the afternoon. With all the

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posing, picture taking, and tape recording completed and the lunch in Mackinaw City consumed, the schedule called for the return trip northbound with Governor Williams paying the first bridge toll to Prentiss M. Brown. Once again we got into the Chrysler parade car and this time it was agreed that Governor Williams would drive. But, unfortunately, he had let his driver's license expire. He really had no occasion to drive; governors rarely do. So Nancy Williams took the wheel and in those pre-ERA days, it raised a few eyebrows.

Pursuant to the plan, Brown donned a fare collector's cap. Governor Williams handed him his check for $3.25 to dramatize the fact that there was no free passage, not even for governors, for those crossing the Mackinac Bridge. Of course, checks are not accepted either, but the governor never told me he was going to use a check, and it was too late to invoke the rule. Williams knew well that everybody must pay to cross the bridge. Several years later, the governor was hosting John F. Kennedy, then a candidate for president, on a trip to the Upper Peninsula. There were four cars in the party which had stopped at one of the anchor blocks for pictures. The governor was in the lead car when they arrived at the fare booths. Somehow a car that was not part of the official entourage got in among those that were. The governor, always the soul of graciousness, paid for five cars and left a curious bridge crosser wondering why the fare collector would not accept his money.

The first official car, the first official payee, and the first official bridge-crosser ceremony went off without a hitch. However, when it came to first among the general public, there were many claims for this honor, and they may be valid but not official. Al Carter, a jazz band drummer from Chicago who made a hobby of being "first" at various events, had been in line since the night before the opening in order to be first across the bridge. As soon as the governor paid his fare the signal was given for the fare booths to open, and Carter made his famous dash to be first, and he was so proclaimed by the press. The car he used is now in the Grand Rapids Historical Museum.

accident held up traffic for more than four hours until the wind subsided. One lane in each direction was then opened. It was the worst wind experienced at the bridge, which of course sustained no damage.

The driver of the southbound tractor-trailer combination who agreed to be an escort when he paid his fare was not asked and did not reveal that his trailer was empty. But because it was empty, the updraft at Pier 17 in those record-high winds was enough to topple his trailer, which in turn pulled over his tractor. His injuries were not too serious, but he nevertheless decided to sue the Authority in the State Court of Claims. His wife also sued the Authority for lack of consortium. Several weeks later at a meeting of the Authority, I reported the incident and the two law suits.

Former governor Murray D. Van Wagoner, then seventy-six years old, vice-chairman of the Authority, and known for speaking his mind and his detestation of big words, wanted to know what "lack of consortium" was. When it was explained to him, he said, "Hell, give her my phone number!" Both law suits, however, were withdrawn.

Within a week after the opening, the bridge got its first test of Mackinac Straits winds and its first encounter with lightweight trailers, which would gently blow over on their sides. It was embarrassing, and very soon the buddy system was established. Drivers of trucks and other heavily loaded, solid vehicles were requested to escort the lightweight vehicles by driving on the windward side of them. This system was nearly 100 percent perfect, and after its inauguration the only times vehicles turned over was either when the wind came up so suddenly that there was no time to invoke the procedure or when some impatient driver outran his escort.

There was, however, one incident that bears retelling. On November 10, 1975—the same day the ore carrier *Edmund Fitzgerald* broke up and sank in a storm on Lake Superior with the loss of thirty-two lives—the buddy system had been operating at the bridge for southbound vehicles since about 1:00 P.M. The winds out of the west increased as the afternoon wore on. At about 3:00 P.M., an Authority patrol car radioed that a southbound tractor-trailer combination, an escort vehicle, had toppled over onto the compact car it was escorting at Pier 17, the south anchor block and the scene of most wind accidents. I inquired if anybody were hurt, and the report came back that the driver of the semitrailer complained of injury. Instructions were given to get him to the nearest hospital, in St. Ignace, but he would not go back across the bridge, so he was taken to Cheboygan. Chief Engineer Orlando Doyle and I went out to assess the situation. The tractor trailer had flattened the compact car, but the owner of that car miraculously had escaped injury. His only concern was for his dog, which was retrieved for him unharmed by bridge personnel. The wind-toppled vehicle had fallen across the pavement, blocking all lanes so that traffic could not move in either direction. In a few minutes wreckers were on the scene intent upon clearing at least one and possibly two lanes, but by this time the wind velocity had increased to gusts of up to ninety miles per hour. The men could not stand upright. Walking bent over or on their hands and knees was too dangerous for the work to be done. The

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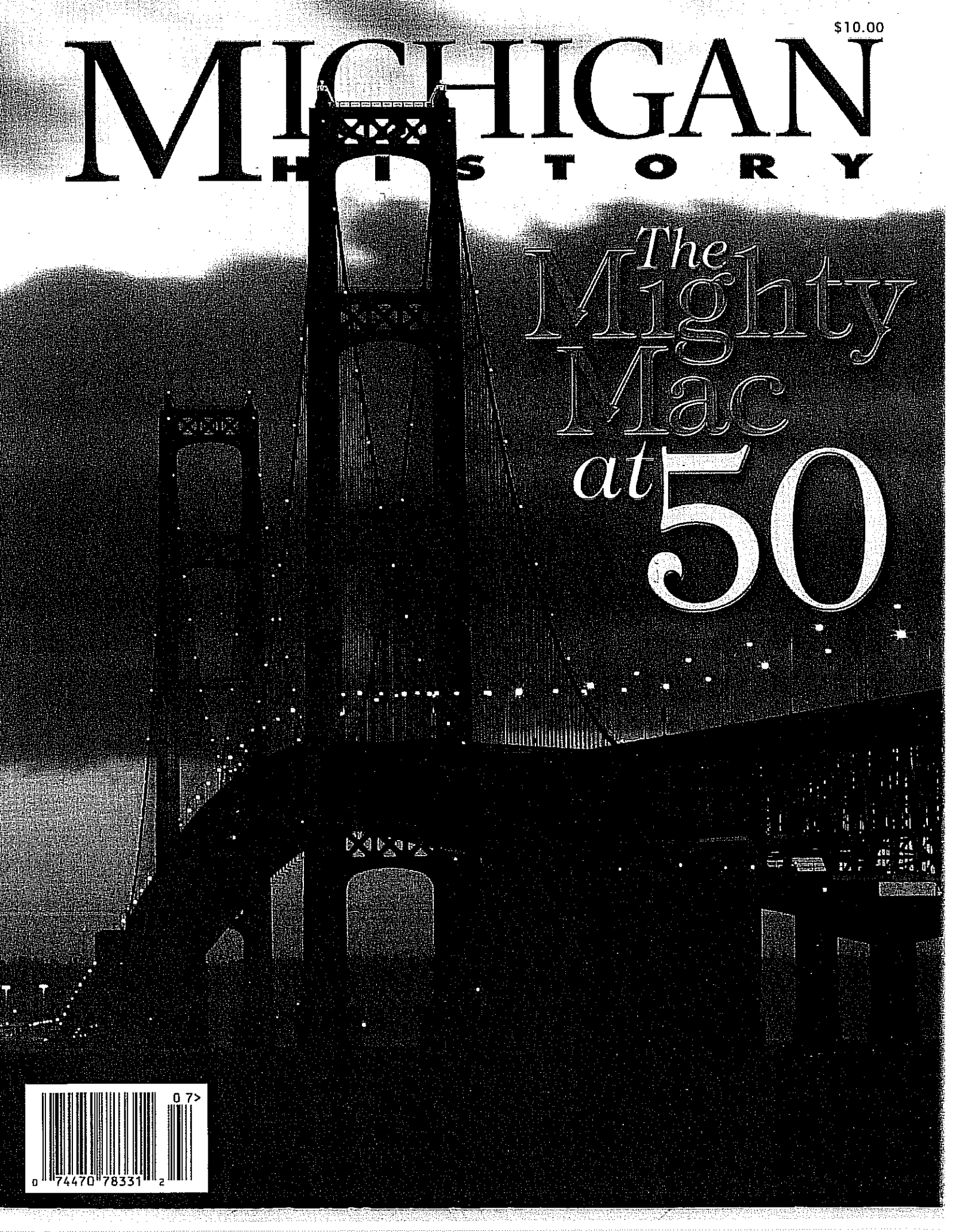
$10.00

MICHIGAN HISTORY



The Mighty Mac at 50

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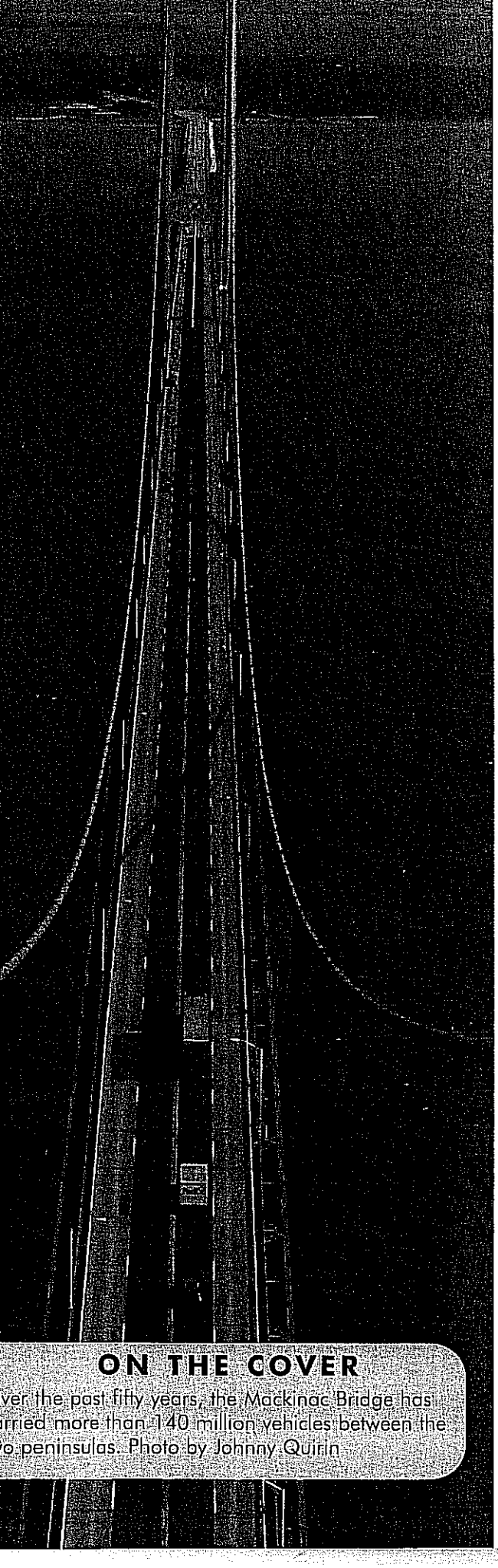
MICHIGAN HISTORY

INSIDE

Johnny Quirin

JULY/AUGUST 2007



ON THE COVER

ver the past fifty years, the Mackinac Bridge has rried more than 140 million vehicles between the o peninsulas. Photo by Johnny Quirin

Photo Johnny Quirin

DEPARTMENTS

MICHIGAN HISTORY

Volume 91 ▪ Number 4 ▪ July/August 2007

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Michigan History (ISSN 0026-2196) is published six times a year, with an annual subscription rate of $19.95 by the Michigan Historical Center, Department of History, Arts and Libraries, P.O. Box 30741, Lansing, MI 48909-8241. Periodicals postage paid at Lansing, MI and other locations. Postmaster: Send address changes to *Michigan History*, Department of History, Arts and Libraries, P.O. Box 30741, Lansing, MI 48909-8241 or visit our website at www.michiganhistorymagazine.com

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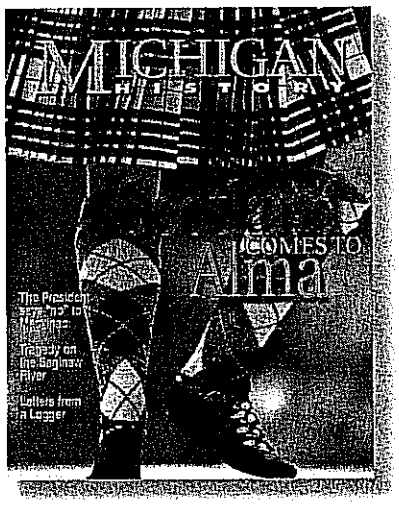


"It is amazing the number of bands from distant places this competition brings. This year it was a band from Charleston, South Carolina, that made the longest trek."

–Mary (Wellman) Oliver
Central Lake

HIGHLAND FESTIVAL

KUDOS TO GORDON Beld on his article about the Alma College and the Highland Festival and Games (May/June 2007). I just attended my twenty-seventh consecutive festival. I have attended as a spectator, competitor and, most recently, a dance teacher. I had also attended some of the earliest games, as my father and brother both played with the Clan MacRae pipeband.

It is amazing the number of bands from distant places this competition brings. This year it was a band from Charleston, South Carolina, that made the longest trek.

Sharing the article at the festival brought on a great game of "guess the year the picture was taken," especially of the picture of the piper and dancer on page 35. (Piper Bill Weaver of Alma and dancer Anna-Jane Hawley from Ontario, thought to be from the mid-80s).

Thanks for a wonderful publication.

Mary (Wellman) Oliver
Central Lake

SUMMER WHITE HOUSE

READING LE ROY BARNETT'S article about Michigan's failed attempts to lure presidents to Mackinac Island for the summer (May/June 2007) made me sad and reminded me of senior boys trying to get dates for the prom. But honestly, though rejected, we shouldn't feel too bad. Gerald Ford visited the island when he was president (even though he seemed to prefer to ski in Vail, Colorado) and young Mitt Romney, although the former governor of Massachusetts, returned to Michigan to begin his presidential quest. No one born in Michigan has ever been elected president. Thomas Dewey of Owosso is our only native son to get a nomination. But Romney, if nominated, shows an inclination that his fond memories may lead him back to our beautiful Mackinac Island for the summer.

Michael Dent
Northville

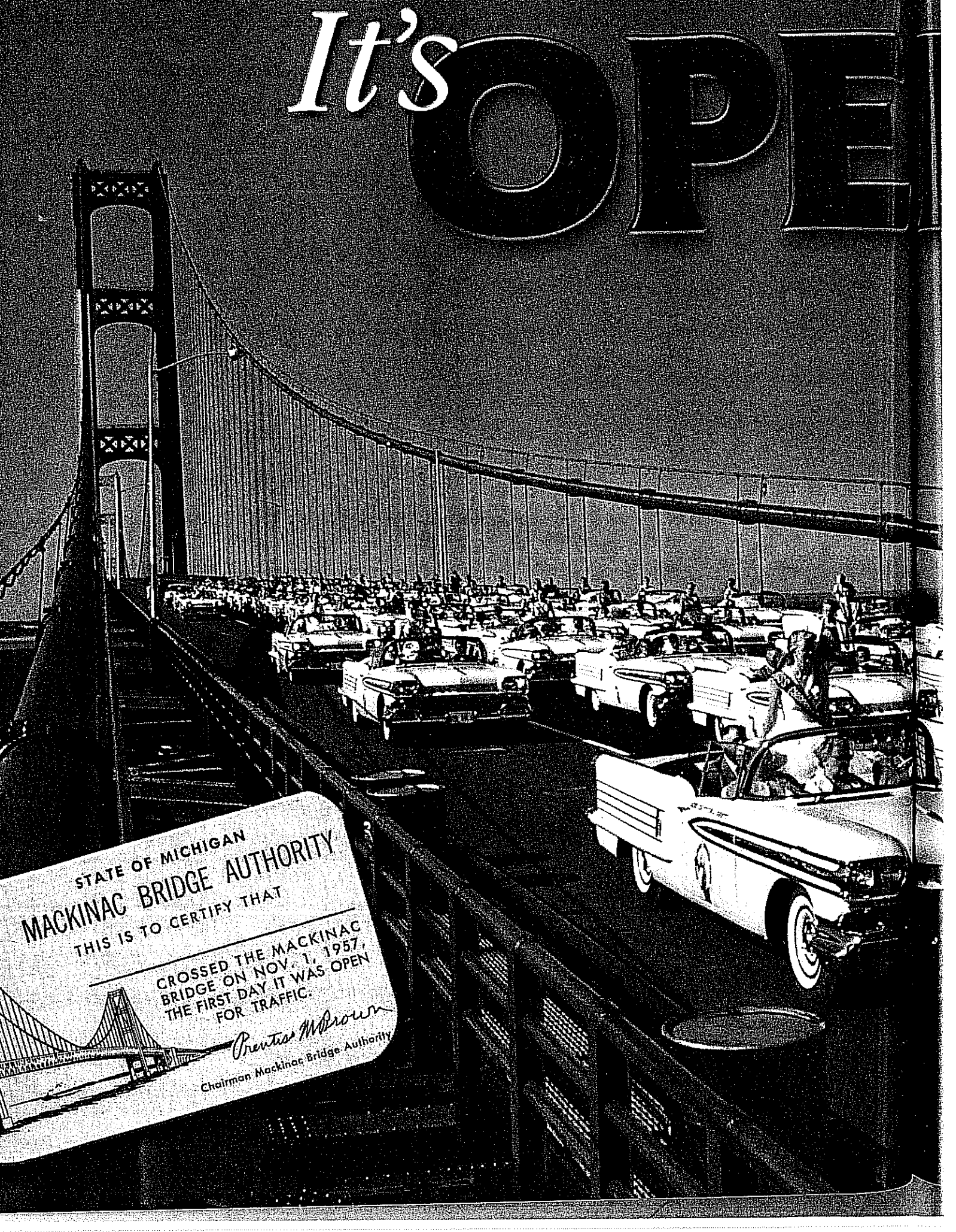
MEANINGFUL ARTICLES

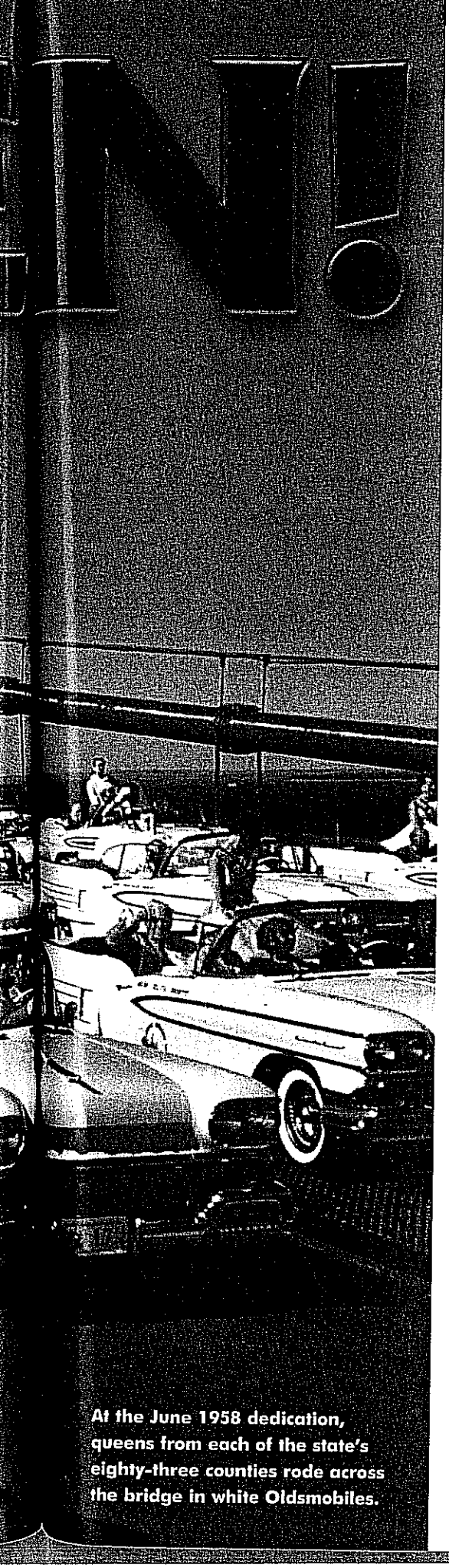
THE MAY/JUNE 2007 issue of *Michigan History* magazine came this week. As always the articles are interesting. Two, though, had special meaning to me; the story on Will Carleton ("Memorial Day at Arlington") and the article on the history of Lapeer.

My mother lived in Hudson, Michigan, from the time she was about six years old until graduation from high school in 1922. My dad taught school in Hudson and I was born there. My mother talked about Will Carleton. When we visited Hudson, Will's house was pointed out to me. When Mom was in eighth grade, or thereabouts, there was a parade in Will's honor and Mom was the "queen."

The story of Lapeer by Catherine Brakefield has raised a few questions. The

It's OPEN


STATE OF MICHIGAN
MACKINAC BRIDGE AUTHORITY
THIS IS TO CERTIFY THAT
CROSSED THE MACKINAC BRIDGE ON NOV. 1, 1957, THE FIRST DAY IT WAS OPEN FOR TRAFFIC.
Prentiss M. Brown
Chairman Mackinac Bridge Authority



At the June 1958 dedication, queens from each of the state's eighty-three counties rode across the bridge in white Oldsmobiles.

"Mighty Bridge Unifies Michigan" read the headline of the *Kalamazoo Gazette* on November 1, 1957. Across the state, newspapers agreed that the opening of the Mackinac Bridge was cause for great celebration.

With the bridge ready for traffic, but fearing inclement autumn weather at the Straits, officials decided to have an official "opening" on November 1, 1957, but an official "dedication" in late June of the following year.

Ironically, the weather on the first day of November (preceded by two days of rain and fog) was sunny and pleasant. However, the weather in late June was so cold and wet (with six-foot waves on the Straits) that some of the events were shortened or canceled altogether. According to one observer, it "was a bleak, gray day, more like March than June, and the only parader who looked happy was a snow queen from Cadillac, who rode on an ice throne float, throwing snowballs made of popcorn."

The media hailed the completion of the Mackinac Bridge as "Michigan's biggest historical event in 100 years," (which begs the question, "What about the automobile?") One newspaper ran a front-page story whose headline read, "Here's What Bridge Users Can Expect." The thirteen-item list concluded, "There will be no free fares, except bridge authority vehicles or for bridge employees."

On November 1, after paying the $3.25 toll (taken symbolically by former U.S. Senator Prentiss Brown), Governor G. Mennen Williams crossed the bridge (driven in a car by Mrs. Williams because the governor had forgotten his driver's license). Then, according to *United Press International* correspondent Thomas Farrell, cars lined up for one mile on both sides of the Straits "swarmed" on to a bridge whose size "staggers the imagination." Among those who came to the Straits that day was eighty-two-year-old E. S. Miller of Winter Park, Florida. Miller claimed he "watched 'em start this bridge [and wanted to be there] when they finished it."

In his opening day remarks, Governor Williams predicted that the bridge would add $100 million annually to the state's tourist trade. He continued, "Michigan at last is to be one state, geographically, economically and culturally, as well as politically."

At the June dedication, Williams thanked those responsible for building the bridge, then dedicated it to an assortment of different groups, but especially "the million of children from all over America who will come to ride across it and who will see in it the spirit of man's conquest over the obstacles of nature." Williams returned to his earlier theme about unification, adding, "Where nature divided us we have bound ourselves together with this great web of steel. This mighty bridge, the world's greatest, is a symbol of our strength."

