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INSPECTION AND REHABILITATION OF THE JOHN A. ROEBLING BRIDGE FORMERLY KNOWN AS THE COVINGTON-CINCINNATI SUSPENSION BRIDGE

ABSTRACT

THE JOHN A. ROEBLING BRIDGE, formerly known as the Covington-Cincinnati Suspension Bridge, is a National Historic Civil Engineering Landmark, one of only about 30 bridges so honored nationwide. This bridge, designed and constructed by John A. Roebling, is also on the National Register of Historic Places. The Covington-Cincinnati Suspension Bridge served as a milestone in Roebling's career which culminated in the design of his more famous Brooklyn Bridge. In 1987, the Kentucky Department of Highways began an effort to inspect and rehabilitate this structure so that it may continue to function as a modern highway bridge while at the same time preserve and restore its significant historical features. This paper provides a summary of the inspection, rehabilitation, and historic documentation efforts of the last five years.

INTRODUCTION

The John A. Roebling Bridge, formerly the Covington-Cincinnati Suspension Bridge, was the first permanent bridge to span the Ohio River between Kentucky and Ohio. Begun in 1856 and completed in 1867, the bridge stands today, after 125 years of uninterrupted service, as a tribute to the skill of its designer--John A. Roebling. At the time of its opening, the Covington-Cincinnati Suspension Bridge represented both the old and the new. Soaring masonry towers representative of construction methods to that date supported a state-of-the-art iron wire cable technology. A photograph of the original bridge soon after completion is shown in Figure 1. This monument to civil engineering of the mid-1800's boasted the longest span in the world (1,056 feet) at the time of its opening. It remained the longest span for 16 years until Roebling's Brooklyn Bridge was completed. Today, the bridge remains the second longest span in Kentucky.

The Covington-Cincinnati Bridge Company (CCBC) owned and operated the bridge as a private toll facility. In the mid-1890's the bridge underwent a major reconstruction to enable it to carry heavier vehicles. A second pair of suspension cables was added, and the original uniform-depth stiffening truss was replaced with arched steel trusses and new floor system. Surprisingly, all of this work was completed with the bridge open to traffic.

A second major reconstruction occurred in the mid-1950s, when the bridge was sold to the Commonwealth of Kentucky. Included in this work was the replacement of the timber decking with an open steel grid deck.

In September 1987, the Commonwealth of Kentucky, Transportation Cabinet, Department of Highways contracted with the consulting engineering firm of Parsons Brinckerhoff Quade & Douglas, Inc. for the detailed inspection of the John A. Roebling Bridge (Figure 2). The inspection, done under the direction of the Division of Maintenance, culminated in the submittal of a Bridge Inspection Report to the Department of Highways in September, 1988. The inspection and preparation of the inspection report comprised Phase I of the Roebling Bridge Project.

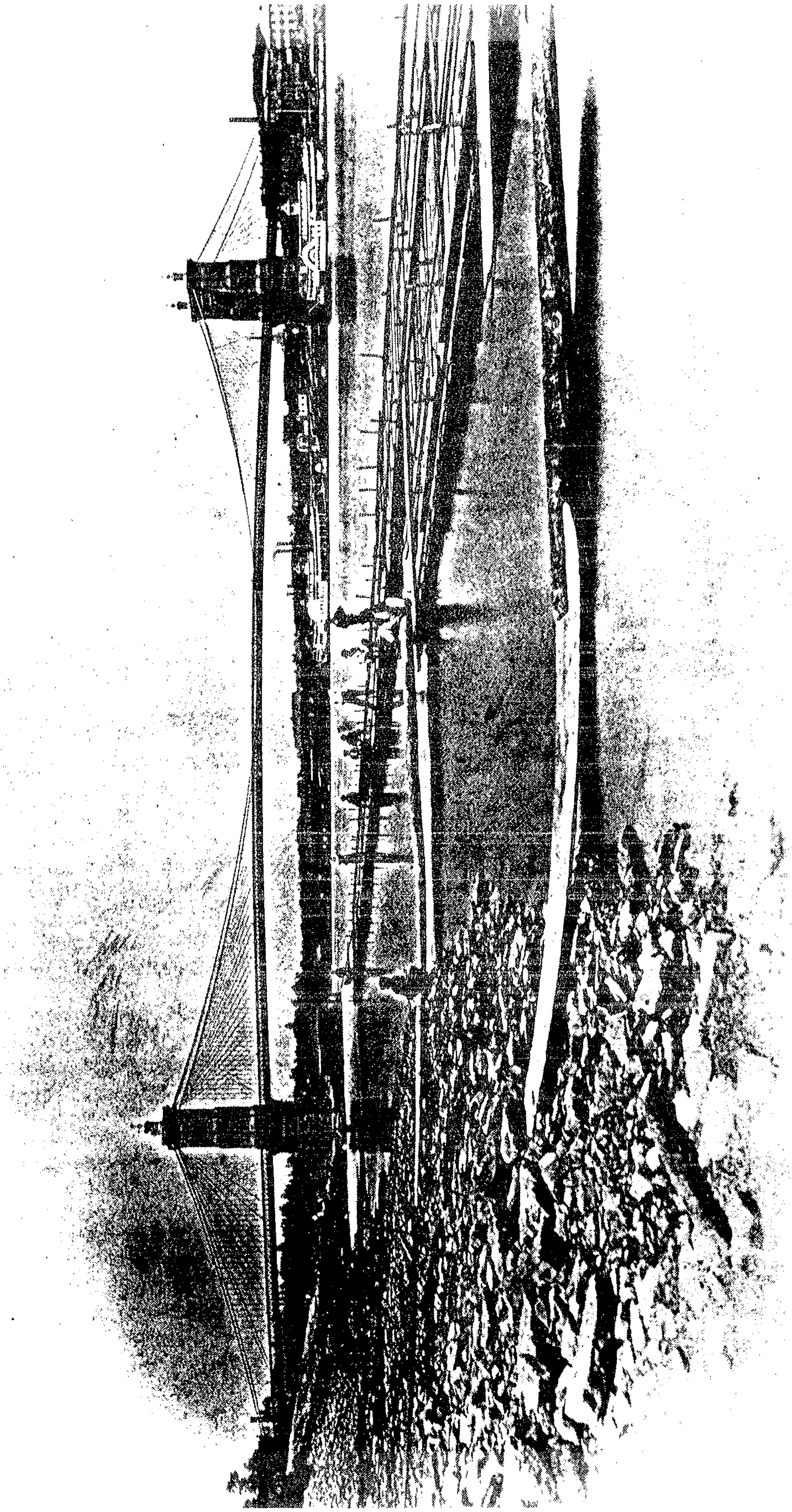


FIGURE 1. THE COVINGTON-CINCINNATI SUSPENSION BRIDGE
(CIRCA 1866 TO 1895)
NOTE THE TURRET DESIGN AT THE TOP OF THE TOWERS, THE STAY CABLES, AND THE UNIFORM DEPTH STIFFENING TRUSS SUPPORTED BY ONLY A SINGLE PAIR OF CABLES