Let us remember his words next time we cross the Mighty Mac.

traffic through it.

Text of Mr. Moses' Letter

Mr. Moses' letter was dated Oct. 9. Mr. Jack read it at the opening of yesterday's hearing. Addressed to "Dear Hulan," it said:

"We understand you propose that the width of the roadway through Washington Square connecting Fifth Avenue with West Broadway be thirty-six feet.

"This is ridiculously narrow and is, in fact, no better than the present roadway. It ignores the new developments south of Washington Square and their traffic requirements. This new roadway must provide four lanes of moving traffic. All modern lanes following established and recognized principles are at least twelve feet wide which means in this instance that there must be forty-eight feet of pavement.

"We believe this park roadway should be divided by a center mall at least five feet in width and that trees should be planted on this mall. The mall will provide safer crossing for pedestrians and greater safety for motorists. Since the road must be divided at Washington Arch it should be divided all the way across the park.

"As I understand it you propose two lanes southbound through the Arch and two lanes northbound east of the arch, and to compress these four lanes into three lanes south of the arch. This can't work.

"We will have to oppose a thirty-six foot roadway wherever it comes up and must as a matter of principle present in the City Planning Commission the arguments against the adoption of any such inadequate roadway through Washington Square Park.

"We shall have to prepare our development plan for the reconstruction of Washington Square to show a divided treatment with two roadways each twenty-four feet wide, separated by a five-foot mall with trees."

'Not Going to Dictate'

After reading Mr. Moses' letter, Mr. Jack told the fifty persons crowded into his office, "I am going to say right now that the Park Department is not going to dictate this roadway."

Observing that he could not satisfy everybody, nor was he trying to, Mr. Jack emphasized that he would oppose any plan to close the park to all traffic. His plan for the park, he said, envisaged preserving its traditions, having "a minimum of roadway and still meet good engineering standards," and keeping as much space as possible for the recreational needs of children.

"I want to make it absolutely clear," he asserted, "that I will not go along with a forty-eight-foot roadway. I want to make that very clear to both the Park Department and the Traffic Department, and when I make this statement I make it on the basis of conferences with my own engineers."

Several speakers persistently voiced suspicions that a plan for widening lower Fifth Avenue was in the offing. To them, John T. Carroll, consulting engineer to the Borough President, said that "definitely for the record this office is not en-

The inset map shows the location of the 3½-mile bridge and tunnel expressway that was opened yesterday in Vi

Straits of Mackinac Crossed by 5-Mile Suspension Span

By DAMON STETSON

Special to The New York Times.

ST. IGNACE, Mich., Nov. 1—The five-mile Mackinac Bridge, linking Michigan's upper and lower peninsulas, was opened to traffic today.

The $100,000,000 bridge is expected to be a tourist attraction and an important economic factor in the development of northern Michigan.

In a brief comment while standing at mid-span, 199 feet above the Straits of Mackinac, Gov. G. Mennen Williams predicted that the bridge would have a unifying influence on Michigan, culturally, socially, politically and geographically.

"This bridge," he said, "opens a great new trade route, a new northwest passage."

Prentiss M. Brown, chairman of the Mackinac Bridge Authority, and a long-time resident of Michigan's upper peninsula, said the bridge foreshadowed the "dawn of a new era of prosperity for northern Michigan, particularly the upper peninsula."

Dedication in June

Today's ceremonies were relatively simple because the formal dedication of the bridge was scheduled next June. But hundreds of residents from St. Ignace, northern terminus of the bridge, and Mackinaw City, southern terminus, lined the approaches at both ends to watch the first cars cross.

Prior to the opening at 2:05 P. M., cars were lined up for about a mile and a half on the north side of the bridge and for about three-quarters of a mile on the south side. During the first hour after the bridge was opened 930 vehicles crossed and paid $3,697.75 in tolls.

The toll per car, including driver and passengers, is $3.25. Rates, based on the number of axles, range to $14 for truck combinations with more than five axles.

Governor Williams, with his wife Nancy at the wheel, was in the first car after making the crossing from Mackinaw City to the toll plaza on the St. Ignace side. He paid the toll to Mr. Brown. A few minutes of picture-taking followed. Then the bridge authority chairman announced that the span was opened to the public.

Two southbound drivers, who had been waiting since last night to cross, were the first to pay tolls after the Governor. One was Al Carter, an orchestral drummer, from Chicago. The other was Emil Syversen of St. Ignace, driving a 1923 Dodge.

35-Year-Old Ferry Discontinued

The state ferry service, which has been operating across the straits for thirty-five years, was discontinued this afternoon shortly after the bridge opened.

By most comparisons the new suspension bridge is the biggest and costliest in the world. The distance from anchor block to anchor block, where the 24½-inch cables are fastened, is 8,344 feet. That is almost 2,000 feet more than the Golden Gate Bridge at San Francisco, making the new bridge the largest of the suspension type in the world.

The center span of the Mackinac Bridge, however, is 3,800 feet, 400 feet less than the center span of the Golden Gate Bridge. The over-all length of the Michigan bridge, including approaches, is 26,444 feet.

Dr. David B. Steinman was the bridge's designer. The 34-pier sub-structure of the bridge was built by Merritt-Chapman & Scott Corporation of New York. The steel superstructure was fabricated and erected by the American Bridge Division of the United States Steel Corporation.

Project With Tunnel Connects Norfolk and Hampton

Special to The New York Times.

HAMPTON, Va., Nov. 1—The water barrier between the Virginia cities of Norfolk and Hampton was conquered today with the opening of the Hampton Roads Bridge tunnel, an expressway of slightly more than three miles.

The crossing is the key segment of a twenty-four-mile, $60,000,000 highway improvement program in tidewater Virginia. It unites the peninsular cities of Hampton and Newport News with Norfolk and Portsmouth to form an urban area of more than 500,000 inhabitants.

Replacing ferry service, the tunnel and its bridge approaches reduce the travel time between Norfolk and Hampton from forty to six minutes.

Toll traffic began to flow in both directions soon after ribbons at the Norfolk and Hampton ends had been cut. The ceremonies were necessarily brief because of wind and rain.

6,400 Vehicles a Day Expected

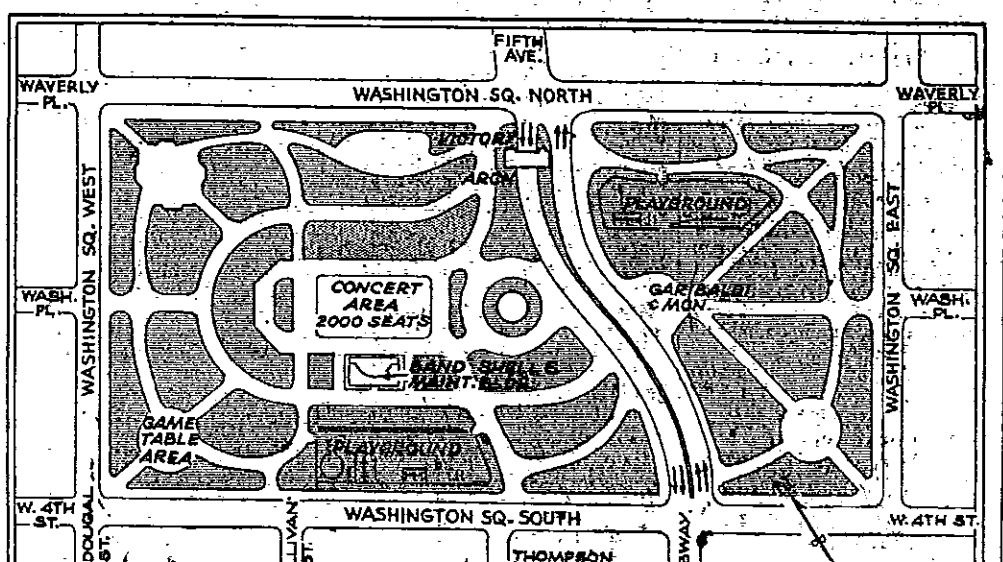
At least 6,400 vehicles are expected to use the crossing daily at the outset. But officials expect the figure to increase to 10,000 by 1980.

The Hampton Roads two-lane tunnel is the sixth longest underwater tunnel in the world. It is made up of twenty-three sections of double shell steel tube.

These tubes were constructed ashore, towed to the tunnel site, lowered into a previously dredged trench and locked together by divers.

The 6,860-foot tunnel is the world's longest of the trench type. It is the first built with portals emerging on man-made islands, which are 3,250 and 6,110 feet from shore.

The Posey tube in Oakland, at 3,545 feet, is the second longest of the trench type.



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Section 4

Comparable Projects

At the time of its completion the Mackinac Bridge was the largest suspension bridge in the world. Few bridges can compare to Mighty Mac's size and seasonal weather conditions, obstacles which engineers would consider, conceiving what would seem to be an invincible link between St. Ignace and Mackinac City. Similar bridges include the Golden Gate Bridge (NHCEL 1984), Verrazano-Narrows Bridge, the George Washington Bridge, the Akashi Kaikyo (Japan) and the Humber Bridge (England). Reference 1 includes a list of historical landmark bridges.

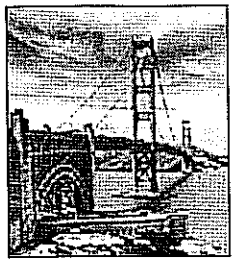
1. "Long Span Bridges." *ASCE List of National Civil Engineering Landmarks.* ASCE. 1996-2009. Retrieved fm http://www.asce.org/history/monuments_millennium/bridges.cfm August 2009.

- Also see comparable bridge spans noted in reference 2.3 of Section 2 regarding Prentiss M. Brown.

Long-Span Bridges

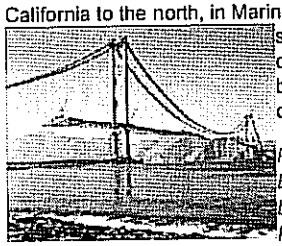
Bridges of increasing size and span have created phenomenal changes in the social patterns and economic conditions of areas by effectively eliminating water barriers between communities. They open new routes of communication between disintegrated and isolated communities, provide safe and efficient access to work, schools and recreation for people, and spur economic growth by facilitating trade within and between regions. From the late 19th century through the early 20th century the use of steel enabled the production of increasingly longer, continuous main span traversing large, deep bodies of water. As the symbolic soul of cities, bridges shape a city's character and, in turn, are shaped by the lives of the people served by them.

Golden Gate Bridge: A Monument of the Millennium

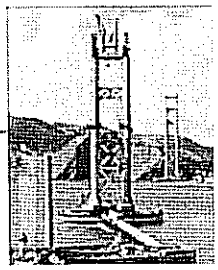


Date of Dedication:
May 30, 2001

One of the most recognized landmarks in the world, the Golden Gate Bridge, connects geographically isolated areas of California to the north, in Marin and Sonoma counties, with San Francisco. When the bridge opened in 1937, with a main suspension span length of 4,200 feet, it was the longest in the world. The engineering obstacles poised by the mile-wide, turbulent Golden Gate Strait led engineers to devise a bridge that required four years to build, 83,000 tons of steel, 389,000 cubic yards of concrete, and enough cable to encircle the earth three times.



Previous ASCE designations for the Golden Gate Bridge include: the National Civil Engineering Landmark (1984) and Seven Wonders of the World (1955). Other significant bridges include the Verrazano-Narrows Bridge, the George Washington Bridge, the Akashi Kaikyo (Japan) and the Humber Bridge (England).



Additional Information

http://www.goldengatedesign.com/goldengate.html
Brief history of the massive construction project examines the politics, tragedies, and odds that seemed to hinder its completion.

http://www.thoma.com/thoma/ggbfacts.html
Mike Thomas has compiled this fact and statistics sheet about the enormous Art Deco structure that details the bridge's design and lighting features.

http://www.goldengatebridge.org/
The official web site for the Golden Gate Bridge, heralded as one of the top ten construction achievements of the 20th Century.

http://www.goldengate.org/
Chronicles the planning and construction of the engineering marvel of the western world including several photographs.

ASCE does not endorse any of the above Web sites. They are presented here for informational purposes only.

Back to the Monuments of the Millennium main page.

Back to the top ▲

- If a project is part of the Heritage Knowledgebase Database, its name is linked directly to that particular Web page.
- * Projects which have been documented by Historic American Engineering Record.
- + Projects which have been designated by the National Park Service as a National Historic Landmark or part of such a landmark

Project Name, Location	Designated Year
Alvord Lake Bridge, San Francisco, California, USA * + Built in 1889 by Ernest L. Ransome, this bridge, located in San Francisco's Golden Gate Park, is the oldest (and first to be constructed in the United States) concrete arch bridge with steel reinforcing bars.	1969
Armour-Swift-Burlington Bridge, Kansas City, Missouri, USA This unique, telescoping vertical-lift, steel-truss bridge spanning the Missouri River at Kansas City since 1912 is representative of the innovative moveable bridges designed by former ASCE President, and leading bridge engineer, John Alexander Low Waddell. It was originally designed with a movable lower span to carry the rail traffic while the upper span carried uninterrupted highway traffic. Recent renovation has removed the highway traffic.	1996
Bailey Island Bridge, Harpswell, Maine, USA * Completed in 1928, the Bailey Island Bridge traverses an 1,150-foot stretch of high tidal water with swift currents, severe saltwater exposure, and heavy winter ice floes. This challenge was met with an innovative split-stone open crib construction, carrying the concrete deck; a concrete span crosses the navigation channel. The bridge continues to serve its function without impeding tidal flow; an exceptional example of an engineering solution to meet extremely unusual conditions.	1983
Bayonne Bridge, New Jersey/New York State, USA * Completed in 1931, this steel arch bridge, designed principally by Othmar Ammann (Hon.M.ASCE), was the greatest span (1,675 feet) of its type in the world and remained so until the New River Gorge Bridge at West Virginia exceeded it by twenty-five feet in 1977. The Bayonne, which connects Bayonne, N.J. to New York City, N.Y, was the first major bridge to use manganese steel for its main structural members. The construction process employed an innovative system of falsework, developed to preclude the need for heavy anchorages.	1985
Bidwell Bar Suspension Bridge, Oroville, California, USA * An example of the typical suspension bridges constructed during California gold rush days, the Bidwell Bar Suspension Bridge was built in 1856 over the Feather River approximately ten miles northeast of Oroville. The bridge has been reconstructed at a historical park about a mile from its original site and it is the only remaining suspension bridge of its time in the West.	1967
Blenheim Bridge, North Blenheim, New York, USA + Constructed in 1855, this covered wooden truss bridge, designed and built by Nicholas Powers, is the longest (210 feet) bridge of its kind in the world. This record clear span was achieved by an ingenious interlocking of truss and arch action and remains today as a tribute to American engineering. This bridge is one of the few bridges on the Register of National Historic Landmarks of the National Park System.	1983
Bollman Truss Bridge, Savage, Maryland, USA * + The noted Baltimore bridge engineer Wendel Bollman built this eighty foot double truss span in 1869. It is the only remaining example of a patented design that was used extensively on the Baltimore & Ohio and other railroads.	1966
Bridgeport Covered Bridge, Nevada City, California, USA Built in 1862, this bridge is the longest single span (230 feet) covered bridge west of the Mississippi River. The design is best described as a Burr truss. This bridge, which originally carried heavy freight between Marysville, California and Virginia City, Nevada, remains in service.	1970

Bridges of Keeseville, Keeseville, New York, USA **1987**
Keeseville has three remarkable operational 19th century bridges of different types all within five hundred yards of each other: a one hundred foot span stone arch (1843); a wrought iron Pratt truss (1878); and a twisted wire cable suspension bridge (1888). The evolution of civil engineering materials, analysis, and design, are clearly illustrated by these structures, all of which remain in service.

Bridges of Niagara, Niagara Falls, Canada/United States **1992**
The Niagara River gorge has been the site of a number of historically significant bridges. Charles Ellet, Jr.'s suspension bridge of 1849, John A. Roebling's railroad suspension bridge of 1855, Charles C. Schneider's railroad cantilever of 1883, Leffert L. Buck's two arch bridges (1897-1898), and Shortridge Hardestry's Rainbow (1941) all influenced the development of long-span bridge design and construction.

Brooklyn Bridge, New York City, New York, USA * + **1972**
When completed in 1883, the Brooklyn Bridge was the longest suspension bridge in the world. It was the first to use steel cables and trusses. Designed by John A. Roebling, it was built under the supervision of his son Washington.

Bunker Hill Covered Bridge, Claremont, North Carolina, USA **2001**
The Bunker Hill Covered Bridge, constructed in 1895 and restored in 1994, is the only remaining example of the improved lattice truss timber bridge patented by Herman Haupt in 1839. Haupt, who was in charge of railroad engineering for the Union Army during the Civil War, evolved the design while developing a rational method for truss analysis as outlined in his 1851 book, <I>General Theory of Bridge Construction</I>, one of the earliest American books on bridge engineering.

Cabin John Aqueduct, Cabin John, Maryland, USA * + **1972**
Built between 1857 and 1863 under the direction of Capt. Montgomery C. Meigs, this was the longest span stone masonry arch in the world until 1903. This structure is still serving the basic purpose for which it was built, providing water to Washington, DC, as well as carrying traffic loads.

Canton Viaduct, Canton, Massachusetts, USA * **1998**
Since its opening in 1835, the Canton Viaduct has been in continuous service to high speed rail. This 21-arch granite masonry bridge was uniquely designed with hollow spaces between walls, connected by solid buttresses between arches. The slightly curved, functional bridge is 615 feet long, 70 feet high and 22 feet wide.

Carrollton Viaduct, Baltimore, Maryland, USA * + **1982**
Designed and built by Casper Weaver, the viaduct was the first major structure on an American railroad. Completed in 1829, this two-span masonry arch remains in full service today, a monument to our civil engineering heritage.

Choate Bridge, Ipswich, Massachusetts, USA * + **2008**
The Choate Bridge of Essex County, completed in 1764, is the oldest documented two-span masonry arch bridge in the United States. It presents a unique example of two co-existent forms of 18th century masonry arch construction in one bridge.

Columbia-Wrightsville Bridge, Columbia, Pennsylvania, USA **1984**
When completed in 1930, this was the longest (one-mile) multiple-arch concrete highway bridge in the world. To achieve this economically, civil engineers developed a unique system of combining a parallel construction railway, track mounted whirly cranes and re-usable steel forms. It remains in full service today and is also the site of a historic American Covered Bridge that existed between 1812 and 1833.

Conwy Suspension Bridge, Conwy, Wales **2002**
A major structure on the strategically important Bangor-to-Chester road, Conwy Suspension Bridge, Telford's most dramatic creation in the gothic style, was built with the identical technology developed for the larger Menai Bridge and still has its original iron chains.

Conwy Tubular Bridge, Conwy, Wales **2002**
Built for the Chester-Holyhead Railway, which provided rail access to the sea crossing to Ireland, this bridge was a forerunner to Robert Stephenson's Britannia Bridge over the Menai Strait. Conwy Tubular Bridge was the first railway bridge in which trains ran through the main girders. It represents a pioneering use of wrought iron for bridges and a major advance in the development of box-section girder elements.

Cornish - Windsor Covered Bridge, Windsor, Vermont, USA * **1970**
This two-span covered bridge, with an overall length of 460 feet, is the longest covered bridge existing in the United States. It is a Town lattice timber truss design, a type widely used on many early timber bridges and later in building construction. Rebuilt in 1988, the bridge was originally constructed in 1866.

Cortland Street Drawbridge, Chicago, Illinois, USA **1981**
Completed in 1902 and still in use, this trunnion-bascule highway bridge was the first of its kind and became the model for this type of urban transportation structure.

Craigellachie Bridge, Moray, Scotland **2007**
This elegant 150 ft span cast iron arch was erected in August-September 1814. It is the earliest surviving example of a new portable lattice-braced standard type developed for use at wide sites unsuitable for masonry spans. Thomas Telford was the designer and engineer for this new type of arch. At least 10 arches were erected in Britain from 1812-30.

Delaware Aqueduct of the Delaware & Hudson Canal, Lackawaxen/Minisink Ford, Pennsylvania/New York State, USA * + **1972**
This span is John A. Roebling's earliest, still-standing suspension bridge and perhaps the oldest existing cable suspension bridge in the world (that retains its original principal elements). This bridge is considered one of the nation's most significant engineering relics and the earliest work of Roebling. It was completed in 1848 as an aqueduct bridge to carry the Delaware & Hudson Canal across the Delaware River. It was completely restored by the National Park Service in 1983. It goes from Lackawaxen, PA to Minisink Ford, N.Y.

Duck Creek Aqueduct, Metamora, Indiana, USA **1992**
Constructed in 1846, this 71-foot span is the oldest covered wooden aqueduct in the country. It still carries the Whitewater River Canal over Duck Creek. The aqueduct was reconstructed in 1948 using much of the original material.

Dunlap's Creek Bridge, Brownsville, Pennsylvania, USA * **1978**
Dunlap's Creek Bridge is the oldest all-metal arch bridge in the United States. Conceived by Captain Richard Delafield in 1830, it was completed in 1839, and it emphasized the feasibility of cast iron in bridge construction at that time.

Eads Bridge, St. Louis, Missouri, USA * + **1971**
Completed in 1874, this celebrated bridge is named for James Buchanan Eads, its designer and builder. To found the mid-river piers on solid rock, Eads used the first large pneumatic caissons in the United States. Their sinking represented the deepest subaqueous construction work in the world at the time. The scale of the structure was unprecedented: the more than five hundred foot span of the center arch exceeded by some two hundred feet any arch built previously. The arch ribs were made of steel, its first extensive use in a bridge. An innovation was the cantilever erection of the arches, without falsework, the first instance of this for a major bridge.

Fink Deck Truss Bridge, Lynchburg, Virginia, USA **1979**
A unique survivor of a truss system widely used between 1854 and 1875, this cast and wrought iron truss system was patented by Albert Fink (1880 ASCE President) in 1854. Constructed in approximately 1870 as a railroad bridge, it was converted to vehicular use in 1893. The truss elements were moved to a park in Lynchburg, Virginia in 1985, where it is now used as a footbridge.

Fink Through Truss Bridge, Hamden, New Jersey, USA * **1979**
Possibly the oldest metal truss bridge in the nation, this bridge, completed in 1858, was constructed of cast and wrought iron and demonstrated a major breakthrough in patented railroad bridge design and construction. A car collision in 1978 destroyed this bridge.

Firth of Forth Railway Bridge, Queensferry, Scotland **1985**
Built between 1882 and 1890, this British railway bridge held for twenty-seven years the world's record for span (521 meters). To achieve this, John Fowler and Benjamin Baker (Hon.M. ASCE) developed a unique double cantilever profile and utilized mild steel. This structure remains in service today as a link in the British Rail system. The 101-meter tall towers allow a shipping clearance of forty-six meters. The overall length of the bridge is 2,529 meters.