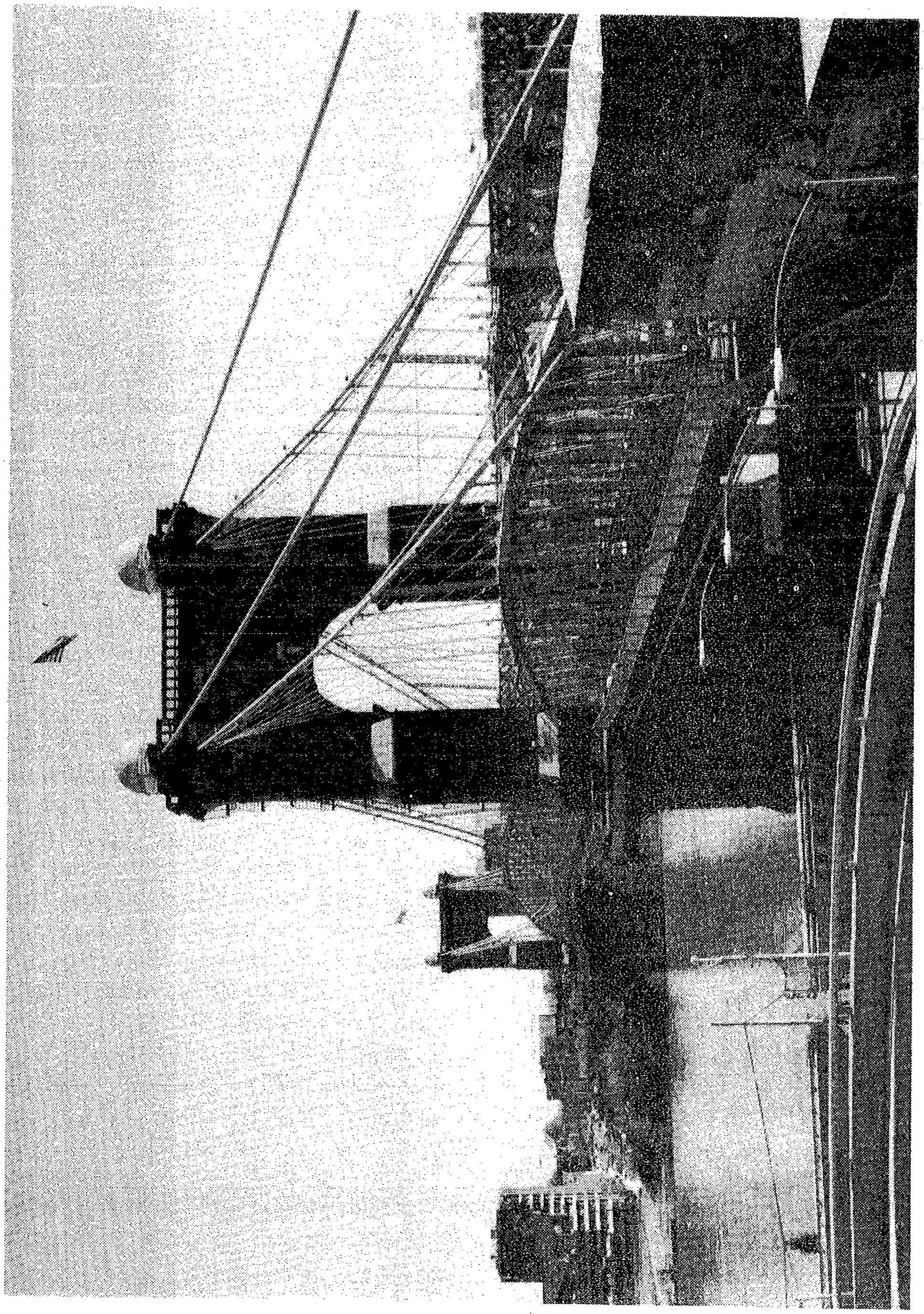


FIGURE 2. GENERAL VIEW OF THE JOHN A. ROEBLING BRIDGE (1987)

Based on the 1987 inspection findings, the Department of Highways initiated a program of repair and rehabilitation for this landmark bridge. The Phase II effort, currently in progress, began in March of 1989 after careful evaluation of the priority and economics of each item of the Phase I recommendations. Due to its high level of familiarity with the project, Parsons Brinckerhoff was again retained to provide the design engineering for Phase II, working again under the direction of the Division of Maintenance. The Division of Bridges is also involved in conducting reviews of repair plans.

It was recognized early on, that due to the historical significance of the Roebling Bridge, any repairs or rehabilitation would need to be designed to minimize disruption to the historic fabric of the site -- and, if possible, to enhance the historic image of the bridge by restoring certain elements to their original appearance. The purpose of this report is to acquaint those interested in historic preservation with the project, describe the conditions discovered during the 1987 inspection, and outline the Phase II program for repair and rehabilitation.