Five Stone Arch Bridges, Hillsborough, New Hampshire, USA **2002**
These five bridges, Carr Bridge (mid 1800's), Gleason Falls Bridges (circa 1830), Gleason Falls Road over Beard's Brook (mid 1800's), Second New Hampshire Turnpike Bridge (circa 1864), and Sawyer Bridge (circa 1866), constitute the largest extant cluster of dry-laid stone arch bridges within the U.S. They were built by trained masonry craftsmen and continue to demonstrate the durability of such construction.

Frankford Avenue Bridge, Philadelphia, Pennsylvania, USA **1970**
This three-span stone arch bridge over Philadelphia's Pennypack Creek was built in 1697 and has served as an important roadway ever since. It is the first known stone arch to be built in this country and probably the oldest bridge in the United States.

George Washington Bridge, Fort Lee/New York City, New Jersey/New York, USA * **1981**
The 3,500 foot center span of this world-renowned suspension bridge, completed in 1931, virtually doubled the span of its largest predecessor. Othmar H. Ammann (Hon. M. ASCE) directed the planning, design and construction. This bridge connects Fort Lee, N.J. with New York City, N.Y.

Golden Gate Bridge, San Francisco, California, USA **1984**
Put in service in 1937, this world-renowned bridge, conceived by Joseph Strauss and designed largely by Charles Ellis, was the longest single span (4,200 feet) in the world for a quarter century.

High Bridge, Jessamine, Kentucky, USA * **1985**
Known as the first major cantilever bridge in the United States, this span was built between 1876-1877 by Charles Schaler Smith, and was the highest (275-feet) and longest span cantilever (three 375-foot spans) in the world at that time. The structure utilized portions of an earlier uncompleted bridge, designed by John A. Roebling in its construction. High Bridge was replaced, because of increases in train loads, by a bridge of similar construction in 1911 by Gustav Lindenthal, (Hon.MASCE). The 1911 bridge is still in service for the Norfolk Southern Railway.

Ironbridge, Coalbrookdale-Ironbridge, England **1979**
This bridge, completed in 1779, is recognized as the first iron bridge in the world. Standing today, it is an outstanding international monument to both the civil engineering profession and the industrial revolution.

John A. Roebling Bridge, Cincinnati, Ohio, USA * + **1982**
When completed by John A. Roebling in 1866, this suspension bridge, with a main span of 1,057 feet, was the greatest structure of its kind in the world and was the prototype for his greatest achievement, the Brooklyn Bridge, which followed sixteen years later. This bridge, due to renovations, has remained in continuous service since its opening, even in 1937 when the Ohio River rose eighty feet.

Kinzua Railway Viaduct, Kane, Pennsylvania, USA * **1982**
Constructed in only 102 days and completed in 1882, this structure was by far the highest (302 feet) and the longest (2,053 feet) viaduct in the world at that time. Reinforced in 1900 because of heavier service loads, the new bridge included the first Vierendeel type truss in the western hemisphere. Octave Chanute (1891 ASCE President) participated in the engineering of both structures.

Lacey V. Murrow Bridge and Mount Baker Ridge Tunnels, King County, Washington, USA **2008**
These structures constitute the world’s first reinforced concrete floating bridge - the largest floating structure ever built - and the largest diameter soft-earth tunnels when completed in 1940. This project greatly reduced highway travel time and distance to Seattle from the east and led to the construction of other major floating bridges in the United States, Canada, Norway, and Japan. Civil engineer Homer Hadley conceived this unique application for concrete and civil engineer Lacey V. Murrow led project design and construction. Contractors were Pontoon Bridge Builders for the bridge and Bates and Rogers for the tunnel. The bridge pontoons were replaced during rehabilitation in 1993.

Menai Suspension Bridge, Menai, Wales **2002**
Built for the Chester-Holyhead Railway, this bridge was a major structure on the road connecting London with Holyhead and by sea to Ireland. The bridge had the world's longest span and greatly advanced suspension bridge development.

Missouri River Bridges, Chamberlain, South Dakota, USA **1994**
Five Pratt truss steel bridges, completed between 1924 and 1926, constituted the first Missouri River highway crossings in South Dakota. Designed for economy and endurance by the South Dakota Highway Commission, only the Chamberlain Bridge remains in service. It now includes trusses from the original Wheeler Bridge. Subsequent Missouri River dams made the river too wide for the original structures.

Morison's Memphis Bridge, Memphis, Tennessee, USA **1987**
Erected in 1892 by George S. Morison (1895 ASCE President), this cantilever truss was built entirely of the then-newly-developed basic open hearth steel. When completed, its 790-foot main span was the longest railroad truss in North America. The bridge is now called the Frisco Bridge.

Moseley Wrought Iron Arch Bridge, North Andover, Massachusetts, USA **1998**
Designed, patented, and built by Thomas W.H. Moseley in 1864, this arched ninety-six foot span bridge incorporated for the first time in the United States the use of riveted wrought iron plates for the triangular-shaped top chord and preceded by years the standard use of wrought iron for bridges.

Navajo Bridge, Page, Arizona, USA **1997**
This 616-foot main span, three-hinged, braced spandrel steel arch bridge was completed in 1929, and for the next sixty-six years it served as the only crossing of the Colorado River for six hundred miles. The bridge's opening provided the first permanent connection between the states of Utah and Arizona. The span provides access between the southern and northern rims of the Grand Canyon, and connects the Navajo nation and three national parks. At the time of its construction it was the highest steel arch bridge in the United States.

Northampton Street Bridge, Phillipsburg/Easton, New Jersey/Pennsylvania, USA **1997**
Completed in 1896, the Northampton Street Bridge, which runs from Phillipsburg, N.J. to Easton, PA, is the sole existing through-type cantilever eyebar bridge in the United States serving only highway traffic. The structure's graceful lines were a prototype for aesthetic appeal in bridge design.

Northern Pacific High Line Bridge No 64, North Dakota, USA **2004**
This 1908 steel viaduct across the Sheyenne River Valley allowed the railroad to avoid steep grades. At 3,886 feet long and 155 feet high, it is an excellent example of its bridge type.

Old Wisla Bridge, Tczew, Poland **2004**
Completed in 1857, this historic bridge is the first example of a long span lattice-truss bridge on the European mainland. By combining the original American idea of wooden trusses with the tubular concept of the Britannia Bridge, Wales, a new type of dense lattice truss structure made of iron was developed. This pattern of engineering was then disseminated throughout the continent.

Ponte Maria Pia Bridge, Oporto, Portugal **1990**
When opened in 1877, it was the longest iron arch bridge in the world with its parabolic arch being 160 m in span. Designed and built by Gustave Eiffel, it marked the beginning of his ascent to the top ranks of the world's best bridge engineers. Eiffel used the technique of cantilevering the arch elements by means of cables connected to the tops of the end towers.

Quebec Bridge, Quebec City, Quebec, Canada **1987**
This bridge is the longest span (549 meters) cantilever bridge in the world. It was the longest overall single span bridge in the world from 1917 to 1929. The bridge carries railway and highway traffic across the St. Lawrence River. ASCE and the Canadian Society for Civil Engineering jointly designated it.

Rockville Stone Arch Bridge, Rockville, Pennsylvania, USA * **1979**
When opened in 1902, this bridge represented the zenith of American stone arch construction. This span is one of the longest (3,820 feet) and widest (52 feet) multiple stone arch bridges in the world.

Rogue River Bridge, Gold Beach, Oregon, USA * **1982**
Completed in 1931, this seven-span arch bridge was the first major structure in America to use the concept of the pre-stressed concrete arch. Each twin-ribbed arch spanned 230 feet. As an experimental structure sponsored by the Federal Bureau of Public Roads, it successfully demonstrated the engineering application of the pre-compression technique of the French engineer Freyssinet and formed the basis for its later widespread use.

Salginatobel Bridge, Shiers, Switzerland **1990**
Designed by Robert Maillart, the bridge represents a major innovation of structural type - the three-hinged, hollow-bow arch of reinforced concrete - using a new method of staged-arch construction. This unprecedented form by the most celebrated bridge designer of the time was completed in 1930 and is considered a work of structural art.

San Francisco - Oakland Bay Bridge, San Francisco, California, USA * **1986**
Built between 1933 and 1936, this was the longest crossing over water and most costly bridge of its time. Construction was possible due to the use of compressed-air flotation caissons. The two-mile wide West Bay was bridged by two suspension spans, linked in tandem by the world's largest bridge anchorage.

Second Street Bridge, Allegan, Michigan, USA **1982**
This 225-foot span Whipple double intersection through truss, erected in 1886 by the King Iron Bridge and Manufacturing Company, represented the culmination of an era during which cast iron was replaced by the far more reliable wrought iron as an engineering material.

Seventh Street Improvement Arches, St. Paul, Minnesota, USA **2000**
The Seventh Street Improvement Arches celebrates the engineering application of mathematics to improve living conditions. In 1909, the *Associations of Engineering Societies Journal* described the skewed, helicoidal, stone arch design as "the most important piece of masonry in the city." It is currently one of the only documented examples of helicoidal arch construction in the United States and the only known example in the State of Minnesota.

Sewall's Bridge, York, Maine, USA **1986**
Built over the York River in 1761, this bridge was designed and constructed by Major Samuel Sewall, Jr. It is the first pile structure for general highway traffic constructed in accordance with an engineering plan based upon a site survey. It was reconstructed in 1934 as a treated wooden pile structure, designed to look like the original bridge while accommodating modern day traffic.

Smithfield Street Bridge, Pittsburgh, Pennsylvania, USA * + **1975**
This project, completed in 1883, represents a unique adaptation of a contemporary European engineering device, the lenticular truss, to suit American needs. It served as a guide for the many highway bridges of similar design built in America during the ensuing decades. Probably the oldest extant major steel truss in the United States, it was the earliest major project of Gustav Lindenthal (Hon. M. ASCE).

Starrucca Viaduct, Lanesboro, Pennsylvania, USA * **1973**
This key masonry viaduct of the New York and Erie Railroad was one of the earliest structures between the Eastern seaboard and the Midwest. It was constructed in record time, and was among the first, if not the first, important engineering work to utilize structural concrete. It was built in 1848 to the design of Julius Adams (1875 ASCE President) and under the supervision of James B. Kirkwood (1868 ASCE President). It is still in use today.

Stone Arch Bridge - Great Northern Railway, Minneapolis, Minnesota, USA **1974**
Constructed in 1883, this oldest extant railroad bridge over the Mississippi River was a key element in the development of the northwest part of the country. This span is a double track structure, 2,100 feet long, 76 feet high, 26 to 28 feet wide, with 23 circular stone arch spans of various lengths.

Sydney Harbour Bridge, Sydney, New South Wales, Australia **1988**
A steel through-arch multi-modal structure, this was the second longest span (503 m) of its type when completed in 1932. J.J.C. Bradfield and Sir Ralph Freeman were the designers of this bridge that is now an international symbol of Australia and her engineering achievements.

Triborough Bridge Project, New York City, New York, USA **1986**
This three and a half mile, three-branched waterway crossing, opened in 1936, comprises a major suspension bridge, a large vertical lift span, a fixed span designed to be convertible to a lift span, a long viaduct, and an innovative three-legged roadway interchange. It included fourteen miles of arterial highway approaches and urban design features such as parks and recreational facilities. The project is an early example of the complete planning and development of a major transportation project in an urban environment. Robert Moses and Othmar H. Ammann (Hon. M. ASCE) were key to the project.

Tunkhannock Viaduct, Nicholson, Pennsylvania, USA * **1975**
This reinforced-concrete structure, the largest of its kind ever built, was put in service in 1915 by the Delaware, Lackawanna & Western Railroad. The Tunkhannock Viaduct represents a great feat of construction skill and a successful departure from contemporary, conventional concepts of railroad location in that its main line traversed the regional drainage pattern, therefore reducing the distance and grade impediments to economy of operation.

Viaducto del Malleco, Collipulli, Chile **1994**
This early steel viaduct, opened in 1890, was designed by the Chilean engineer Jose Victorino Lastarria, and utilized steelwork prefabricated in France. It has an overall length of 408 m, and carries the rail line 91 m above the Malleco River. As one of the key structures in the Chilean railway system, it typifies the engineering challenge associated with design and construction in remote mountainous areas.

Victoria Falls Bridge, Victoria Falls, Zimbabwe/Zambia **1995**
The Victoria Falls Bridge, completed in 1905, is a 152-meter span, steel-lattice, two-hinged arch bridge with a deck level 122 m above the Zambezi River. Conceived by Cecil Rhodes as a key link in his proposed Cape-to-Cairo railway, it is situated just downstream of the Victoria Falls in a site of unsurpassed grandeur. Although a product of the colonial period, it continues to serve and enhance the lives of all people living in the region.

Waldo-Hancock Suspension Bridge, Bucksport, Maine, USA * **2002**
This bridge was innovative in its use of Verendeel truss towers and has been a key structure on U.S. Route 1 connecting down east Maine to the international maritime commerce of the coast. Completed in 1931, the main span is 800 feet long and provides a navigational clearance of 135 feet. On December 30, 2006, the Waldo-Hancock Bridge was officially closed and the replacement bridge, Penobscot Narrows Bridge, was opened to traffic.

Walnut Street Bridge, Harrisburg, Pennsylvania, USA * **1997**
The Walnut Street Bridge, completed in 1890 with fifteen truss spans and an overall length of 2,820 feet, is the finest and largest example of the standardized wrought iron truss bridges produced by the Phoenix Bridge Company.

Wheeling Suspension Bridge, Wheeling, West Virginia, USA * + **1968**
Built in 1849 by Charles Ellet, Jr., this is the oldest existing major suspension bridge in the United States. It was the first long-span wire-cable suspension bridge in the country and served as a link in the National Highway from Washington, DC to the west. Wrecked in a storm in 1854, it was reconstructed in 1856 and remains in service today.

Whipple Truss Bridge, Schenectady, New York, USA **1981**
The Whipple Truss Bridge (circa 1855), relocated to Union College, was built from a design patented in 1841 by Squire Whipple (Hon. M. ASCE) and was the first scientifically designed truss bridge in the United States.

White River Concrete Arch Bridge, Cotter, Arkansas, USA **1986**
When completed in November 1930 (only one year after initiation) this innovative structure included the first major use of a cableway in association with lattice steel ribs that acted as reinforcement and precluded the need for conventional centering. This structure remains in full service. The key civil engineer responsible for this beautiful multi-span arch bridge was J. Barney Marsh.

1989

Zhaozhou (or Anji) Bridge, Hopei Province, China

This segmental stone arch, built between 595 and 605 AD with a span of 37 meters, has double arch spandrels, and is the earliest known bridge with this type of construction. Li Chun, the designer of the bridge, is recognized as one of China's great builders. The Zhaozhou Bridge (in Chinese literature known as the Anji Bridge) still serves its original function with a substantial number of its original components.

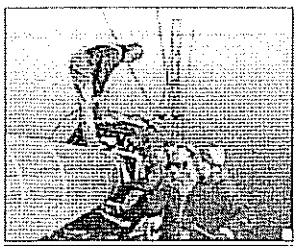
Section 5

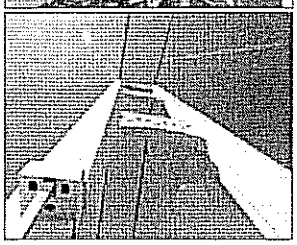
Unique Features

At the time of its completion on November 1 1957, the Mackinac Bridge became an icon of civil engineering achievement. Building over the Straits of Mackinac, where the elements of high winds and ice rule the territory, required engineers to modify traditional suspension designs to create a superstructure to triumph over the icy waters allowing commuters to travel between the peninsulas year round.

1. "Facts and Figures." *The Mackinac Bridge*. Michigan Department of Transportation. n.d. August, 2009. http://www.mackinacbridge.org
2. "Statistics of Bridge Show Size of Project." The Daily Mining Gazette. 21 October 1957.
3. Steinman, David B. and Watson, Sara Ruth. "Great Suspension Bridges." Bridges and Their Builders. New York: Dover Publications, 1957. 368-371.

Facts & Figures

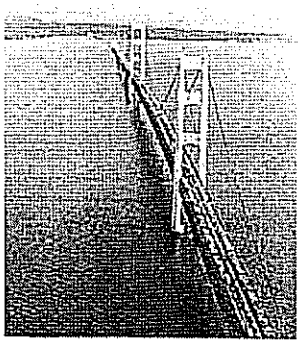




Facts & Figures

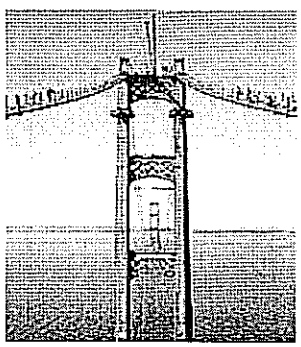
The Mackinac Bridge is currently the third longest suspension bridge in the world. The bridge opened to traffic on November 1, 1957.

LENGTHS



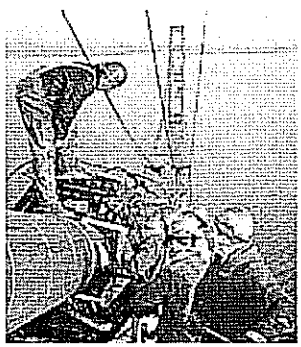
Total Length of Bridge (5 Miles)	26,372 Ft.	8,038 Meters
Total Length of Steel Superstructure	19,243 Ft.	5,865 Meters
Length of Suspension Bridge (including Anchorages)	8,614 Ft.	2,626 Meters
Total Length of North Approach	7,129 Ft.	2,173 Meters
Length of Main Span (between Main Towers)	3,800 Ft.	1,158 Meters

HEIGHTS AND DEPTHS



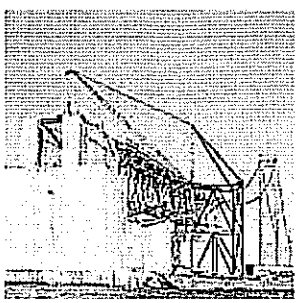
Height of Main Towers above Water	552 Ft	168.25 Meters
Maximum Depth to Rock at Midspan	Unknown	Unknown
Maximum Depth of Water at Midspan	295 Ft.	90 Meters
Maximum Depth of Tower Piers below Water	210 Ft.	64 Meters
Height of Roadway above Water at Midspan	199 Ft.	61 Meters
Underclearance at Midspan for Ships	155 Ft.	47 Meters
Maximum Depth of Water at Piers	142 Ft.	43 Meters
Maximum Depth of Piers Sunk through Overburden	105 Ft.	32 Meters

CABLES



Total Length of Wire in Main Cables	42,000 Miles	67,592 km
Maximum Tension in Each Cable	16,000 Tons	14,515,995 kg
Number of Wires in Each Cable	12,580	
Weight of Cables	11,840 Tons	10,741,067 kg
Diameter of Main Cables	24 1/2 Inches	62.23 cm
Diameter of Each Wire	0.196 Inches	.498 cm

WEIGHTS

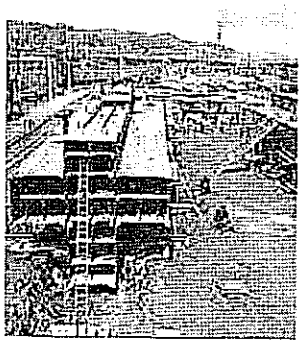


Total Weight of Bridge	1,024,500 Tons	929,410,766 kg
Total Weight of Concrete	931,000 Tons	844,589 kg
Total Weight of Substructure	919,100 Tons	833,793,495 kg
Total Weight of Two Anchorages	360,380 Tons	326,931,237 kg
Total Weight of Two Main Piers	318,000 Tons	288,464,747 kg
Total Weight of Superstructure	104,400 Tons	94,710,087 kg
Total Weight of Structural Steel	71,300 Tons	64,682,272 kg

Weight of Steel in Each Main Tower	6,500 Tons	5,896,701 kg
Total Weight of Cable Wire	11,840 Tons	10,741,067 kg
Total Weight of Concrete Roadway	6,660 Tons	6,041,850 kg
Total Weight of Reinforcing Steel	3,700 Tons	3,356,584 kg

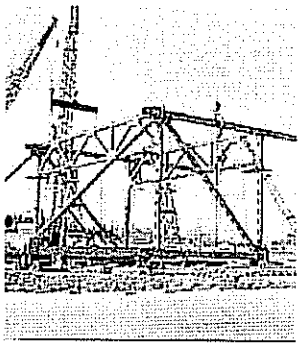
RIVETS AND BOLTS

Total Number of Steel Rivets	4,851,700
Total Number of Steel Bolts	1,016,600



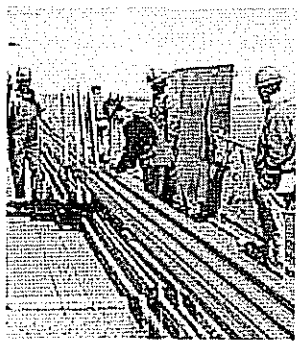
DESIGN AND DETAIL DRAWINGS

Total Number of Engineering Drawings	4,000
Total Number of Blueprints	85,000



MEN EMPLOYED

Total, at the Bridge Site	3,500
At Quarries, Shops, Mills, etc.	7,500
Total Number of Engineers	350



IMPORTANT DATES

Mackinac Bridge Authority Appointed	June, 1950
Board of Three Engineers Retained	June, 1950
Report of Board of Engineers	January, 1951
Financing and Construction Authorized by Legislature	April 30, 1952
D.B. Steinman Selected as Engineer	January, 1953
Preliminary Plans and Estimates Completed	March, 1953
Construction Contracts Negotiated	March, 1953
Bids Received for Sale of Bonds	December 17, 1953
Began Construction	May 7, 1954
Open to traffic	November 1, 1957
Formal dedication	June 25-28, 1958

50 millionth crossing	September 25, 1984
40th Anniversary Celebration	November 1, 1997
100 millionth crossing	June 25, 1998

COPPER COUNTRY VERTICAL FILE
Bridge Mackinac
DAILY MINING GAZETTE
Monday, October 21, 1957

Statistics of Bridge Show Size of Project

By THE ASSOCIATED PRESS

Here are some statistics and interesting dates regarding the 100-million-dollar Straits of Mackinac Bridge:

LENGTHS

Total length, 26,372 feet (28 feet less than 5 miles).

Length of steel superstructure, 19,243 feet.

Suspension span, including anchorages, 8,614 feet.

Distance between towers, 3,800 feet.

HEIGHTS and DEPTHS

Towers above water, 552 feet.

Depth of tower piers below water, 210 feet.

Midspan above water, 199 feet.

Depth of water at midspan, 295 feet.

Ship clearance at midspan, 155 feet.

CABLES

Miles of wire in main cables, 42,000.

Number of wires in each cable, 12,580.

Weight of cables, 11,840 tons.

Tension in each cable, 16,000 tons.

Cable diameter, 24½ inches.

CONCRETE

Total concrete, 466,300 cubic yards.

In substructure, 451,000 cu. yards.

In superstructure, 15,300 cu. yards.

Total in one anchorage, 96,600 cu. yds.

Total in one pier, 80,600 cu. yds.

WEIGHTS

Weight of whole bridge, 1,024,500 tons.

Concrete, 931,000 tons.

Structural Steel, 71,300 tons.

Reinforcing steel, 3,700 tons.

Steel in towers, 13,000 tons.

Concrete roadway, 6,600 tons.