BRIDGE HISTORY

John A. Roebling was born in Germany on June 12, 1806, was educated at the Royal Polytechnic Institute in Berlin, and emigrated to the United States in 1831 to begin a career in civil engineering. Roebling gained experience on numerous bridge projects throughout the East and Midwest, and his professional reputation grew. In 1846, Roebling submitted a plan and report to an association of gentlemen who were applying for a charter to construct a bridge across the Ohio River between Cincinnati and Covington. Despite much resistance, particularly from the steamboat interests, the Covington and Cincinnati Bridge Company (CCBC) was incorporated by the Legislature of Kentucky in 1846 and by the Legislature of Ohio in 1849. By charter, the tower locations were set outside of the low water mark limits on both shores, resulting in a clear span opening of just over 1,000 feet; vertical clearance was set at 122 feet, but was later reduced to 100 feet. To further confound the situation, the Bridge Company was confined to a corridor centered between the main thoroughfares of Vine and Walnut in Cincinnati and Scott and Greenup Streets on the Covington side.

After a lapse of ten years, construction of the bridge was started in 1856 with John A. Roebling serving as Head Engineer, and continued until 1858 when construction was halted due to insufficient funds. At the time when work stopped, only the lower portions of both towers had been completed.

The Civil War began on April 12, 1861. Confederate invasions of Kentucky throughout the Civil War probably pointed out the strategic importance of a link in this area between Ohio and Kentucky. Additional funds were obtained, by selling more bonds, and construction resumed in 1863 and continued through the latter years of the Civil War which ended on April 9, 1865. The bridge was completed and opened to pedestrians on December 1, 1866. It is truly remarkable that such a monumental work was achieved in an era of civil strife. On December 2, 1866 at least 75,000 pedestrians crossed the bridge. The bridge was opened to vehicular traffic on January 1, 1867. Final project cost was $1,800,000. After the Covington-Cincinnati Bridge was completed, John Roebling moved on to begin the design and construction of the Brooklyn Bridge.

Throughout its history, the John A. Roebling Bridge has proven its ability to accommodate new modes of transportation. Modifications have permitted the bridge to evolve from carrying pedestrian traffic and horse-drawn wagons to carrying trolleys and is currently used by automobiles, buses, and trucks.

The bridge was reconstructed in the mid-1890's under the direction of William Hildenbrand, Chief Engineer, in order to increase its capacity for modern highway loadings. Hildenbrand was assisted by

E. F. Farrington, who served John Roebling as Master Carpenter during the original construction and Hildenbrand as Master Mechanic during the 1890's reconstruction. Unfortunately, Farrington was killed during the reconstruction after being struck by an electric car while crossing the track of the Cincinnati approach.

During the 1890's reconstruction, the primary cable ends in the anchorages were reconditioned, and a second set of suspension cables and anchorages was added. The original tower-top turrets were dismantled to facilitate installation of the new cables. Brick masonry domes and wooden sheds were then erected to enclose the two-tiered cable/saddle system. The original ornamental spires were discarded. The stiffening trusses and floor system were replaced. Exterior tower staircases were added to allow for easier access to the tops.

The sidewalks were replaced in 1934. During the 1937 flood, the Suspension Bridge was the only bridge over the Ohio River between its confluence with the Mississippi River and Steubenville, Ohio to remain open.

The bridge was operated by the CCBC as a private toll facility until 1953, when it was purchased by the Commonwealth of Kentucky for $3.6 million.

A second reconstruction occurred in the mid-1950's. Approximately 765 feet of the Ohio Approach were removed from Third Street to Front Street and replaced with an earthen embankment. New bus ramp bridges to the Dixie Terminal Building and a new bridge over Second Street were built. An open steel grid deck replaced a timber deck on the suspension spans.

Tolls were removed in 1963. Also in 1963, completion of the Markland Locks and Dam downstream from the bridge, raised the navigation pool, thus permanently inundating the bases of the towers.

The bridge was listed on the National Register of Historic Places in 1975. The Covington-Cincinnati Suspension Bridge was renamed the "John A. Roebling Bridge" by the Commonwealth of Kentucky in 1983. The John A. Roebling Bridge was designated a National Historic Civil Engineering Landmark by the American Society of Civil Engineers in 1984.