Cables, 11,840 tons.

Total weight superstructure, 104,400 tons.

Total weight substructure, 919,100 tons.

Total weight anchorages, 360,380 tons.

RIVETS and BOLTS

Rivets, 4,851,700.

Bolts, 1,016,600.

DRAWINGS

Engineering drawings, 4,000.

Blueprints 85,000.

EMPLOYMENT

At bridge site, 2,500.

At quarries, shops, mills, etc.,

42,000.
Number of wires in each cable, 12,580.
Weight of cables, 11,840 tons.
Tension in each cable, 16,000 tons.
Cable diameter, 24½ inches.

CONCRETE

Total concrete, 466,300 cibic yards.
In substructure, 451,000 cu. yards.
In superstructure, 15,300 cu. yards.
Total in one anchorage, 96,600 cu. yds.
Total in one pier, 80,600 cu. yds.

WEIGHTS

Weight of whole bridge 1,024,500 tons.
Concrete, 931,000 tons.
Structural Steel, 71,300 tons.
Reinforcing steel, 3,700 tons.
Steel in towers, 13,000 tons.
Concrete roadway, 6,600 tons.
Cables, 11,840 tons.
Total weight superstructure, 104,400 tons.
Total weight substructure, 919,100 tons.
Total weight anchorages, 360,380 tons.

RIVETS and BOLTS

Rivets, 4,851,700.
Bolts, 1,016,600.

DRAWINGS

Engineering drawings, 4,000.
Blueprints 85,000.

EMPLOYMENT

At bridge site, 2,500.
At quarries, shops, mills, etc., 7,500.
Engineers, 350.

IMPORTANT DATES

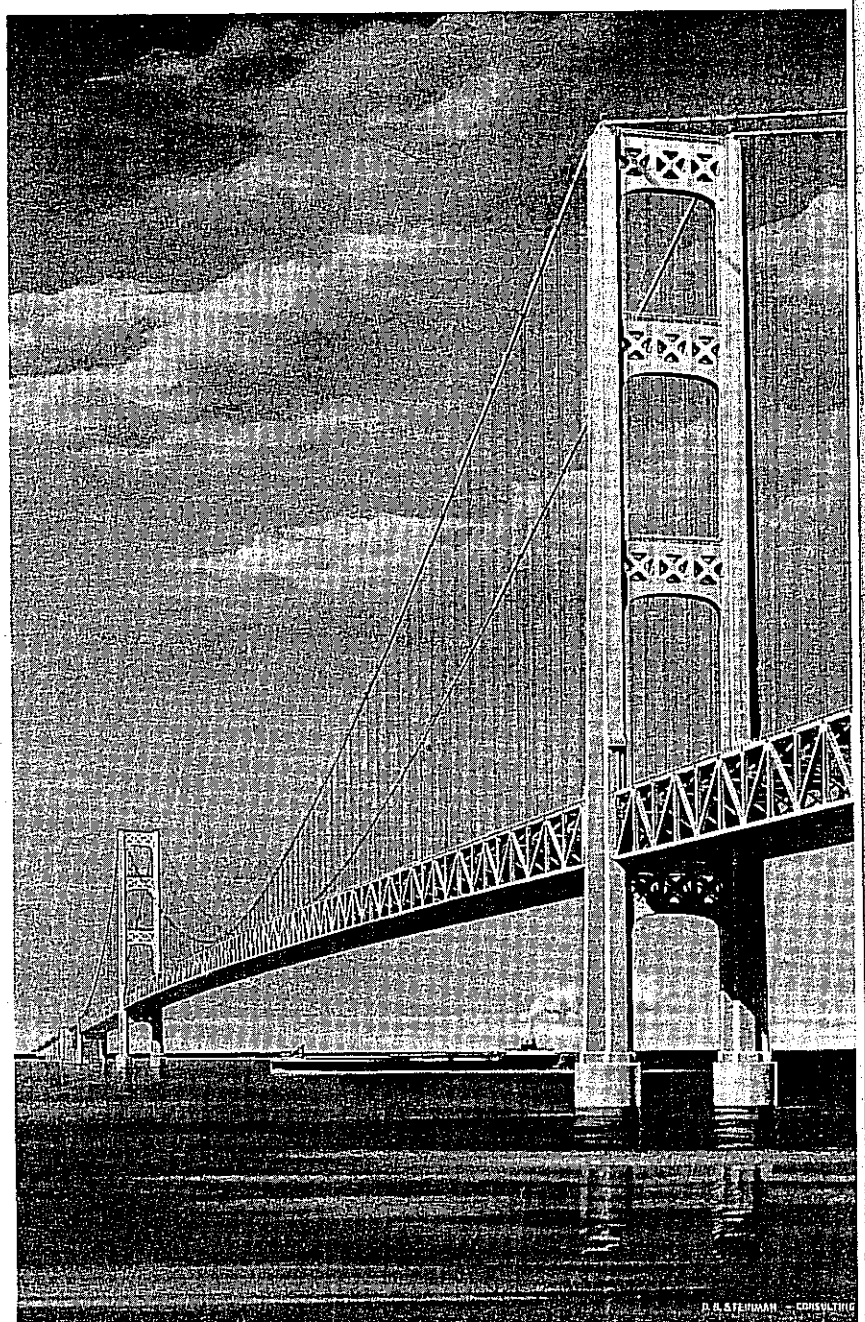
Mackinac Bridge Anthority created June 6, 1950.
Financing and construction authorized, April 30, 1952.
D. B. Steinman chosen engineer, Jan. 1, 1953.
Bonds sold, Feb. 17, 1954.

Equipment assembled for construction, March, 1954.

Foundation construction started, May, 1954.
Anchorages reach 10 feet above water, November, 1954.
First winter shutdown, Jan. 14, 1955.
First pier reaches bedrock, April 30, 1955.
Steel erection (main towers) started, July 13, 1955.
Main towers completed, November, 1955.
Second winter shutdown, Dec. 19, 1955.
Cable spinning started, July 18, 1956.
Third winter shutdown, Dec. 15, 1956.
Final gap of steel closed, May 17, 1957.

First automobile crosses, Sept. 11, 1957 (Driver, Godron Dallas, assistant resident engineer for D. B. Steinman.).

First woman to ride across, Mrs. Amelia Cole, Grand Rapids, Sept. 11, 1957. (Rode with Eugene Yanko, Merritt-Chapman & Scott superintendent).



The Mackinac Bridge, Michigan, is the largest suspension bridge in the world.

BRIDGES AND THEIR BUILDERS

DAVID B. STEINMAN
& SARA RUTH WATSON

DOVER PUBLICATIONS INC.
NEW YORK

Published simultaneously in Canada by McClelland & Stewart, Ltd.

This new Dover edition, first published in 1957 is a revised and expanded edition of the first edition.

Library of Congress Catalog Card Number: 57-13151
Manufactured in the United States of America.

There can be little doubt that in many ways the story of bridgebuilding is the story of civilization. By it we can readily measure an important part of a people's progress.

—Franklin D. Roosevelt
October 18, 1931

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Book III: Pioneer Bridgebuilders.

Book IV: Twentieth-Century Bridges and Their Builders.

ILLUSTRATIONS

Since World War II, the suspension bridge for long-span construction has developed rapidly. It was the war that made Alaska an important outpost and that made the international Alcan highway essential. On August 30, 1943, American and Canadian officials opened a most important link on the highway—the Peace River Bridge. It is a suspension bridge with a 930 foot main span, erected by the Roebling Company, under the direction of Army Engineers for the United States government, who then turned the bridge over to Canada. Weather conditions and wartime exigency combined to render construction difficult. The concreting for the main piers had to be executed at forty degrees below zero, and the work of erecting the main towers went forward on the ice, which was several feet thick, because this erection had to be completed before the April thaw. The structure was built in eight months—in spite of ice and snow, wind and floods.

Four years later, two emergency operations had to be performed on this structure. During the winter of 1947 engineers worked under seven feet of ice to build a steel cofferdam to save the bridge. Swift flood waters had undermined one of the 250-foot towers and had caused it to lean fourteen inches out of line. The engineers' race was against both water and ice. If the spring thaw melted the ice before the cofferdam was in place to stop further erosion, huge blocks of ice might knock the pier off its foundations. And the race was won when the last piece of steel was sunk into the river bed a few days before the thaw. This operation was completed when one thousand cubic feet of concrete was poured to reinforce the leaning tower.

The other repair operation was necessitated by the continued fatigue-breaking of wires, caused by aerodynamic vibrations of the individual strands of the opentype of cable. Most of the wire breaks occurred during the winter when temperatures were as low as twenty to seventy degrees below zero. The same trouble developed on another suspension bridge on the Alaskan Highway, the 543-foot span of the Liard River Bridge. To eliminate the vibrations that were causing the wire-breaking, engineers installed cable clamps of wood spacer blocks midway between the suspenders.

The largest suspension bridge in the British Empire is the Lion's Gate Bridge over the first narrows of the harbor at Vancouver, British Columbia, with a main span of 1550 feet, completed in 1938. The Angus L. MacDonald Bridge, completed in 1955 across Halifax Harbor, is the second largest suspension bridge in Canada. Its main span is 1,447 feet long, and the total length 5,290 feet. British engineers have announced plans for two new long-span bridges, one over the Firth of Forth and one over the Severn. This latter one is designed to have a 3200 foot span, with towers 500 feet high!

But it is in the United States that the suspension bridge is achieving its greatest expression. The Paseo Bridge that crosses the Missouri River at Kansas City carries forward the European tradition of the self-anchored suspension type. Its length of 1232 feet makes it the longest bridge of its kind in the world. Opened to traffic in 1954, the American Institute of Steel Construction awarded it first prize for its beauty of design. Its main span is 616 feet; side spans are 308 feet each. The towers, 136 feet high, are simple and unadorned. Howard, Needles, Tammen and Bergendoff were the consulting engineers.

Another remarkable suspension bridge forms a part of the Delaware Memorial Bridge system which links the DuPont Highway with the New Jersey Turnpike. The total length is three and a half miles; the suspension span is 2150 feet long, the sixth longest suspension bridge in the world. The chief construction problem concerned the anchorage foundations. The west anchorage required a caisson 95 by 221 feet, the largest ever built, and the east anchorage, built in an open cofferdam, required the largest tremie concrete seal ever used in bridge abutments. The seal was 99 by 225 by 32 feet deep, poured continuously for seven-and-a-half days. Like the Paseo Bridge, which was designed by this same firm, it is extremely severe in design; the clean lines of simple reinforcing truss and of the towers suggest strength and sheer functionalism.

The biggest suspension bridge now being built is the Mackinac Straits Bridge which connects the two parts of Michigan. Designed by David B. Steinman, this bridge will contain the second longest suspension span in the world (exceeded only by the Golden Gate) and, taking into consideration the side-spans of

the suspension bridge, it will be the longest. Main span will be 3,800 feet; length from anchorage to anchorage will be 8,614 feet. The total length, including all approach spans, will be five miles.

For over seventy years, since 1884, the need for this bridge had been recognized, but the difficulties, both physical and financial, appeared insurmountable. Still, despite many obstacles and difficulties, the project advanced: construction began in July, 1954, and the schedule date for completion is November, 1957.

The massive foundations for the two towers were carried down to rock at 205 and 210 feet below the surface of the water. The geologic changes that produced this rock formation occurred 340 million years ago. During the past one million years, it has been repeatedly preloaded and pretested by the weight of a solid glacier from one to five miles high, which represents a load at least ten times greater than the maximum pressure under the bridge foundations. To form the massive piers and anchorages, 890,000 tons of concrete and steel were used. The designing engineer has declared that these foundations are more enduring than the pyramids. Because it has been said that no bridge could withstand the pressure of ice at the site, these piers and anchorages were designed with a factor of safety of twenty against the greatest conceivable ice-pressure that could possibly happen.

And furthermore, the bridge was planned with a high factor of safety against the highest wind pressure; in fact, it was designed for exceptional aerodynamic stability. Other large suspension bridges are so designed that critical wind velocities of thirty to seventy-six miles per hour will begin to cause aerodynamic oscillations, but the critical wind velocity for "Big Mac" is the fantastic figure of 632 to 966 miles per hour under extreme, abnormal conditions with deck openings closed solid by ice and snow; under normal conditions the critical wind velocity is infinity. This design for one hundred per cent aerodynamic stability represents the attainment of a new goal in suspension bridgebuilding.

Over the two main towers, standing 552 feet high, hang the 24½-inch cables. Each one contains thirty-seven strands made up of 340 wires each, or a total of 12,580 parallel steel wires,

each one of which is about one-fifth of an inch in diameter, or approximately the thickness of a lead pencil. Over 42,800 miles of wire make up the two cables, enough to go around the earth at the equator more than one and two-thirds times. Traffic moving across the bridge will employ only about a sixth of the total stress on the cables; they will have enough reserve strength to carry a moving load at least ten times greater than the heaviest traffic possible, including twenty-ton trucks.

This great bridge is indicative of the bridges to come. For example, David Steinman has designed a suspension bridge to cross the Messina Straits, connecting Italy and Sicily, which would have a main span of 5,000 feet. Its side spans would be 2,400 feet long each. The foundation work would also establish a new record; the two main piers would have to be sunk in water 400 feet by the open-caisson method. But the stiffening devices would be its most special feature, because the bridge is designed to carry railroad trains as well as highway vehicles. Trusses would resemble those of the Florianapolis Bridge, reaching a depth of 165 feet at the quarter-points of the main span and at the mid-points of the side-spans. In addition, auxiliary cable stays, radiating from a point on the towers just above the roadway, increase the degree of rigidity demanded for resistance to aerostatic and aerodynamic forces and torques and to earthquake vibrations. According to the designer, the Messina Straits bridge is not only feasible and practical; it would be one of the safest and most rigid suspension bridges ever built.

The decades immediately ahead will see the realization and the construction of other bridges of even greater span. A generation ago, the feasibility of a span of 3,000 feet was seriously questioned. Now bridge engineers confidently agree that suspension bridge spans as long as 10,000 feet are practically feasible. *And such spans will be built.*

Section 6

Contributions to the Civil Engineering Profession, and Nation

Built with the lessons learned from the Tacoma Narrows Bridge failure in Washington, the Mackinac Bridge was designed to withstand unimaginable conditions, providing testament to what is conceivable by mankind.

1. Hoffman, Kathy Barks. "Mackinac Bridge tops list of century's civil engineering projects." Daily Mining Gazette. 15 December, 1999.
2. Steinman, David B. The Aerodynamic Stability of the Mackinac Bridge. Lansing: State of Michigan Mackinac Bridge Authority. 27 May, 1955.
3. Steinman, David B. Modes and Natural Frequencies of Suspension Bridge Oscillations. 268 no. 3. Philadelphia: Franklin Institute, 1959.

RHG 12-15-99

Mackinac Bridge tops list of century's civil engineering projects

Bridges - Mackinac Bridge

AP Photo/Dale Atkins

With a picture of the Mackinac Bridge to the left, Lt. Gov. Dick Posthumus talks about watching the construction of the bridge in his youth as he speaks at a presentation by the Michigan section of the American Society of Civil Engineers in Lansing, Mich. Tuesday.

By KATHY BARKS HOFFMAN
Associated Press Writer

LANSING, Mich. — Michigan's biggest civil engineering project of the century almost didn't get built.

The Mackinac Bridge nearly fell victim to a lack of legislative support and financing before construction finally began in 1954, said Larry Rubin, first executive officer for the Mackinac Bridge Authority from 1950-83.

"There was a great deal of antipathy toward the bridge," said Rubin, 87, of St. Ignace. "People in many places, high and low, fought us tooth and nail."

On Tuesday, the Michigan Section of the American Society of Civil Engineers named "Mighty Mac" the top Michigan civil engineering project of the century during a ceremony at the R.E. Olds Museum.

The bridge, stretching five miles across the Straits of Mackinac between Mackinaw City and St. Ignace, was the longest suspension bridge of its type when it opened in 1957. Before its construction, travelers often had to wait five hours or more to cross the straits on ferries.

"Crossing over to the U.P. on the Mackinac Bridge has become second nature to us, and it is easy to forget the planning and design that went into constructing this amazing structure," Lt. Gov. Dick Posthumus

Please see page 9

At a glance

The top 10 civil engineering projects in Michigan this century, as chosen by the Michigan Section of the American Society of Civil Engineers:

1. Mackinac Bridge
2. Soo Locks, Sault Ste. Marie
3. Detroit-Windsor Tunnel
4. Ambassador Bridge, Detroit
5. Ford Motor Co. Rouge Complex, Dearborn
6. Detroit Wastewater Treatment Plant
7. Interstate highway system
8. Monroe Avenue Water Filtration Plant, Grand Rapids
9. Ludington Pumped Storage Facility
10. St. Clair River Railroad Tunnel, Port Huron

first U.S. water treatment plant to put fluoride into a community water system to prevent tooth decay, which it began in 1945.

"A lot of these projects involve water," said Jim Hegarty, president-elect of the Michi-

construction.

Environmental concerns also have played a part in Michigan's civil engineering history. The Ludington Pumped Storage Facility (No. 9) owned by Consumers Energy Co. and Detroit Edison Co., generates

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Mackinac Bridge tops list

Continued from Page 1

said during the ceremony.

The Soo Locks at Sault Ste. Marie came in second, followed by the Detroit-Windsor Tunnel, which opened in 1930 as the world's first underwater tunnel to connect two countries.

Many of the projects were included because they made economic and social contributions to the state.

The Ambassador Bridge, ranked No. 4, is the busiest international border crossing in the United States, linking the United States and Canada.

The 1,421 miles of the state's interstate highway system (No. 7) has opened Michigan to commerce and tourism.

The Monroe Avenue Water Filtration Plant (No. 8) drastically reduced typhoid fever and other waterborne diseases in Grand Rapids after opening in 1913. It also was the first U.S. water treatment plant to put fluoride into a community water system to prevent tooth decay, which it began in 1945.

"A lot of these projects involve water," said Jim Hegarty, president-elect of the Michigan section of ASCE and a civil engineer at Prein & Newhof in Grand Rapids. "Water that separates two busy, vibrant areas, it begs for a way to get across."

The demand for bridges, tunnels and roads might not have been so great if Michigan wasn't also a major trade partner with Canada and a major transportation corridor connecting Canada, the United States and Mexico.

Building the St. Clair River Railroad Tunnel (No. 10 on the list) between Port Huron and Sarnia, Ontario, for instance, enabled the Canadian National Railway to move multilevel rail cars through the tunnel that it used to have to ship across the river border on barges.

"It knocked 12 hours off the travel time from Halifax (Nova Scotia) to Chicago," said Duncan MacLennan, CN's chief of construction.

Environmental concerns also have played a part in Michigan's civil engineering history. The Ludington Pumped Storage Facility (No. 9) owned by Consumers Energy Co. and Detroit Edison Co., generates power with little or no pollution by pumping water from Lake Michigan and then running the water through turbines to produce electricity as the water returns to the lake.

The Detroit Wastewater Treatment Plant, ranked No. 6, has helped improve the quality of the Detroit River, the engineering society said.

"We're surrounded by the greatest body of fresh water in the world in Michigan, which puts a focus on us to try and keep that clean," said Robert Patzer, executive director of AUC, the state's largest heavy construction association.

Eds: Information on Michigan's top 10 civil engineering projects of the century as selected by the Michigan Section of the American Society of Civil Engineers can be viewed on the Internet at www.aucmi.org/Resources/tptenindex.html.

State of Michigan

Mackinac Bridge Authority

Report

THE AERODYNAMIC STABILITY OF THE MACKINAC BRIDGE

by

D. B. STEINMAN

Consulting Engineer

May 27, 1955

D. B. STEINMAN
CONSULTING ENGINEER

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"STEINMANCE". N. Y.

May 27, 1955

Mackinac Bridge Authority
Hon. Prentiss M. Brown, Chairman
Prudden Building
Lansing, Michigan

Gentlemen:

I am pleased to transmit herewith my report on the aerodynamic stability of the Mackinac Bridge.

This report is based on the results of an exceptionally thorough series of investigations conducted under the supervision of Professor F. B. Farquharson in the Suspension Bridge Laboratory at the University of Washington. Arrangements for the investigations of the degree of aerodynamic stability inherent in the design of the Mackinac Bridge were concluded on March 18, 1954, and the aerodynamic studies and tests have now been completed. A copy of Professor Farquharson's final report, dated May 20, 1955, is appended.

You will be pleased to know that the results of these investigations afford a most gratifying confirmation of my prediction of complete aerodynamic stability for the Mackinac Bridge as designed. Extensive wind-tunnel tests on a large-scale dynamic model of the suspension bridge demonstrate conclusively that no modification of the design is necessary, or desirable.

The results of the investigations show that the Mackinac Bridge is, by far, the most stable suspension bridge, aerodynamically, that has ever been designed.

Tests on the bridge model were made for all angles of wind attack – even to the extreme of an upward angle of attack of 20 degrees. (The terrain surrounding the Mackinac site would permit only horizontal winds, or, at most, vertical angles of attack of not more than one or two degrees.)

The test results may be summarized as follows:

1. show, as anticipated, that the Mackinac Bridge, as designed, has complete and absolute aerodynamic stability against all modes of oscillation (vertical, torsional, and coupled) at all wind velocities and all angles of attack.

2. Even for the hypothetical and abnormal condition where all openings in the deck are assumed to be completely closed by ice, the Mackinac Bridge has complete and absolute aerodynamic stability against all modes of oscillation at all wind velocities up to a wind velocity of a fantastic and impossible order of magnitude, namely, a wind velocity of 632 miles per hour for the lowest mode of oscillations and 942 miles per hour for the next higher mode.

You will be pleased, I am certain, to have this confirmation that the Mackinac Bridge is one hundred percent safe aerodynamically, even under the most adverse conditions that could conceivably occur.

Respectfully submitted,

D. B. Steinman

D. B. STEINMAN
Consulting Engineer

THE AERODYNAMIC STABILITY OF THE MACKINAC BRIDGE

The main span (Fig. 1) at Mackinac is a suspension bridge. This is the safest possible type of bridge. The stiffening trusses are 38 feet deep, or 1/100th of the span length. This is the same ratio adopted (after years of exhaustive aerodynamic tests) for the proposed Severn River Bridge in England, and 68 percent greater than the ratio used in the Golden Gate Bridge.

Even without this generously high depth-to-span ratio, the Mackinac suspension span would have more than ample aerodynamic stability. In fact, by scientific design, utilizing all of the new knowledge of suspension bridge aerodynamics, particularly the writer's discoveries, analysis, and design principles, the Mackinac Bridge has been made the most stable suspension bridge, aerodynamically, that has ever been designed.

This result has been achieved, not by spending millions of dollars to build up the structure (in weight and stiffeness) to resist the effects, but by scientific design of the cross-section to eliminate the cause of aerodynamic instability. The vertical and torsional aerodynamic forces tending to produce oscillations are eliminated.

The outstanding original feature contributing this high degree of aerodynamic stability is the provision of wide open spaces between the stiffening trusses and the outer edges of the roadway. The trusses are spaced 68 feet apart and the roadway is only 48 feet wide, thus leaving open spaces 10 feet wide on each side, for the full length of the suspension bridge. The effectiveness of this feature was demonstrated to the engineering profession by the writer in 1940, and this feature has since been used in varying degrees in the construction or reconstruction of all large suspension bridges.

For further perfection of the aerodynamic stability, the equivalent of a wide longitudinal opening is provided in the middle of the roadway. (See Fig. 2.) The two outer lanes, each 12 feet wide, are made solid, and the two inner lanes and the center mall (24 feet of width) are made of open-grid construction (of the safest, most improved type). Wind-tunnel tests have confirmed the high aerodynamic stability of this design of cross-section, combining the two outer openings with an opening in the middle of the roadway.

In addition to the foregoing design features yielding assured aerodynamic stability, maximum torsional stability has been secured by providing two systems of lateral bracing, in the planes of the top and bottom chords, respectively. (This feature has recently been added on the Golden Gate Bridge, at a cost of $3,500,000.)

The Mackinac Bridge represents a triumph of the new science of suspension bridge aerodynamics. The design of the bridge was predetermined scientifically in final form, without spending years in groping, cut-and-try experimentation. Now, two years after determination of the design and award of construction contracts, extensive wind-tunnel

tests have finally been completed on a large-scale dynamic model of the bridge. No modification of the design has been found necessary or desirable. The wind-tunnel tests show conclusively, as predicted by the writer, that the Mackinac Bridge, as designed, has:

1. Complete and absolute aerodynamic stability against *vertical* oscillations at all wind velocities and all angles of attack.

2. Complete and absolute aerodynamic stability against *torsional* oscillations at all wind velocities and all angles of attack.

3. Complete and absolute aerodynamic stability against *coupled* oscillations (combining vertical and torsional) at all wind velocities and all angles of attack.

Professor F. B. Farquharson states in his report:

"When the model was tested with the central portion of the roadway and the sidewalks open, *no motion developed at angles of attack up to ±20° (the limits of tunnel) and over the full range of wind velocities available.* . . . These tests were conducted under very low structural damping conditions ($\delta s = 0.005$) and for several values of the ratio of torsional to vertical frequencies, N_2/N_1.

"This section was also investigated with its center of rotation fixed on the longitudinal centerline of the bridge. Under this condition no oscillation developed for any angle of attack or at any wind velocity."

The Wind Tunnel Tests at the University of Washington

Arrangements were concluded by the writer on March 18, 1954, for a thorough aerodynamic investigation to be conducted by Professor F. B. Farquharson in the Suspension Bridge Laboratory at the University of Washington covering the degree of aerodynamic stability inherent in the design of the Mackinac Bridge. These investigations have now been completed, and a copy of Professor Farquharson's Final Report, dated May 20, 1955, is appended.

The model used for these wind-tunnel tests was a 1/50 scale section model, 60.75 inches long, with details of shape reliably duplicated. (See Figs. 3, 4, 5, 6). The tests were made in an open-jet wind tunnel with a wind-jet 12 feet long and 4 feet high.

The extremely high aerodynamic stability of the Mackinac Bridge exceeded all prior experience in aerodynamic investigations. Professor Farquharson had to revise his test equipment when he found that this bridge had features of stability much higher than had ever been previously investigated. In fact some of the features of stability of the Mackinac Bridge, such as the very high frequency ratio of 3.5 and the high estimated structural damping of 0.10 (for the iced condition) were actually too high to be fully duplicated in the model.

Test Results for the Bridge as Designed

(With center.roadway and sidewalk grids open)

When the model was tested for the normal operating condition of the structure, namely, with the grids in the central portion of the roadway and the sidewalks open, no motion developed at any angle of attack up to plus or minus 20 degrees (the limits of the tunnel) and over the full range of velocities available. These tests were conducted under very low damping conditions ($\delta s = 0.005$) ; the actual structural damping in the

Bridge will be ten to twenty times as high ($\delta s = 0.05$ to 0.10), yielding further emphasis to this tested confirmation of *complete aerodynamic stability.*

The wind-tunnel tests show, as predicted, that the Mackinac Bridge, as designed, *has complete and absolute aerodynamic stability against vertical, torsional, and coupled oscillations at all wind velocities and all angles of attack.*

These test results for the design of the Mackinac Bridge may be summarized in a single phrase: *Perfect aerodynamic stability.* This goal has never before been attained or approximated in any bridge section previously investigated.

Test Results for the Bridge for the Abnormal Condition of Roadway and Sidewalk Grids Closed by Ice

Professor Farquharson also tested the Mackinac Bridge model with all roadway and sidewalk grids closed (solid), to represent the abnormal condition of all openings completely closed by ice.

For the normal condition, with the grids open, as recorded above, the Mackinac Bridge section has been proved to have perfect aerodynamic stability.

For the abnormal condition, with all grids completely closed by ice, the aerodynamic stability is found to be *so nearly perfect that the difference is practically meaningless.*

The Mackinac Bridge will have an exceptionally high value of *structural damping* (resisting any tendency to start oscillations). The high vertical rigidity and the still higher torsional stiffness contribute this high value of the structural damping. The magnitude of the structural damping factor or logarithmic decrement (δs) will certainly be at least 0.05. Professor Farquharson has estimated for the Mackinac Bridge a structural damping factor of approximately 0.08. For the abnormal condition of all deck openings completely closed by ice and snow, the action of the interlocked ice and the packed snow will contribute further to the structural damping, and for this condition the structural damping may be estimated as 0.10.

For a minimum assumed value of 0.05 for the structural damping, the wind-tunnel tests for the bridge with the deck completely closed show complete and absolute stability against *vertical* oscillations at *all* wind velocities; complete and absolute stability against *torsional* oscillations at *all* wind velocities; and complete and absolute stability against *coupled* oscillations at all wind velocities up to a wind velocity of 524 miles per hour for the lowest mode of oscillations, **779** miles per hour for the next mode, and 800 miles per hour for the next higher mode.

For the higher and more probable estimated value of 0.10 for the structural damping, the wind-tunnel tests for the bridge with the deck completely closed (as by ice) show complete and absolute stability against *vertical* oscillations at *all* wind velocities; complete and absolute stability against *torsional* oscillations at *all* wind velocities; and complete and absolute stability against *coupled* oscillations *at all wind velocities up to a wind velocity of 632 miles per hour for the lowest mode of oscillations, 942 miles per hour for the next mode of oscillations, and 966 miles per hour for the next higher mode of oscillations.*

Accordingly, even under the worst abnormal conditions, the Mackinac Bridge is

ultra-safe against any possibility of aerodynamic oscillations. The indicated critical velocities (for the assumed abnormal conditions) approach the supersonic range.

The highest wind velocity ever recorded in the vicinity of Mackinac is **78** miles per hour. The required "critical velocities" of 632, 942, and 966 miles per hour may be dismissed as fantastically impossible.

Comparison with Prior Suspension Bridges

The outstanding superior aerodynamic stability achieved in the Mackinac Bridge is best shown by a comparison with the critical velocities determined by similar wind-tunnel investigations for other notable suspension bridges.

For the prior long-span bridges, the critical wind velocities listed in the following tabulation are taken from published reports by Professor F. B. Farquharson in official Bulletins (1954) of the University of Washington Engineering Experiment Station.

Table **1**

Bridge	Critical Wind Velocity
Bronx-Whitestone (after addition of stiffening trusses)	30 M. P. H.
Golden Gate	40 M. P. H.
George Washington	55 M. P. H.
New Tacoma Narrows	76 M. P. H.
Mackinac (with deck closed)	***632*** M. P. H.
Mackinac (with deck open, as designed)	Infinite

The methods developed and applied by the writer for predetermining a design of assured aerodynamic safety constitute the key to the future design of suspension bridges for aerodynamic stability.

Conclusion

The Mackinac Bridge is one hundred percent safe, aerodynamically, even under the most adverse conditions that may be expected to occur.

The Mackinac Bridge represents the achievement of a new goal of perfect aerodynamic stability, never before attained or approximated in any prior suspension bridge design.

D. B. STEINMAN
Consulting Engineer

May 27, 1955

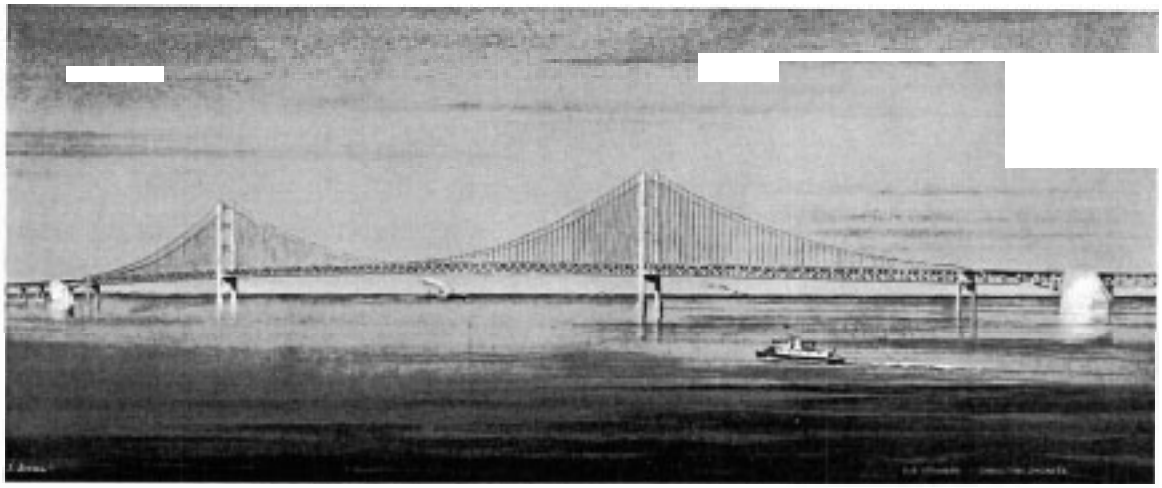

Fig. 1—Perspective drawing of the suspension spans of Mackinac Bridge. The 8,614-foot distance between anchorages establishes a new world record. The main span is 3,800 feet long.

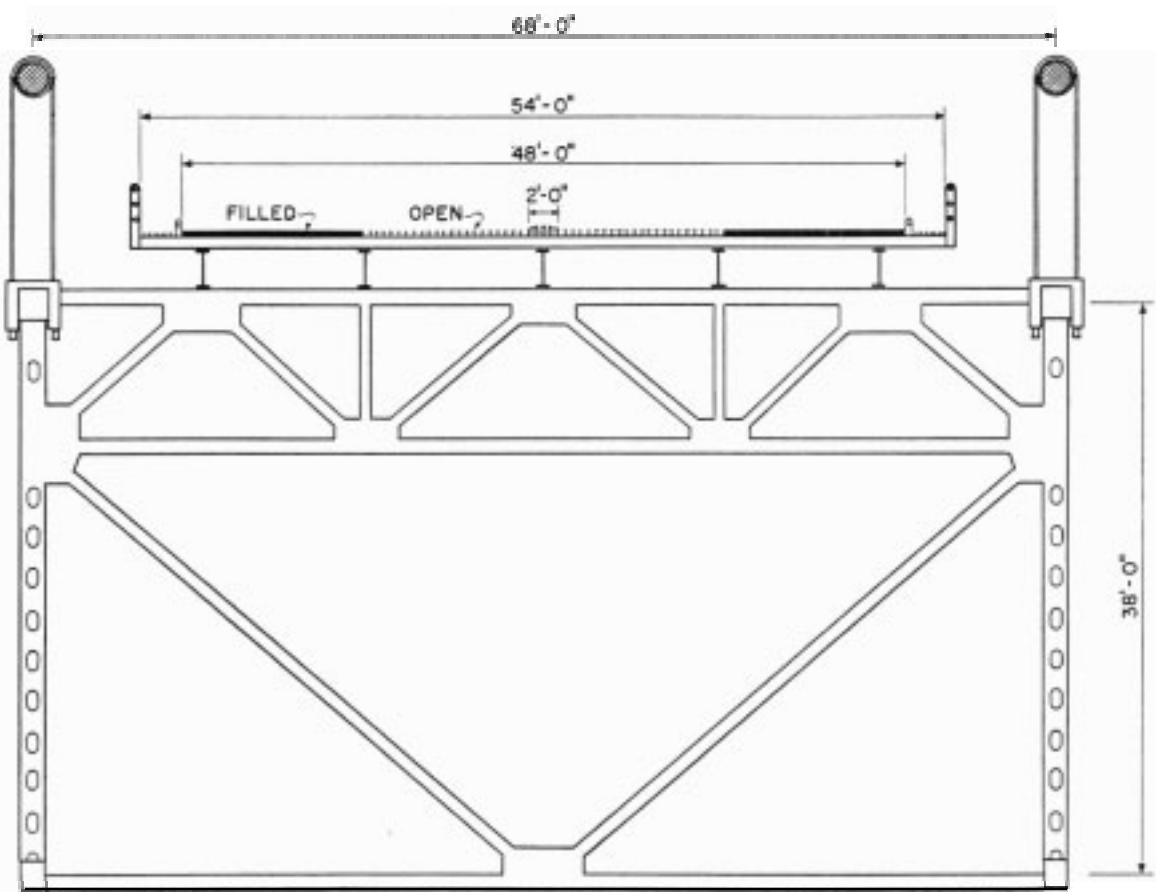

Fig. 2—Cross-section of the suspension spans of Mackinac Bridge illustrates the designer's provision of broad open spaces between the stiffening trusses and the outer edges of the roadway, and along the centerline of the roadway. This feature contributes basically to the structure's high degree of aerodynamic stability.

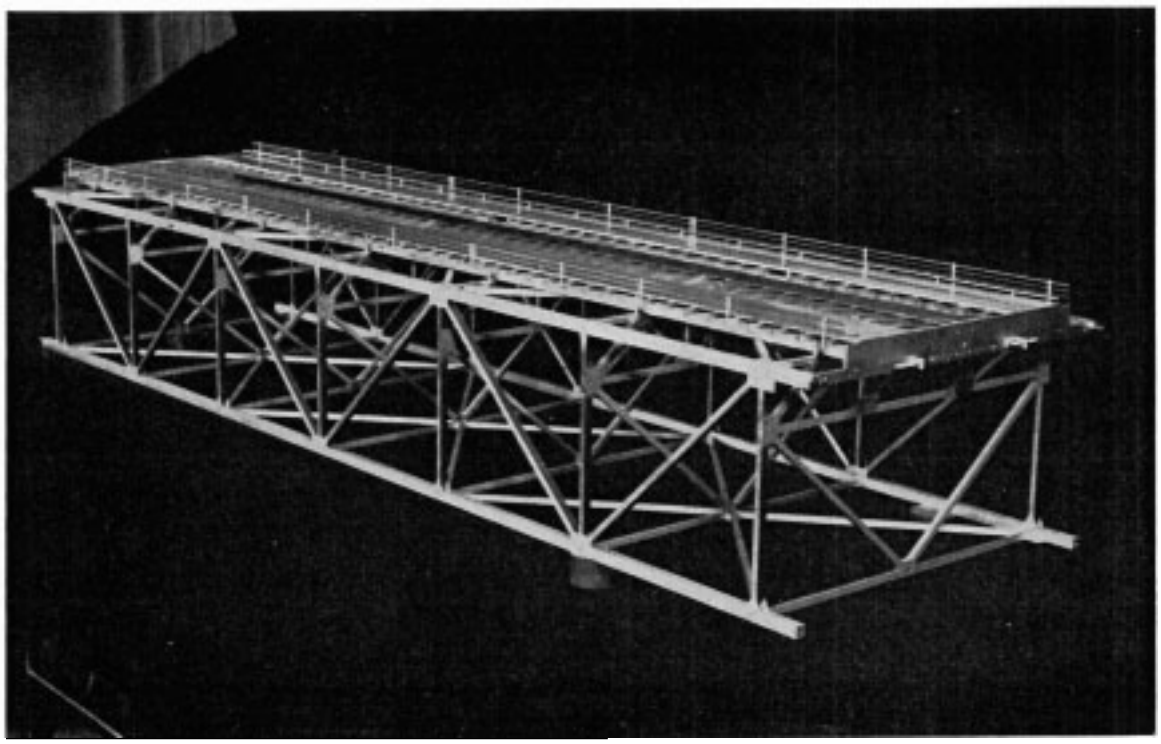

Fig. 3—Model for aerodynamic tests is built to 1/50 scale, and represents a 253-foot section of the bridge. Shape and weight distribution have been reliably duplicated. This view shows the roadway.

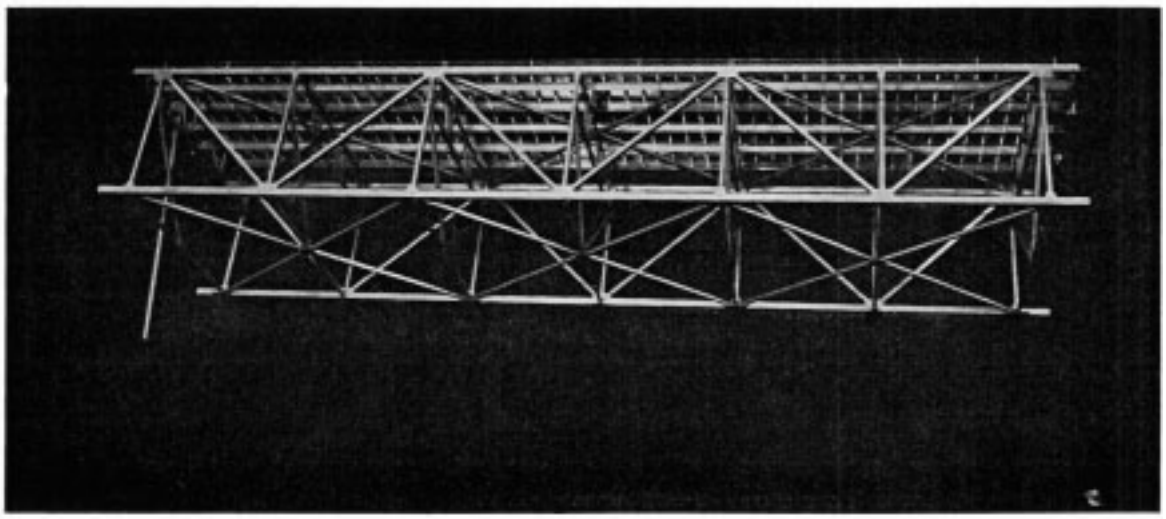

Fig. 4—Dynamic model of the Mackinac Bridge, showing the framing details.

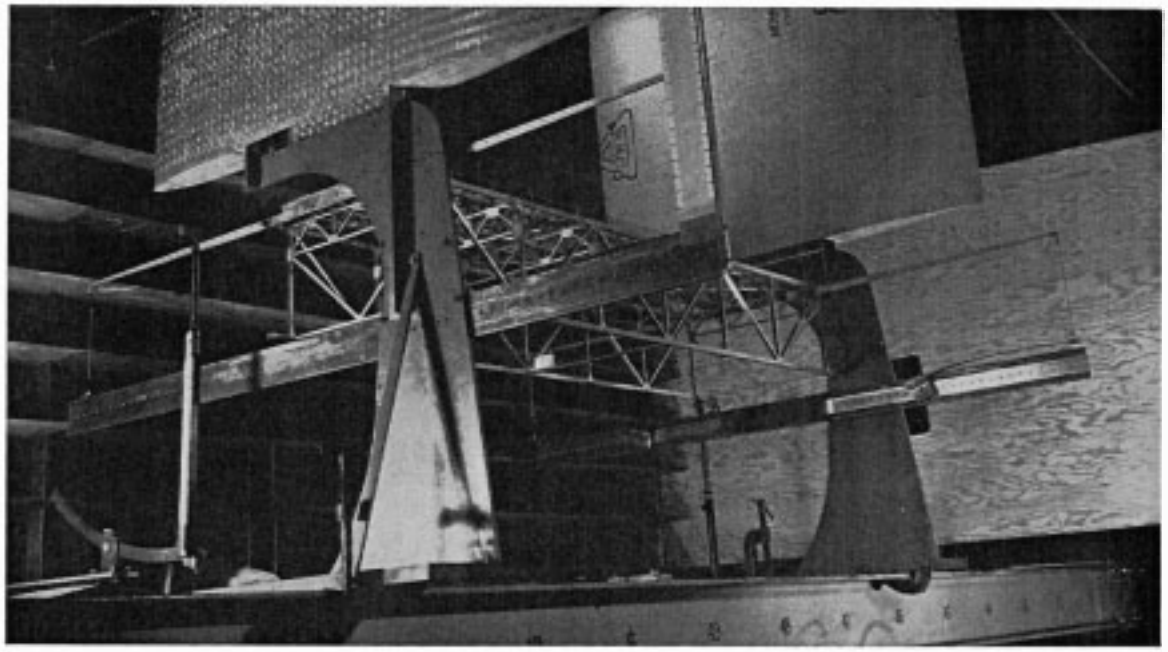

Fig. 5—Tests were made in an open-jet wind tunnel with a wind jet 12 feet long and 4 feet high. Model is suspended by means of four vertical coil springs (concealed by large streamlined fairings).

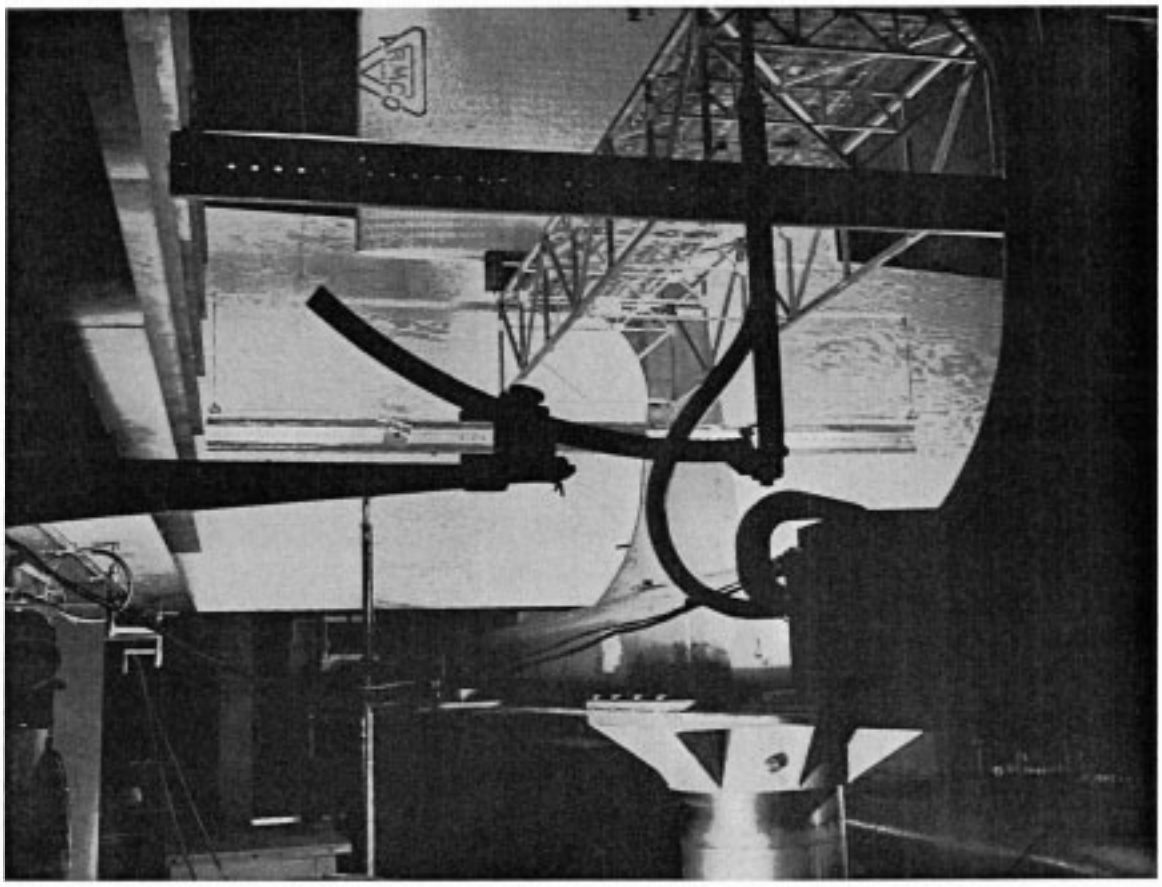

Fig. 6—Since the Mackinac Bridge, as designed, was found to have a much higher degree of aerodynamic stability than any structure previously investigated, it was necessary to install an auxiliary set of cantilever springs. These are secured to the model by four horizontal arms.

File Reference Material

MODES AND NATURAL FREQUENCIES OF SUSPENSION BRIDGE OSCILLATIONS

By

D. B. STEINMAN

Reprinted from Journal of the Franklin Institute
Vol. 268, No. 3, September, 1959

Reprinted from JOURNAL OF THE FRANKLIN INSTITUTE,
Vol. 268, No. 3, September, 1959
Printed in U. S. A.

MODES AND NATURAL FREQUENCIES OF SUSPENSION BRIDGE OSCILLATIONS

BY
D. B. STEINMAN[1]

SYNOPSIS

The natural frequencies of potential modes of suspension bridge oscillations constitute basic data required in studies for aerodynamic stability.

The formulas presented herein were derived by the author in 1941–1943 and have since been tested, for simplicity and practical usefulness, by fifteen or more years of application in the author's office practice. They have also been independently checked, for validity and accuracy, by others using more difficult formulas involving transcendental (complex or hyperbolic) functions. The author's formulas appear to be the simplest and most practical thus far developed for the calculation of the natural frequencies of all possible modes of suspension bridge oscillations.

For convenience of reference and application, these formulas are here assembled, derived and presented in definitive form, together with numerical examples to illustrate their practical application. The numerical examples are based on computations for the Mackinac Bridge.[2]

DEFINITIONS AND BASIC RELATIONS

If N is the natural frequency (cycles per second) of any harmonic oscillation, and w is the circular frequency (radians per second), then

$$\omega = 2\pi N = \sqrt{\frac{K}{m}} \tag{1}$$

where m = w/g is the oscillating mass (in the case of a span, m is the mass per unit span-length) and K is the "spring constant," or ratio of the elastic force of restitution (Aw), per unit span-length, to the displacement η at any point. Hence, by definition,

$$K = m\omega^2 = \frac{\Delta w}{\eta}. \tag{2}$$

K is also termed the "*Coefficient of Rigidity*" of the oscillating system, a significant criterion for aerodynamic stability.

For an oscillation of any span (I) in the form of a simple sine-curve (see Figs. 1 and 2), with n segments (half-waves) in the span, the amplitude η at any point x is given by:

$$\eta = a \sin \frac{\pi n}{\mathrm{I}} x \tag{3}$$

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[2] EDITOR'S NOTE: See this JOURNAL, Vol. 262, p. 453 (1956).

where a is the amplitude at mid-segment. The displacement η_t at any instant t is

$$\eta_t = \eta \sin \omega t \tag{4}$$

for $\eta_t = 0$, at $t = 0$.

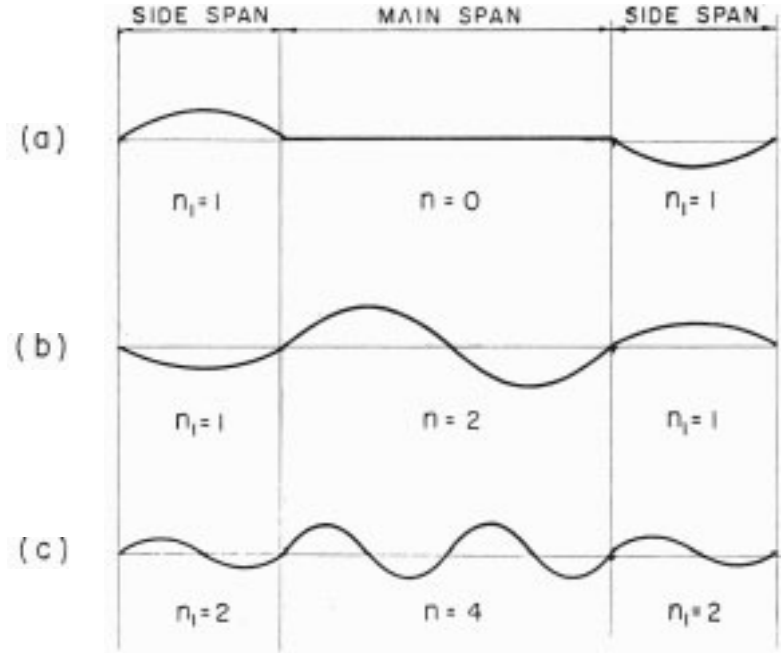

FIG. 1. Antisymmetrical modes.

In the derivations that follow, useful integrals are:

$$\int_0^l \eta dx = 0 \quad (\text{for } n \text{ even}) \tag{5}$$

$$\int_0^l \eta dx = \frac{2\,al}{\pi\, n} \quad (\text{for } n \text{ odd}) \tag{6}$$

$$\int_0^l \eta^2 dx = \tfrac{1}{2} a^2 l. \tag{7}$$

Useful differentials are:

$$\dot{\eta}_t = \frac{\partial \eta_t}{\partial t} = \omega \eta \quad (\text{at } \eta_t = 0) \tag{8}$$

$$\ddot{\eta}_t = \frac{\partial^2 \eta_t}{\partial t^2} = -\,\omega^2 \eta_t \tag{9}$$

$$\frac{d^2\eta}{dx^2} = -\frac{\pi^2 n^2}{l^2}\eta \tag{10}$$

$$\frac{d^4\eta}{dx^4} = \frac{\pi^4 n^4}{l^4}\eta. \tag{11}$$

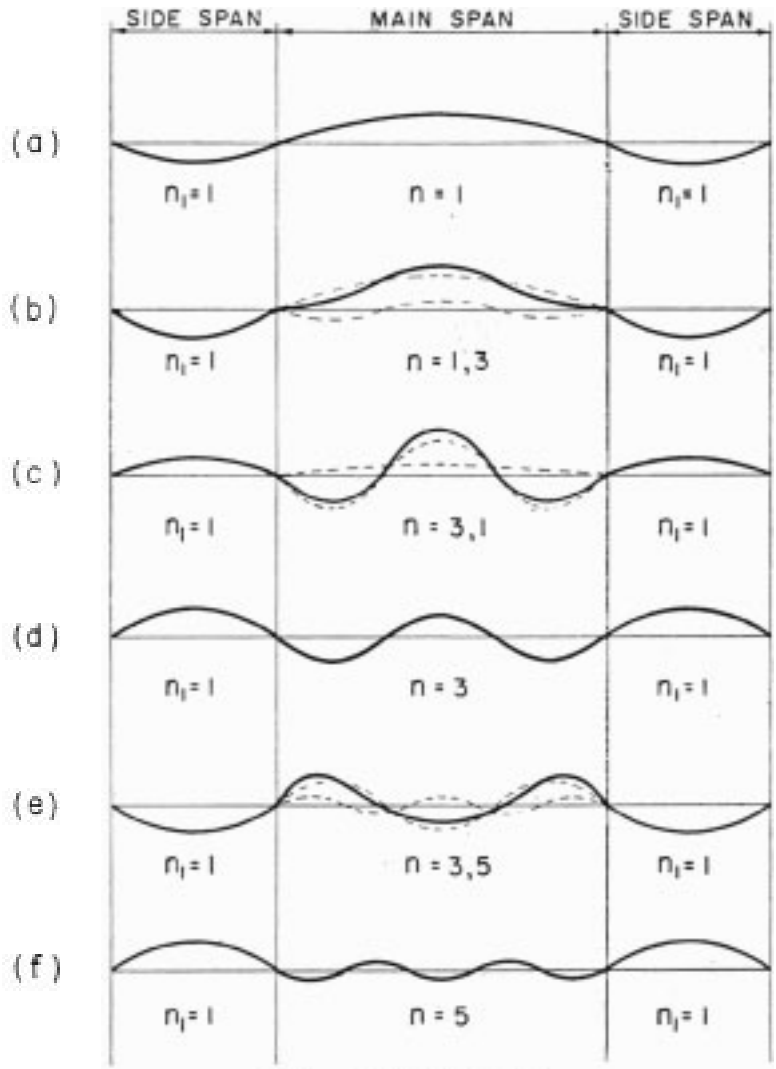

FIG. 2. Symmetrical modes.

The cable curve (with sag f) is assumed parabolic

$$y = 4x(l - x)\frac{f}{l^2} \tag{12}$$

yielding

$$\frac{d^2y}{dx^2} = -\frac{8f}{l^2}. \tag{13}$$

By Eq. 9, the force equation at any instant on any unit length of span is

$$-\omega^2\eta_t m + K\eta_t = 0 \tag{14}$$

yielding

$$K = m\omega^2. \tag{15}$$

This is the derivation of Eq. 1.

BASIC FORMULA FOR K

For any element (dx) of the span-length, the potential energy at full displacement ($\eta_t = \eta$) will be

$$W_p = \tfrac{1}{2}\eta\Delta w dx. \tag{16}$$

By Eqs. (8) and (15), the kinetic energy at zero displacement ($\eta_t = 0$) will be

$$W_k = \tfrac{1}{2}m(\dot{\eta}_t)^2 dx = \tfrac{1}{2}K\eta^2 dx. \tag{17}$$

Equating the energy transformation ($W_p = W_k$) and applying the summation to cover all spans and all component sine-curves, the basic formula for K is obtained:

$$K = \frac{\sum \int_0^l \eta\Delta w dx}{\sum \int_0^l \eta^2 dx}. \tag{18}$$

If a span has a coupled synchronous *longitudinal* oscillation of amplitude e, then W_k, given by integration of Eq. 17, is augmented by

$$\Delta W_k = \tfrac{1}{2}m(\dot{e})^2 l = \tfrac{1}{2}m\omega^2 e^2 l = \tfrac{1}{2}Ke^2 l \tag{19}$$

and Eq. 18 becomes

$$K = \frac{\sum \int_0^l \eta\Delta w dx}{\sum \int_0^l \eta^2 dx + \sum e^2 l}. \tag{20}$$

GENERAL FORMULA FOR K

The fundamental equilibrium equation for a suspension bridge is

$$\Delta w = -\frac{d^2M}{dx^2} = -\frac{d^2}{dx^2}\left[H\eta + y\Delta H - EI\frac{d^2\eta}{dx^2}\right] \tag{21}$$

where H is the horizontal cable tension, AH is the increment produced by displacement, I is the moment of inertia of the section of the stiffening truss, and E is the modulus of elasticity for the truss.

By Eqs. 10, 11 and 13, Eq. 21 yields:

$$\Delta w = \frac{\pi^2 n^2}{l^2} H\eta + \frac{\pi^4 n^4}{l^4} EI\eta + \frac{8f}{l^2} \Delta H. \tag{22}$$

For any case in which A H = 0, Eq. 2 or 18 then yields:

$$K = \frac{\pi^2 n^2}{l^2} H + \frac{\pi^4 n^4}{l^4} EI. \tag{23}$$

Equation 23 is the simplest and most useful formula for K. It is exact for all *even* values of n (n = 2, 4, 6, $\cdots$), the so-called "*anti-symmetric modes*" (Fig. 1), since, for these modes, AH = 0.

The value of K for $n = 2$ is the "*Coefficient of Rigidity*" of the suspension bridge, a useful criterion for aerodynamic stability.

In Eq. 23, the H-term and the EI-term represent the respective contributions of the cable and the stiffening truss to the rigidity of the suspension bridge. The ratio of the truss term to the total is designated by R and is significant for aerodynamic stability.

From Eqs. 20, 22, 6 and 7,

$$K = \frac{\pi^2 \sum \left(\frac{n^2 a^2}{l}\right) H + \pi^4 \sum \left(\frac{n^4 a^2}{l^3}\right) EI + \frac{32}{\pi} \sum \left(\frac{af}{nl}\right) \Delta H}{\frac{1}{w_0} \sum (wa^2 l) + \frac{2}{w_0} \sum (we^2 l)} \tag{24}$$

This is the most general form of the equation for K. It covers all possible combinations of spans, modes, and superimposed harmonics.

In Eq. 24 and the following equations, and in all similar formulas involving summations of functions of the amplitudes, it is not necessary to know the absolute magnitudes of the several concurrent amplitudes (a and *e*), but merely the relative magnitudes.

Equation 24 is completely general for any number of spans of any respective lengths (I), simple or continuous, with any respective cable sags (f), including straight or unloaded backstays, for any combinations of values of n and a in simple or superimposed harmonic oscillations in the different spans, with any concomitant longitudinal oscillations (e) in any spans, with different values of w, H, EI, in different spans, and with any value of ΔH producing harmonic cable stretch.

In the denominator of Eq. 24, w_0 is the value of w for the main span.

Example 1

Antisymmetric Modes—K by Eq. 23
(Fig. 1)

For the Mackinac Bridge:

l = 3800 ft. l_1 = 1800 ft.
w = 9400 lb./ft.
H = 48,478,000 lb. (for two cables)
E I = 3,768 × 10^9 lb. ft.^{2} (for two trusses)
(K in lb./ft.^{2})

	By Eq. 23	By Eq. 1
For $n = 2$,	K = 132.5 + 28.2 = 160.7	N = 7.09/min.
$n = 4$,	K = 530.1 + 450.6 = 980.7	N = 17.50/min.
$n_1 = 1$,	K = 147.7 + 35.0 = 182.7	N = 7.55/min.
$n_1 = 2$,	K = 590.7 + 559.4 = 1150.1	N = 18.95/min.

EVALUATION OF ΔH

The virtual work represented by the vertical displacements η is

$$W_1 = \Sigma \frac{8f}{l^2} H \int_0^l \eta dx. \tag{25}$$

The virtual work represented by the cable stretch due to ΔH is

$$W_2 = \Sigma H \frac{\Delta H}{E_c A_c} \int_0^l \frac{ds^2}{dx^2}. \tag{26}$$

Hence, for $W_1 = W_2$, with Eq. 6,

$$\Delta H = \frac{16}{\pi} \frac{E_c A_c}{L_c} \Sigma' \left(\frac{af}{nl}\right) \tag{27}$$

where

$$L_c = \Sigma \int_0^l \frac{ds^2}{dx^2} \approx \Sigma \left(l + \frac{8f^2}{l}\right) \sec^2 \gamma. \tag{28}$$

In these equations, and those that follow, E_c is the elastic modulus and A, the section of the cable, and γ is the inclination of the cable-chord. Also, Σ denotes summations covering all similar expressions in all spans, and Σ' denotes a summation covering only the odd values of n in the several spans.

COMPOSITE MODES

A simple or "**primary** *mode*" is one represented by a single sine-curve—hence, single values of n and of a, as in Eq. 23. The term

"composite *mode*" is used herein to denote oscillations comprising a plurality (superimposed or coupled, or both) of simple modes, as in Eq. 24 (see Fig. 2).

From Eq. 24, using the expressions of Eqs. 23 and 27, the general formula for K for any *single* component mode (any simple sine-curve) is

$$K = K_n + C\frac{1}{na}\Sigma'\left(\frac{af}{nl}\right) \tag{29}$$

where

$$C = \frac{512}{\pi^2}\frac{f}{l^3}\frac{E_cA_c}{L_s}, \tag{30}$$

a dimensional constant for the structure, and K_n is the value of K given by Eq. 23. For $\Sigma' = 0$, Eq. 29 reduces to Eq. 23.

For symmetric modes (necessarily composite), as illustrated in Fig. 2, Eq. 29 is valid for each component mode; and, with the consistent (normal) relative amplitudes substituted, it must yield the same value of K (and, hence, the same frequency N) for each component mode. To satisfy this condition, Eq. 29 yields two simple governing relations between K and the respective values of n, a, and K_n of the component modes:

$$\Sigma'\left[\frac{1}{n^2}\frac{C\frac{f}{l}}{(K - K_n)}\right] = 1 \tag{31}$$

and

$$na \propto \frac{1}{K - K_n}. \tag{32}$$

Equation 31 yields the desired value of K for the normal (balanced) composite mode, and Eq. 32 gives the relative amplitudes of the component modes.

In practical application, the largest number of component modes necessary to be considered and substituted in Eq. 31 is three, and that is the case of the lowest symmetric mode ($n = 1, 3$; and $n_1 = 1$, Fig. 2b). In the higher symmetric modes, the superimposed harmonics prove negligible, and only two primary K_n-values need to be substituted, one for each span (Example: $n = 3$ and $n_1 = 1$, Fig. 2d). Accordingly, Eq. 31 is in reality a quadratic, or cubic, equation for K. Each real root of this equation will represent a *normal* composite mode with a mathematically and physically consistent set of relative amplitudes.

In practical application, Eq. 31 lends itself to *a* simplified numerical solution by an expedited method of trial substitution. It is the sum of two or three fractions equated to unity, with the sole unknown, K, in each denominator. If the mode represented by the first fraction is dominant, substitute an approximate trial value of K in the other term

or terms, and solve the first fraction for K. The first or second trial will generally suffice. Similarly, the one or two other roots are obtained by treating the other fraction or fractions, respectively, as dominant.

The subscripts in a_1, n_1, f_1, etc., designate values for the side spans.

Example 2

Symmetric Composite Modes—K by Eq. 29

Mode: $n = 1, 3$; $n_1 = 1$

(Figs. 2*b*, 2*c*)

Components:	$n = 1$	$n = 3$	$n_1 = 1$
Amplitudes:	a	a_3	a_1
K_n (by Eq. 23):	34.9	440.8	182.7

(Compare Example 1.)

For the Mackinac Bridge:

$A_e = 744$ sq. in. $\qquad L_e = 9140$ ft.

$C = 2866$ lb/ft²

$C\frac{f}{l} = 264.0 \qquad C\frac{f_1}{l_1} = 125.0$

By Eq. 31:

$$\frac{264.0}{K - 34.9} + \frac{264.0/9}{K - 440.8} + \frac{2(125.0)}{K - 182.7} = 1$$

Three solutions:

Dominant	K	Eq. 32
$n = 1$	$K = 99.5$	$a_3/a = -0.063$
	$(N = 5.57)$	$a_1/a = -0.776$
$n = 3$	$K = 405.6$	$a/a_3 = -0.285$
	$(N = 11.26)$	$a_1/a_3 = -0.474$
$n_1 = 1$	$K = 696.7$	$a/a_1 = 0.777$
	$(N = 14.75)$	$a_3/a_1 = 0.670$

Example 3

Mode: $n = 3, 5$; $n_1 = 1$ (Fig. 2*e*)

Components:	$n = 3$	$n = 5$	$n_1 = 1$
Amplitudes:	a_3	a_5	a_1
K_n (by Eq. 23):	440.8	1928.6	182.7

Eq. 31: $$\frac{264.0/9}{K - 440.8} + \frac{264.0/25}{K - 1928.6} + \frac{2(125.0)}{K - 182.7} = 1$$

Three solutions:

Dominant	K	Eq. 32
$n = 3$	363.2	$a_1/a_3 = -1.290$
	$(N = 10.65)$	$a_5/a_3 = 0.030$
$n = 5$	1941.2	$a_3/a_5 = 0.014$
	$(N = 24.62)$	$a_1/a_5 = 0.036$
$n_1 = 1$	537.6	$a_3/a_1 = 1.222$
	$(N = 12.96)$	$a_5/a_1 = -0.051$

For $n = 5$, dominant, the small value of a_3/a_5 indicates that the superposed harmonic $n = 3$ is negligible. Similarly, for $n = 3$, dominant, the superposed harmonic $n = 5$ is negligible.

Example 4

Mode: $n = 3, n_1 = 1$ (Fig. *2d*)

Amplitudes:	a_3	a_1
K_n (*by* **Eq.** *23*):	440.8	182.7

Eq. *31*:

$$\frac{264.0/9}{K - 440.8} + \frac{2(125.0)}{K - 182.7} = 1$$

Two solutions:

Dominant	K	Eq. 32
$n = 3$	363.8	$a_1/a_3 = -1.276$
	$(N = 10.66)$	
$n_1 = 1$	539.1	$a_3/a_1 = 1.209$
	$(N = 12.98)$	

Note that these results are practically identical with those obtained in Example **3.** The inclusion of the third component ($n = 5$) in Example **3** was unnecessary ; the effect is almost imperceptible.

Example 5

Mode: $n = 5, n_1 = 1$ (Fig. *2f*)

Amplitudes:	a_5	a_1
K_n (*by* **Eq.** *23*):	1928.6	182.7

Eq. *31*:

$$\frac{264/25}{K - 1928.6} + \frac{2(125.0)}{K - 182.7} = 1$$

Two solutions:

Dominant	K	Eq. 32
$n = 5$	1940.9	$a_3/a_5 = 0.035$
	$(N = 24.62)$	
$n_1 = 1$	430.9	$a_5/a_1 = -0.033$
	$(N = 11.60)$	

These results for $n = 5$ are practically identical with those obtained in Example 3.

For $n = 3, 5, \ldots$, with $n_1 = 1$, the inclusion of a third component in applying Eqs. 29–32 is unnecessary.

STRAIGHT OR UNLOADED BACKSTAYS

For the case of straight backstays, assuming zero sag ($f_s = 0$), all of the foregoing equations, including Eqs. 29–32, are applicable without any modification. The sole effect is in the reduced numerical value of L_s given by Eq. 28, reflected in the increased numerical value of C, given by Eq. 30.

For application to *unloaded* backstays with the small cable-sag (f_s) considered, Eqs. 29, 31 and 32 require a simple modification. Instead of the usual relation of equal unit dead loads in main and side-spans ($w_1 = w$), the weight of the cable becomes the sole dead load (w_1) in the side spans. Consequently, in reducing Eq. 24 to Eq. 29 for a side-span mode, the multiplying factor w_0/w_1 must be retained. The C term is unchanged, since C, (Eq. 30), contains the factor f/l^2 which is proportional to w_1/w_0. Accordingly the *sole* change in Eqs. 29, 31 and 32 is to replace K_{n_1} for any side-span component by $\frac{w_0}{w_1} K_{n_1}$. This yields:

$$K_1 = \frac{w_0}{w_1} K_{n_1} + C \frac{1}{n_1 a_1} \Sigma' \left(\frac{af}{nl} \right) \tag{33}$$

$$\Sigma' \left[\frac{\frac{1}{n^2} C \frac{f}{l}}{K - \frac{w_0}{w} K_n} \right] = 1 \tag{34}$$

$$\frac{n_1 a_1}{na} = \frac{K - K_n}{K - \frac{w_0}{w_1} K_{n_1}} \tag{35}$$

Example **6**

Straight Backstays

For the hypothetical case of the Mackinac Bridge with straight backstays, assume $L_s = 7540$, $C = 3474$, $C f/l = 320.0$.

For the lowest symmetric mode ($n = 1, 3$), **Eq.** 31 becomes:

$$\frac{320.0}{K - 34.9} + \frac{320.0/9}{K - 440.8} = 1$$

Two solutions:

Dominant	K	Eq. 32
$n = 1$	292.9	$a_3/a = -0.581$
$n = 3$	538.4	$a/a_3 = +0.582$

Compare Example 2. The straight backstays raise the corresponding values of K from 99.5 to 292.9, and from 405.6 to 538.4.

***Example* 7**

Unloaded Backstays (with Cable Sag Considered)

For this case, $\frac{w_1}{w_0} = \frac{2670}{9400} = 0.284$. Assume $l_1 = 1000$ ft. Hence $f_1/l_1 = 0.0069$, $C\, f/l = 320.0$ and $C\, f_1/l_1 = 24.0$.

For the mode: $n = 1, 3; n_1 = 1$, (Compare Example 2.)

Eq. 34 becomes: $\frac{320}{K - 34.9} + \frac{320/9}{K - 440.8} + \frac{2(24.0)}{K - 182.7/0.284} = 1$

Three solutions:

Dominant	K	Eq. 35
$n = 1$	273.3	$a_3/a = -0.474$
	$(N = 9.24)$	$a_1/a = -0.644$
$n = 3$	496.8	$a/a_3 = 0.364$
	$(N = 12.46)$	$a_1/a_3 = -1.147$
$n_1 = 1$	752.4	$a/a_1 = 0.152$
	$(N = 15.33)$	$a_3/a_1 = 0.117$

Compare Examples 2 and 6. Unloaded backstays with cable sag considered yield K-values somewhat lower than the assumption of "straight backstays," but substantially higher than the K-values with loaded side spans.

COMPACT FORM OF GENERAL EQUATION FOR K

The general formula for K, Eq. 24, may be rewritten in a simple compact expression of equal generality:

$$K = \frac{\sum (Ka^2 l)}{\frac{1}{w_0} \sum (wa^2 l) + \frac{2}{w_0} \sum (we^2 l)} \tag{36}$$

in which K for each span or for each component mode has been computed separately by Eq. 29 or any other pertinent formula.

Equation 36 may also be written directly from the energy relation, **Eq.** 20, with the aid of Eqs. **2** and **7.**

With w equal in all spans and with e = 0, Eq. 36 reduces to the simpler form:

$$K = \frac{\sum (Ka^2l)}{\sum (a^2l)} \tag{37}$$

which may also be written directly from the energy relation, **Eq.** 18.

Equation 37 is an exceedingly convenient and useful formula for practical application. It may be used for beams and other structural combinations, as well as for suspension bridges.

OSCILLATIONS WITH LONGITUDINAL MOTIOK OF SPAN

If n = 2, 6, 10, ..., without participation of the side spans, the longitudinal motion $\Delta(l/2)$ of the midpoint of the cable may be imparted to the suspended span through any physical coupling at midspan, as when center ties are provided. For this case, by Eqs. 6, 25 and 27,

$$\frac{e}{a} = \frac{16}{\pi}\frac{f}{nl} \tag{38}$$

and Eq. 36 yields:

$$K = \frac{K_0}{1 + 2\left(\frac{16}{\pi}\frac{f}{nl}\right)^2} \tag{39}$$

in which K_0 is given by Eq. 23.

If the two side spans oscillate in opposite phase, with the main span free of vertical oscillation $(a = 0)$, Fig. 1a, the parallel and synchronous movement Δl_1 of the two tower tops produces longitudinal motion of the main span equal to Δl_1. For this case,

$$\frac{e}{a_1} = \frac{16}{\pi}\frac{f_1}{n_1 l_1} \tag{40}$$

and Eq. 36 yields:

$$K = \frac{K_1}{1 + \frac{l}{l_1}\left(\frac{16}{\pi}\frac{f_1}{n_1 l_1}\right)^2} \tag{41}$$

in which K_1 is given by Eq. 23 for $n_1 = 1, 3, \cdots$.

Equations 39 and 41 express an apparent reduction in K as the equivalent of an increase in the effective value of the oscillating mass m in Eq. 1.

In any segment (l) of a parabolic cable, by Eqs. 25 and 6,

$$\Delta l = \frac{8f}{l^2}\int_0^l \eta dx = \frac{16}{\pi}\frac{af}{nl'} \tag{42}$$

For $\frac{l}{2}, \frac{n}{2}, \frac{f}{4}$, e = A $\left(\frac{l}{2}\right)$ and Eq. 42 yields Eq. 38.

For l_1, n_1, f_1, e = Δl_1, and Eq. 42 yields Eq. 40.

CABLE ANCHORED AT MID-SPAN

If the cable is anchored at midspan, as by center ties, and longitudinal oscillation of the span is prevented (as by friction brakes, or automatically as in the case of torsional oscillations), the antisymmetric modes n = 2, 6, 10, . · ·, will induce side-span participation, thereby raising the value of K. For this case, Eq. 24 or Eq. 29 is applied over the half-span and side span, or from the point of fixation to either anchorage, using the obviously modified values of n, f, and 1. (Use 1/2 for 1, $n/2$ for n, $f/4$ for f, $\frac{1}{2}L_s$ for L,, 2C for C, and 2C f1/11 for C f1/11; a, K,, and $C\,f/l$ are unchanged.)

Example 8

Antisymmetric Mode with Cable Anchored at Mid-Span

Mode: $n = 2, n_1 = 1$ (Fig. *lb)*

$K_n = 160.7, \qquad 182.7$ (Example *1.)*

Data: C $f/l = 264.0; \qquad 2C\ f_1/l_1 = 249.9$

Applied over the half-span and one side span, Eq. *(31)* for this case becomes:

$$\frac{264.0}{K - 160.7} + \frac{249.9}{K - 182.7} = 1$$

Two solutions:

Dominant	K	N	Eq. (32)
$n = 2$	*171.7*	*7.32*	$a_1/a_2 = -1.000$
$n_1 = 1$	*685.5*	*14.63*	$a_2/a_1 = 0.958$

Compare Example 1. The anchorage of the cable at midspan augments K and N. For $n = 2$, by inducing side-span participation, K is increased from 160.7 to 171.7 (increasing N from 7.09 to 7.32 per minute). For $n_1 = 1$, by inducing main-span participation, K is increased from 182.7 to 685.5, augmenting N from 7.55 to 14.63 per minute.

APPROXIMATE METHODS

The last term in the numerator of Eq. 24 represents the effect of AH. It is also represented by the C-term in Eq. 29. A H is ordinarily either zero (in antisymmetric modes) or of relatively minor magnitude (except for $n = 1$ or $n = 1, 3$). For A H = 0 or neglected, K is given by Eq. 23 for a simple mode or by Eq. 36 or 37 for a composite mode.

There will be no cable stretch between anchorages ($\Delta H = 0$) if

$$\Sigma' \left(\frac{af}{nl}\right) = 0 \tag{43}$$

over all spans, or if

$$\Sigma' \left(\frac{a}{n}\right) = 0 \tag{44}$$

in each span—also, of course, for antisymmetric modes.

A simple short-cut for estimating the value of K is to assume that $\Delta H = 0$. Consistent relative amplitudes are then given by Eq. 43 or 44, and their substitution in Eq. 36 or 37 yields K with sufficient accuracy for all practical purposes.

For $n = 3, 5, 7, \cdots$, the governing requirement $\Delta H = 0$, represented by Eq. 44, may be satisfied, without involving the adjoining spans, by superimposing a single-segment oscillation of relative amplitude $-a/n$, yielding, by Eq. 3,

$$\eta = a \sin \frac{\pi n x}{l} - \frac{a}{n} \sin \frac{\pi x}{l}. \tag{45}$$

Substituting K_n and the relative amplitudes in Eq. 37,

$$K = \frac{\pi^2}{l^2}\left(\frac{n^4+1}{n^2+1}\right) H + \frac{\pi^4}{l^4}\left(\frac{n^6+1}{n^2+1}\right) EI. \tag{46}$$

Equation 46 may be generalized for any case of superimposed undulations of an even number of different odd values of n. If the same relation is maintained—namely, that the respective amplitudes a of the component harmonics are proportional to their values of n—the generalized form, Eq. 37, reduces to

$$K = \frac{\pi^2}{l^2}\frac{\sum n^4}{\sum n^2} H + \frac{\pi^4}{l^4}\frac{\sum n^6}{\sum n^2} EI. \tag{47}$$

For the three spans coupled (to oscillate in unison) as by tower-top movement, with $\Delta H = 0$, Eq. 37 may be written in the form:

$$K = \frac{K_0 + qK_1}{1+q} \tag{48}$$

in which K_0 and K_1 are the K_n-values by Eq. 23 for the respective spans, and

(49)

The main and side spans may oscillate in unison, with a single segment or any odd number of segments (n and n_1, respectively) in each span (Fig. 2). If the bridge is symmetrical, the relative amplitudes to satisfy Eq. 43, substituted in Eq. 49, yield

$$q = \frac{n_1^2 l}{2n^2 l_1}. \tag{50}$$

K is then given by Eq. 48.

If $l_1/n_1 = l/n$, the main and side spans are in resonance and $K = K_0 = K_1$.

If $n = 2, 6, 10, \ldots$, then $\sum A(l/n)$ is zero for the full span but is not zero for the half-span. If the midpoint of the cable is not free to take the longitudinal motion $\Delta(l/2)$, as when effectively anchored by center ties, the lengthening and shortening of the respective half-spans will tend to be taken up by side-span participation to produce $\Delta l_1 = \Delta(l/2)$ at each tower top. For this case, Eq. 43 is applied over 1/2 and l_1. The resulting values of the relative amplitudes, substituted in Eq. 49, yield

$$q = \frac{2n_1^2 l}{n^2 l_1}. \tag{51}$$

K is then given by Eq. 48.

Example *9*

Symmetric Mode—Approximate Method by Eqs. 45–47

For the symmetric composite mode $n = 3, 1$, Eq. 46 yields:

$K = 271.7 + 128.5 = 400.2$ (N = 11.18). For this case (but with side-span participation, Fig. 2*c*), the more exact method (Example 2) yields K = 405.6 (N = 11.26). The error of the approximate method is less than 1.5 per cent in the value of K and only 0.7 per cent in the value of N.

Example *10*

Antisymmetric Mode—Approximate Method by Eqs. 48–51

For the antisymmetric composite mode $n = 2, n_1 = 1$ (Fig. 1b), with center ties forcing side-span participation, Eq. 51 yields $q = 1.056$. With $K_2 = 106.7$ and $K_1 = 182.7$ (from Example 1), Eq. 48 then yields

$$K = 172.0 \qquad (N = 7.33)$$

These results are almost identical with $K = 171.7$, N = 7.32, given by the exact method Eq. 31, in Example 8.

SHORT-CUTS FOR ESTIMATING K AND N

Using the cable term alone, Eqs. 23 and 1 yield the convenient approximate relations:

$$K \approx 1.234 n^2 \frac{w}{f} \tag{52}$$

and

$$P = \frac{1}{N} \approx \frac{1}{n} \sqrt{f} \tag{53}$$

in which f is simply the sag of the cable. (Note: In Eq. 53, **P** is in seconds and f is in feet.) These simplified formulas, Eqs. 52 and 53, may be used for quickly calculating or estimating the coefficient of rigidity K and the natural period **P** or frequency N of an unstiffened suspension bridge or of one with negligible stiffening system, for all values of $n > 1$.

Similarly, using the girder term alone, Eqs. 23 and 1 yield the convenient approximate relations:

$$K \approx 1.27 n^4 \frac{w}{\eta_w} \tag{54}$$

and

$$P = \frac{1}{N} \approx \frac{1}{n^2} \sqrt{\eta_w} \tag{55}$$

in which η_w is the central deflection theoretically producible (with E constant) by the dead load w acting on the span as a simple beam. (Note: In Eq. 55, **P** is in seconds and η_w is in feet.) Equations 54 and 55 may be used for simple girder spans and for self-anchored suspension spans, for all values of n.

For a stiffened suspension bridge (except the self-anchored type), the composite rigidity K is the sum of the respective contributions (Eqs. 52 and 54) of cable and stiffening girder. Hence, by Eqs. 53 and 55,

$$\frac{1}{P} = N \approx \sqrt{\frac{n^2}{f} + \frac{n^4}{\eta_w}}. \tag{56}$$

Equations 53 and 55 are convenient formulas to remember for quick estimates.

Example 11

K and N by Short-Cut Method
For the Mackinac Bridge:

w = 9400 lb./ft.		**f = 350** ft.	η_w = **6773** ft.
For n = **2,**	**Eq. 52** yields	K = **132.6**	
	Eq. 54 yields	K = **28.2**	
		Total **K = 160.8**	

This result is almost identical with the exact value given by Eq. 23. (See Example 1.)

Also, for $n = 2$, Eq. 53 yields N = 6.41
Eq. 55 yields N = 2.92
Hence, Eq. 56 yields N = 7.05/min.

This result is also almost identical with the exact value given by Eqs. 23 and 1. (See Example 1.)

Similar excellent checks of Eqs. 52–56 are obtained for all even values of n.

TORSIONAL OSCILLATIONS

Torsional oscillations may be treated simply as opposed-phase vertical oscillation of the two cables. The angular amplitude at any point of the span is given by

$$\theta = \frac{2\eta}{b} \tag{57}$$

in which b is the width of the bridge measured center to center of girders or trusses.

Ordinarily, the torsional stiffness of the suspended span is relatively negligible. Hence, unless substantial torsional stiffness is provided by special construction (as with a double system of lateral bracing), the values of K and N determined for vertical oscillations, multiplied by simple dimensional constants, yield with sufficient accuracy the corresponding values for.torsional oscillations. The spring constant of the span in torsion, or the coefficient of torsional rigidity, will be

$$K_t = \left(\frac{b}{2}\right)^2 K = (mr^2)\omega_t^2 \tag{58}$$

and the natural frequency will be

$$N_t = \frac{b}{2r} N \tag{59}$$

$$2\pi N_t = \omega_t = \frac{b}{2r}\omega \tag{60}$$

in which r is the polar radius of gyration of the mass of the cross section of the span. It is important to note that, for torsional resistance of a suspension bridge, the polar moment of inertia (r^2m) pertains, not to a localized built-up cross section at the panel points, but to the average cross section throughout, including the long ranges between panel points. For the usual proportions, $b/(2r) = 1.3$ to 1.5.

The polar radius of gyration r is given by

$$r^2 = \frac{\sum (mr^2)}{\sum m} \tag{61}$$

in which the component r for the cable masses is $b/2$, but for all elements of the suspended section it is the *polar* radius to each element from the *center* of *oscillation* of the section.

TORSIONAL RESISTANCE OF WIND TRUSSES

In the derivation of the foregoing formulas for K, the effect of web shear in the stiffening truss or girder has been neglected. The effect of the web shear contribution is found to produce a comparatively infinitesimal or negligible reduction in K. The normal omission of the web shear contribution from the K formulas is completely justified.

If, however, wind trusses are provided in the horizontal planes of the top and bottom chords (or flanges) of the stiffening trusses (or girders), new relations between the bending and shear components come into play in *torsional* displacements. The interaction of the horizontal and vertical trusses (or girders), with common chords, imposes a relative reversal of sign in the bending components of the .horizontal trusses, with a consequent enforced increase in all of the shear components in the deflection and energy equations. In such case the shear terms are no longer negligible but contribute a valuable *increase* in K.

Accordingly, a highly effective method of augmenting resistance to *torsional* oscillations is by providing two planes of lateral bracing, at or near the top and bottom chords (or flanges) of the stiffening trusses (or girders), respectively, so as to secure the integral effect of a hollow rectangular section in torsion. The cross section is assumed rigidly constructed or braced so as to preserve its rectangular form. The resultant transverse *shearing* forces in the four planes of the tubular member, when it is subjected to torsion, will then contribute very material increases in K_t and R.

Let η and z represent the vertical and lateral displacements, respectively, at any section of the chord (or flange). Each is the algebraic sum of bending and shear contributions:

$$\eta = \eta_m + \eta_s \qquad z = z_m + z_s. \tag{62}$$

Between the corresponding elements in the vertical and horizontal planes (distinguished by subscripts where necessary), the five governing static conditions of equal rotation, equal chord stress, identical chords, shear equilibrium, and ratio of shear deflections, in the order named, yield the following five simple basic relations:

$$\frac{\eta}{z} = \frac{b}{d}, \qquad \frac{\eta_m}{z_m} = -\frac{b}{d}, \qquad \frac{I_v}{I_h} = \frac{d^2}{b^2}, \qquad \frac{S_v}{S_h} = \frac{d}{b}, \qquad \frac{\eta_s}{z_s} = k\frac{b}{d} \tag{63}$$

in which d is the vertical truss depth and

$$k = \frac{A_h d^2}{A_v b^2} \tag{64}$$

(non-dimensional). A_v is the vertical web section of the girder, multiplied by E_s/E; or, in the case of a truss, A_v is the equivalent solid web section and is given by

$$A_v = A_d (\cos^2 \phi \sin \phi) \tag{65}$$

in which A_d is the sectional area of the diagonal member or members in a truss panel, ϕ is the inclination of the diagonal from the vertical, and E, is the shear modulus of elasticity. (For steel, E_s/E may be taken as 0.385.) A_h is similarly defined in each horizontal plane of bracing, In Eqs. 63, note the enforced reversal of sign for the z_m ratio; this is. significant.

From Eqs. 62 and 63, the component deflections η_m, η_s, z_m, z_s and z are easily written as simple ratios of η, containing only b, d, and k. Also, substituting η_s in the shear geometry of a girder web yields

$$S_v = \frac{2k}{1 + k} EA_v \frac{d\eta}{dx}. \tag{66}$$

In the case of a truss, the geometry of a truss panel, with the aid of Eq. 65, yields the identical formula, Eq. 66.

Substitution of the foregoing relations, Eqs. 62–66, in the energy equation, as in Eqs. 16–22, yields the desired K-formula:

$$K = \frac{\pi^2 n^2}{l^2} H + \left(\frac{1 - k}{1 + k}\right)^2 \frac{\pi^4 n^4}{l^4} EI + \left(\frac{4k}{1 + k}\right) \frac{\pi^2 n^2}{l^2} EA, \tag{67}$$

in which the three terms represent the respective contributions of cable displacement, chord (or flange) stresses, and diagonal (or shear) stresses. This last term is new, and constitutes a very significant addition to K and an even more significant addition to R.

In Eq. 67, the moment contributions of the vertical and the horizontal trusses are equal; but the corresponding coefficient 2 is omitted from the second term of Eq. 67, because the equality in this case represents a duplication of identical chords counted in both the horizontal and vertical trusses.

Without the two planes of horizontal trussing, $A_h = 0$, $k = 0$, and Eq. 67 reduces to Eq. 23.

Equation 67 replaces K_n in previous formulas. If A H is not zero, add the A H term as in Eq. 29. For simple antisymmetric modes (n = 2, 4, 6, . . .), Eq.. 67 is complete.

K should preferably be written to represent the complete cross section of the bridge, rather than the value for one side or one cable. Accordingly, in Eq. 67, H refers to the *two* cables, **I** and A_v refer to the *two* vertical trusses or girders, and A_h refers to the *two* horizontal trusses.

For the usual case of *two* cables and stiffening trusses, the *total* value of K multiplied by $b^2/4$ gives K_t (in torsion), as in Eq. 58.

Equation 67 assumes the two vertical stiffening trusses (and cables) oscillating in *opposite* phase. Consequently Eq. 67 does not apply to ordinary vertical oscillations, and does *not* represent *vertical* rigidity of the structure.

By **Eq.** 67, the addition of wind trusses (in two horizontal planes) is a highly economical and effective method of providing desired resistance to *torsional* oscillations. It is vastly surpassed, however, in economy and efficiency by the simple device of installing transverse diagonal stays, between the cables and the trusses, as described and successfully applied by the author in 1943.

Example ***12***

Antisymmetric Mode (n = 2) in Torsional Oscillations

For $n = 2$, Example 1, by Eq. 23, gives

$$K = 160.7 \qquad (N = 7.09)$$

Hence, by Eqs. 57–61, with b = 68 ft., $r = 30.4$ ft.

$$K_t = 185{,}800. \qquad (N_t = 7.93/\text{min.})$$

With center ties, causing side-span participation (Fig. lb), Example 8, by Eq. 31 applied over the half-span and one side span, gives

$$K = 171.7 \qquad (N = 7.32).$$

Hence, by Eqs. 57–61,

$$K_t = 198{,}500 \qquad (N_t = 8.19).$$

For the case with two horizontal planes of lateral bracing, we use the data of Example 1 together with $d = 38$, b = 68, $A_v = 15.62$, $A_h = 23.60$, $k = 0.472$. With these data, Eq. 67 gives:

$$K = 132.5 + 3.6 + 1588.4 = 1724.5.$$

Hence, by Eqs. 57–61,

$$K_t = 1{,}993{,}500 \qquad (N_t = 25.96).$$

Compared with $K_t = 185{,}800$, this represents a 973 per cent increase in K_t (and a 227 per cent increase in N_t) due to the provision of the double system of lateral bracing.

With center ties, causing side-span participation (Fig. lb), in addition to the double system of lateral bracing, Eq. 31 applied over the half-span

and one side span, gives:

$$\frac{264.0}{K - 1724.5} + \frac{2(125.0)}{K - 1922.0} = 1$$

This yields, for $n = 2$ dominant,

K = 1807.5 (and K = 2353.0 for $n_1 = 1$ dominant).

Hence, by Eqs. 57–61,

$$K_t = 2{,}089{,}500 \qquad (N_t = 26.58).$$

Compared with the corresponding value of $K_t = 198{,}500$, this represents a 953 per cent increase in K_t (and a 225 per cent increase in N_t) due to the provision of a double system of lateral bracing.

Example 13

Symmetric Mode ($n = 1$) in Torsional Oscillations

For the composite mode $n = 1, n_1 = 1$, Fig. 2a, Eq. 31 yields K = 100.3 (N = 5.60). Hence, by Eqs. 57–61,

$$K_t = 115{,}900 \qquad (N_t = 6.26).$$

For the composite mode $n = 1, 3$, with $n_1 = 1$, Fig. 2b, Example 2, by Eq. 31, gives K = 99.5 (N = 5.57). Hence, by Eqs. 57–61,

$$K_t = 115{,}000 \qquad (N_t = 6.23).$$

This value is slightly lower than $K_t = 115{,}900$, and represents the desired minimum.

For the case with two horizontal planes of lateral bracing, with the data of Example 12, Eq. 67 gives:

$$K_n = 33.1 + 0.2 + 397.1 = 430.4$$

for $n = 1$, also $K_n = 3890.4$ for $n = 3$, and $K_n = 1922.0$ for $n_1 = 1$. With these values of K,, for the composite mode $n = 1, 3$, with $n_1 = 1$, Fig. 2b, Eq. 31 becomes:

$$\frac{264.0}{K - 430.4} + \frac{264.0/9}{K - 3890.4} + \frac{2(125.0)}{K - 1922.0} = 1.$$

This yields, for $n = 1$ dominant, $K = 649.4$. (The relative amplitudes are given by Eq. 32.) Hence, by Eqs. 57–61,

$$K_t = 750{,}700 \qquad (N_t = 15.93).$$

Compared with $K_t = 115{,}000$, this represents a 553 per cent increase in Kt (and a 156 per cent increase in N_t) due to the provision of a double system of lateral bracing.

For the composite mode $n = 1$, $n_1 = 1$, Fig. 2a, Eq. 31 takes the simpler form:

$$\frac{264.0}{K - 430.4} + \frac{2(125.0)}{K - 1922.0} = 1.$$

This yields, for $n = 1$ dominant, $K = 651.0$. Hence, by **Eqs.** 57–61.

$$K_t = 752{,}600 \qquad (N_t = 15.95).$$

The effect of omitting the component $n = 3$ thus appears to be practically negligible. The lower value ($K_t = 750{,}700$) represents the desired minimum.

EFFECT OF TORSIONAL STIFFNESS OF THE TOWERS

Suspension bridge towers are normally designed as flexible cantilevers, fixed at the base. Their contribution to K, the stiffness of the bridge against *vertical* oscillations, is small and usually negligible.

The *torsional* stiffness of the towers, however, offers a larger contribution to K_t, the resistance of the bridge to *torsional* oscillations. This contribution may be material, even without special design of the towers for greater torsional stiffness. In comparison with other methods, such special design of the towers would usually be an uneconomical means of increasing the torsional rigidity of the bridge.

A couple formed by a horizontal cable force P at each saddle will twist the tower about its vertical axis to produce a longitudinal displacement e at each saddle. The torsional stiffness of the tower is denoted by

$$K_T = \frac{P}{e}. \tag{68}$$

Let

$L_{s0} = L_s$ for $\frac{1}{2}$ main span.

$L_{s1} = L_s$ from anchorage to tower.

$$(L_{s0} + L_{s1} = \tfrac{1}{2}L_s)$$

$\Delta H_1 = \Delta H$ from anchorage to tower.

$\Delta H_0 = \Delta H_1 + P = \Delta H$ in $\frac{1}{2}$ main span.

Considering the main span,

$$e = \frac{8}{\pi}A - \frac{\Delta H_0 L_{s0}}{E_c A_c}. \tag{69}$$

Considering the side span,

$$e = -\frac{8}{\pi}B + \frac{\Delta H_1 L_{s1}}{E_c A_c} \tag{70}$$

in which

$$A = \frac{\pi f}{l^2}\int_0^{l/2} \eta dx = -\sum \frac{af}{nl}\left(\cos\frac{n\pi}{2} - 1\right)$$

$$B = \frac{\pi f_1}{l_1^2}\int_0^{l_1} \eta_1 dx = -\sum \frac{a_1 f_1}{n_1 l_1}(\cos n_1\pi - 1). \tag{71}$$

Equating the two expressions for e, the foregoing equations yield:

$$\Delta H_1 = -\frac{16}{\pi}\frac{1}{U}[-(E_cA_c)A + (E_cA_c + K_TL_{s0})B]$$

$$\Delta H_1 + P = -\frac{16}{\pi}\frac{1}{U}[(E_cA_c)B - (E_cA_c + K_TL_{s1})A] \qquad (72)$$

in which

$$U = L_s + \frac{2K_TL_{s0}L_{s1}}{E_cA_c}. \qquad (73)$$

The total potential energy due to cable stretch (AH) in the whole bridge and including the torsion in the two towers will then be:

$$W_p = \frac{256}{\pi^2 U}\left[E_cA_c(A+B)^2 + 2K_TL_{s1}A^2 + 2K_TL_{s0}B^2 + \frac{4K_T}{U}(L_{s1}A - L_{s0}B)^2\right]. \qquad (74)$$

The first three terms in the bracket represent W_p due to cable stretch, and the fourth term represents W_p due to torsion in the two towers.

For $K_T = 0$, Eq. 74 reduces to the A H term in Eq. 24.

The potential energy due to truss distortion has already been determined, as represented in Eq. 67, and gives the first term of the numerator of the following equation. The kinetic energy of the towers is negligible. From Eq. 74 and $W_p = W_k = \frac{1}{2}K \sum a^2 l$, we obtain the equation for K:

$$K = \frac{\sum(K_n a^2 l) + \frac{512}{\pi^2 U^2}[E_cA_cL_s(A+B)^2 + 2K_T(L_s+U)(L_{s1}A^2 + L_{s0}B^2)]}{\sum a^2 l} \qquad (75)$$

in which K_n is given by Eq. 23 or 67 for each component mode.

Equation 75 gives the numerical value of K in terms of the relative amplitudes (a_1/a). For a composite mode consisting of one main-span mode (amplitude a) and one side-span mode (amplitude a_1), the partial derivative $\frac{\partial K}{\partial a} = 0$ yields K and a_1/a for the mode n dominant; and the partial derivative $\frac{\partial K}{\partial a_1} = 0$ yields K and a/a_1 for the mode n_1 dominant. These values will be virtually unchanged if an additional mode of higher n is superimposed. For a composite mode consisting of three or more simple modes superimposed, the resulting simultaneous equations may be solved graphically.

In applying Eq. 75, K_n and A, should be taken as the values for the complete cross-section of the bridge (*two* cables and *two* vertical trusses or girders), in order that Eq. 58 may then be applied to the resulting value of K to give K_t.

From K given by Eq. 75, the values of K_t and N_t are then given by Eqs. 58 and 59.

Equation 75 assumes the two vertical stiffening trusses and cables oscillating in *opposite* phase. Consequently Eq. 75 does not apply to ordinary vertical oscillations, and does *not* represent *vertical* rigidity of the structure.

Example 14

Antisymmetric Mode with Torsional Stiffness of Towers

(Fig. lb)

For the Mackinac Bridge:

$L_s = 9140$ ft.	$E_cA_c = 20.82\ (10)^8$ lb.	
$L_{s0} = 2029$ ft.	$K_T = 873{,}000$ lb./ft.	
$L_{s1} = 2541$ ft.	$U = 10{,}005$ ft.	
$H = 48{,}478{,}000$ lb.	$f/l = 0.0921$	$f_1/l_1 = 0.0436$

By Eq. 67, $K_n = 1724.5$ for $n = 2$ and K, $= 1922$ for $n_1 = 1$

(Compare Example 12.)

For the antisymmetric mode, $n = 2$, $n_1 = 1$, Eq. 75 then yields

$$K = \frac{7.764a^2 + 1.584a_1a + 7.936a_1^2}{0.0038a^2 + 0.0036a_1^2}$$

For $n = 2$, dominant, $\frac{\partial K}{\partial a} = 0$ yields:

$$K = 1895, \quad \text{and} \quad a_1/a = -0.711.$$

Hence

$$K_t = 2{,}190{,}600 \qquad (N: = 27.21).$$

For $n_1 = 1$, dominant, $\frac{\partial K}{\partial a_1} = 0$ yields:

$$K = 2352.8, \quad \text{and} \quad a/a_1 = 0.674.$$

Hence

$$K_t = 2{,}719{,}800 \qquad (N: = 30.32).$$

Comparison with the corresponding values in Example 12 shows that the effect of including the torsional stiffness of the towers is an increase of 4.8 per cent in K_t (and 2.4 per cent in N_t) for the mode $n = 2$, dominant.

Example 15

Symmetric Mode with Torsional Stiffness of Towers
(Fig. 2a)

Data as in Example 14.

By Eq. 67, $K_n = 430.4$ for $n = 1$,

and $K_n = 1922.0$ for $n_1 = 1$.

(Compare Example 13.)

For the symmetric mode $n = 1$, $n_1 = 1$, Eq. 75 then yields

$$K = \frac{2.846a^2 + 1.584a_1a + 7.936a_1^2}{0.0038a^2 + 0.0036a_1^2}$$

For $n = 1$, dominant, $\frac{\partial K}{\text{da}} = 0$ yields:

$$K = 718.2 \quad \text{and} \quad a_1/a = -0.148$$

Hence

$$K_t = 830{,}200 \qquad (N_t = 16.75).$$

For $n_1 = 1$, dominant, $\frac{\partial K}{\partial a_1} = 0$ yields:

$$K = 2235.2 \quad \text{and} \quad a/a_1 = 0.140$$

Hence

$$K_t = 2{,}583{,}900 \qquad (N_t = 29.55).$$

Comparison with the corresponding values in Example 13 shows that the effect of including torsional stiffness of the towers is an increase of 10.3 per cent in K_t (and 5.0 per cent in N_t) for the mode $n = 1$, dominant.

If we superimpose the harmonic $n = 3$ on the oscillation $n = 1$, $n_1 = 1$, the numerical results obtained above are very slightly modified. The value of K_t for $n = 1$, dominant, is reduced from 830,200 to 826,800; and the value of K_t for $n_1 = 1$, dominant, is reduced from 2,583,900 to 2,579,000. The reduction in K_t and N_t is insignificant, and such refinement is not justified.

EFFECT OF CENTER OF SUSPENSION

The effective center of suspension of a suspension bridge cross section in torsional oscillation is the midpoint of the line joining the two points of connection of the suspenders to the outside girders or trusses. The torsional stability of the section is increased by raising this center of suspension relative to the center of gravity of the suspended section. This is confirmed by simple model tests. The spring constant K_t is augmented by a torque of gravity restitution ; a gravity pendulum effect is added to the torsional spring constant.

If h is the vertical height of the center of suspension above the center of gravity of the suspended section, the vertical rise of the center of

gravity of the suspended section, as it swings in an arc like a pendulum, is, by Eq. 57,

$$v = h\frac{\theta^2}{2} = \frac{2h}{b^2}\eta^2 \tag{76}$$

and the potential energy is augmented by

$$\Delta W_p = w_s \cdot v \tag{77}$$

in which w_s is the suspended dead load (exclusive of the cables) per unit length. Accordingly, by Eqs. 16–20, and 57-61, the value of K_t given by Eq. 58 is augmented to

$$K_t = \left(\frac{b}{2}\right)^2 K + w_s h. \tag{78}$$

The total energy W required for any angular amplitude is increased in the same proportion, and consequently the aerodynamic instability, measured by the rate of amplification, is reduced in the same ratio.

In computing the polar radius of gyration r by Eq. 61, the *center of oscillation* of the suspended section was specified. If the polar moment of inertia mr^2 has been computed about the center of gravity of the suspended section, a correction must be made when the center of oscillation is at a height h above the center of gravity. The polar moment of inertia is augmented by

$$A(mr^2) = m,h^2. \tag{79}$$

By combining Eqs. 78 and 79 we may write the equivalent value of K_t:

$$K_t = mr^2\omega_t^2 = \frac{\left(\frac{b}{2}\right)^2 K + w_s h}{1 + \frac{w_s}{w}\left(\frac{h}{r}\right)^2}. \tag{80}$$

In Eq. 80, the numerator represents the augmented potential energy and the denominatoi- represents the augmented kinetic energy. The kinetic energy is augmented by the horizontal velocity of the center of gravity along the arc of the pendulum swing.

Instead of increasing h by raising the points of suspender connection, as by deeper girders or by brackets, the same improvement may be accomplished by lowering the center of gravity of the suspended-section. Accordingly, torsional rigidity and stability may be improved by changing from deck or half-through construction to through construction. The author has demonstrated this conclusion by model tests. An unstable deck truss section became aerodynamically stable when simply inverted.

Example 16

Effect of Center of Suspension

For the Mackinac Bridge:

$w = 9400,$ $\quad b = 68$ ft.

$r = 30.4$ ft.

$w_s = 6530,$ $\quad h = 6.96$ ft.

Hence Eq. 80 becomes:

$$K_t = \frac{(b/2)^2 K + 45{,}449}{1.0364}.$$

For n = 2 (See Example 12), K_t is thus increased from 185,800 to 223,100, an increase of 20 per cent.

For n = 1 (See Example 13), K_t is thus increased from 115,900 to 155,700, an increase of 34 per cent.

For the much higher values of K_t, with two horizontal planes of lateral bracing, the effect of the raised center of suspension (h = 6.96) is found to be negligible.

Section 7

References

In addition to references noted previously, the following references are suggested for technical information (but not included herein).

1. Fornes, Mike. Mackinac Bridge: Images of America. Charleston: Arcadia Publishing, 2007.
2. History Mackinac Bridge. Mackinac Bridge Authority. St. Ignace, October 1985.
3. Post, Robert C. "The Bridge at Mackinac Straits." Technology and Culture. 49.3 July, 2008. 752-763.
4. "'Big Mac' Turns 50." The Daily Mining Gazette. 27 July, 2007.

Section 8

Additional Documents and Resources

In addition to numerous technical documents about the Mackinac Bridge, the following references provide detailed documentation of the bridge construction, and further the biography of David B. Steinman. In addition, nine copies of a CD titled "Mackinac Bridge: Images from Construction to the Present" (MDOT Photography Unit, 517-322-5641) were previously submitted to ASCE in January 2009.

1. *The Mackinac Bridge*. Michigan Department of Transportation. n.d. August, 2009. http://www.mackinacbridge.org
2. Building the Mighty Mac. Dir. Mark Howell. Mighty Mac Films. 2007.
3. Steinman, David B. Famous Bridges of the World. New York: Random House, 1953. (Selected pages from a children's book written for his grandchildren).
4. The Mackinac Bridge. The History Channel 2003, Modern Marvels. (reference only)

Welcome to the Mackinac Bridge Website!

Mission Statement: The Mackinac Bridge Authority is committed to preserve and maintain the State of Michigan's single largest asset and one of the world's leading suspension bridges to provide safe, pleasurable and expedient passage over the Straits of Mackinac for economic benefit and improved quality of life.

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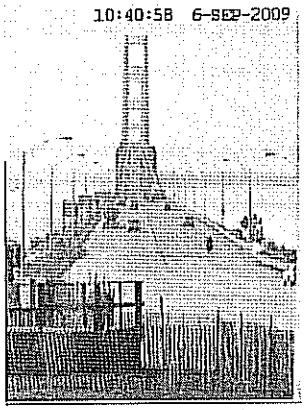
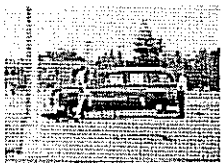
MDOT

Bridge WebCam



Check out our views of the Bridge

Mackinac Bridge reaches 150 millionth vehicle milestone

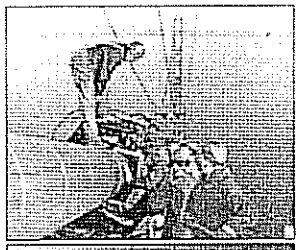


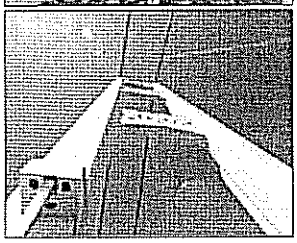
The Mackinac Bridge Authority (MBA), in cooperation with the Michigan Department of Transportation (MDOT), today announced that the 150 millionth vehicle will cross the Mackinac Bridge this Labor Day weekend. According to MBA officials, the milestone is expected to occur sometime between 5 and

... read more

Photo Gallery

E-Cards
Michigan State Ferry Album
Historical Construction Album



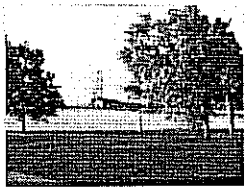


MDOT

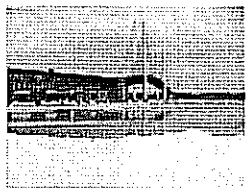
Photo Gallery

Click an image to enter a Photo Album

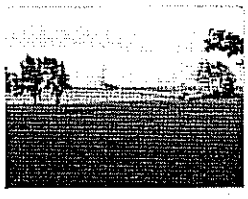
Fall Album



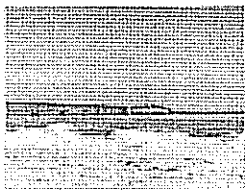
Winter



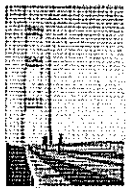
Summer



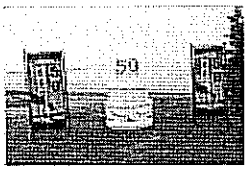
Spring



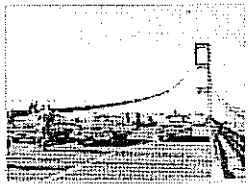
DALMAC



50th Anniversary pictures

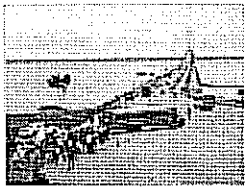


Opening Ceremony

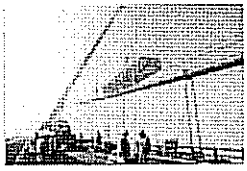


Dirty Jobs

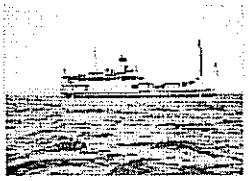
Annual Bridge Walk Album



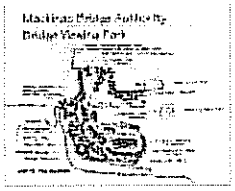
Construction Album



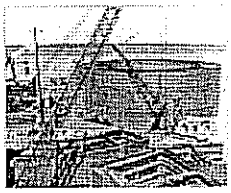
Michigan State Ferry Album



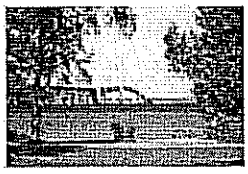
Bridge View Park



Historical Construction Album



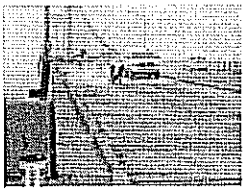
Views of the Mighty Mac



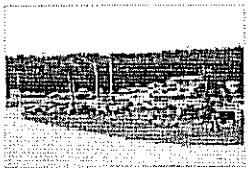
Aerial Album

Group Visits

Resurfacing 2008



Tractor Parade



Responses to: Building the Mighty Mac

"It's another sort of *Big Mac Attack* worth savoring."
- Mike Duffy, Detroit Free Press

"...watched it, it's great."
- Michael Moore, Filmmaker

"Thank you Mighty Mack for making our state and its history interesting, personal and amusing is a great gift."
- Robert J. Scott, VP of Programming, WTVS-TV, Detroit

"Enjoyed watching it, a fine documentary."
- Bob Talbert, Detroit Free Press

"Thank you very much for the splendid documentary on building of the Mackinac Bridge. You've done a wonderful job in assembling the old film footage and weaving it together to make a great [illegible] viewing. It's a beautiful [illegible] and [illegible] — all [illegible] and [illegible] new [illegible] to the [illegible] Mackinac Bridge."
- John F. Steinman, M.D.
(son of Dr. David B Steinman, Architect of the Mackinac Bridge)

"[illegible]"
- Lifeline Magazine

"[illegible]"
- Jacquie Justice, Great Lakes Literary Journal

"[illegible]"
- Inland Seas Magazine (Great Lakes Historical Society)

As seen on PBS

6 89076 50177 4

Length 115 min.

DVD VIDEO

Building the Mighty Mac

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Mighty Mac Films presents

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MIRACLE BRIDGE OVER MACKINAC

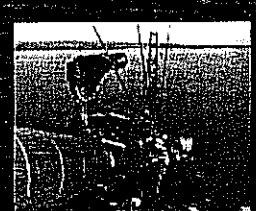
AND MACKINAC BRIDGE DIARY

DVD VIDEO

50th Anniversary Edition

Building the Mighty Mac

The Story of Building the Mackinac Bridge



DVD VIDEO

Famous Bridges of the World

FAMOUS BRIDGES *of the World*

by D. B. Steinman

Illustrated by Kurt Wiese

GATEWAY BOOKS

RANDOM HOUSE · NEW YORK

Acknowledgments

The author wishes to express his indebtedness to the following sources: D. B. Steinman and S. R. Watson, *Bridges and Their Builders* (Putnam, 1941); D. B. Steinman, *The Builders of the Bridge* (Harcourt, Brace, 1945); S. R. Watson and E. Watson, *Famous Engineers* (Dodd, Mead, 1950).

To My Grandchildren PETER and ANN,
JIMMY, JUDY
and JILL

Published in New York by Random House, Inc. and simultaneously in Toronto, Canada by Random House of Canada, Ltd. Library of Congress Catalog Card Number: 53-6274. Manufactured in the U. S. A.

Contents

Preface

This book is written for younger readers with the thought of imparting to them some of the spell and fascination of bridgebuilding and to answer their questions of "How?" and "Why?".

To become a builder of bridges was my boyhood dream, and my dream has come true. Perhaps this book will help to kindle the interest and ambition of others.

I want to record my grateful acknowledgment to Sara Ruth Watson for her invaluable assistance in the writing of this book.

D. B. STEINMAN

New York, January 1953

Section 9

Recommended Designation

The Mackinac Bridge is nominated as a National Civil Engineering Historic Landmark.

Section 10

Owner Support

Statement of support is included from the Mackinac Bridge Authority for the Mackinac Bridge to be a National Historic Civil Engineering Landmark.

STATE OF MICHIGAN
JENNIFER GRANHOLM, Governor

MACKINAC BRIDGE AUTHORITY

N415 I-75 • ST. IGNACE, MICHIGAN 49781 • 906-643-7600 • FAX: 906-643-7668

August 14, 2009

Statement of Support for Mackinac Bridge Nomination as
National Historic Civil Engineering Landmark

Some referred to it as "the bridge that couldn't be built." However, Prentiss M. Brown and Dr. David B. Steinman saw things differently. These visionaries were the founding fathers of Michigan's Mackinac Bridge. Their leadership working with others led to the construction of it. Once it was completed and opened to traffic in 1957, the five-mile long structure historically and uniquely connected Michigan's two peninsulas. More than four decades later, the Michigan Section of the ASCE selected the bridge as Michigan's #1 Civil Engineering project of the 20th Century.

While the history of the Straits-area ferry service, process of obtaining funding, design, planning, and construction of the bridge are all amazing achievements in their own right, it is the bridge itself that never ceases to amaze engineers from across the country. The Bridge stands today with the same structural integrity it had more than 50 years ago. This aerodynamically-invisible and well-maintained structure is a Michigan landmark that is expected to last for generations to come.

The Mackinac Bridge Authority (MBA) board hereby supports the nomination recognizing the Mackinac Bridge as a National Historic Civil Engineering Landmark. Additionally, the MBA appreciates the Michigan Section ASCE for their diligence in pursing this important effort which will help preserve this national icon.

Sincerely,

Robert J. Sweeney, P.E.
Executive Secretary