BRIDGE DESCRIPTION

Today, the John A. Roebling Bridge carries KY 17 over the Ohio River between Covington, Kentucky, and Cincinnati, Ohio. The 1,056-foot main span of the suspension bridge carries a two-lane, 28-foot wide steel grid deck roadway with 8'-6" wide sidewalks cantilevered from the trusses on each side. The towers are 240 feet in height and encompass 400,000 cubic feet of masonry. They are 82 feet long and 52 feet wide at their base. The towers bear on timber mat foundations which are 110 feet long, 75 feet wide, and 12 feet thick which in turn bear on a 12-foot thick layer of course sand and gravel above a bed of blue limestone and shale. The suspension system is composed of two sets of suspension cables restrained by massive masonry anchorages. The anchorages measure approximately 60 feet by 100 feet, and have eleven-ton plates embedded in grout beneath their bases to anchor the eyebar chains and suspension cables. The primary cables (1865) are composed of 5,180 iron wires each and are 12 1/3 inches in diameter. The secondary cables (1897) are composed of 2,226 ungalvanized steel wires each and are 10 1/2 inches in diameter. Stay cables radiate diagonally from the towers to the upper chords of the stiffening trusses. Deck loads are transferred from the stringers and floorbeams to the suspenders, trusses, and stays and then to the suspension cables, anchorages, and towers. The bridge is currently load posted at 17 tons for two-axle trucks and 22 tons for three-, four-, and five-axle trucks. The approach span roadway varies from 20 to 24 feet wide and is composed of a concrete deck supported by riveted steel plate girders. Drawings which show the elevation, typical section and cable strength data are provided in Figure 3.

The bridge is one of four providing local access to the downtown Covington-Cincinnati-Newport street system. Two Interstate bridges also link the central urban areas of the cities. The bridge carries an average daily traffic of 21,843 vehicles per day according to 1985 traffic data supplied by the Kentucky Department of Highways, Division of Planning. The bridge also serves as a focal point of the Covington and Cincinnati riverfront development efforts.

In Ohio, the bridge intersects Second and Third Streets via one-way entrance and exit ramps. There are also bus ramps leading to the Dixie Terminal Building on Third Street. The Ohio approach spans Cincinnati's Riverfront Stadium parking lot. In Kentucky, KY 17 passes over Second Street approximately 150 feet from the south anchorage and divides northbound and southbound traffic in a newly-constructed Y pattern. This new, divided roadway approach connects directly to one-way Greenup and Scott Streets.

PHASE I - INSPECTION

To evaluate the present (1987) condition of the bridge, the Kentucky Transportation Cabinet retained Parsons Brinckerhoff Quade & Douglas, Inc. to perform an in-depth inspection of all bridge elements followed by preparation of a bridge condition report.

INSPECTION METHODOLOGY

The in-depth inspection was performed under stringent traffic control conditions. One lane of traffic was maintained at all times on the two-lane bridge, and lane closures were only permitted between the hours of 9:00 A.M. to 3:00 P.M. on weekdays. Sporting events at Riverfront Stadium and Riverfront Coliseum imposed additional constraints on the inspection activities.

The inspection used a variety of methods to access the individual bridge components:

- Floor system rigging for inspection of the lower chords of the stiffening truss and floor system
- Self-propelled snorkel with 60-foot reach for inspection of the:
  - Lower exterior masonry surfaces of the main towers above deck
  - Upper portions of the stiffening truss
  - Lower portions of the main cables, suspender cables and stays
  - Floor system of the approach spans
- Cable rigging for high level cable inspection shown in Figure 4
- Tower rigging for inspection of the upper exterior tower masonry
- Climbing for inspection of the bearings, anchorages, tower-top cable saddles, and internal chambers at the top of the towers.
- Ladders for inspection of the masonry anchorages and approach bent columns
- Boat for examination of the tower masonry below deck using binoculars
- Diving and channel depth soundings by a subconsultant professional engineer diver from Law Engineering Testing Company for inspection of the submerged portions of the towers

CABLE STRENGTH DATA

PRIMARY CABLES

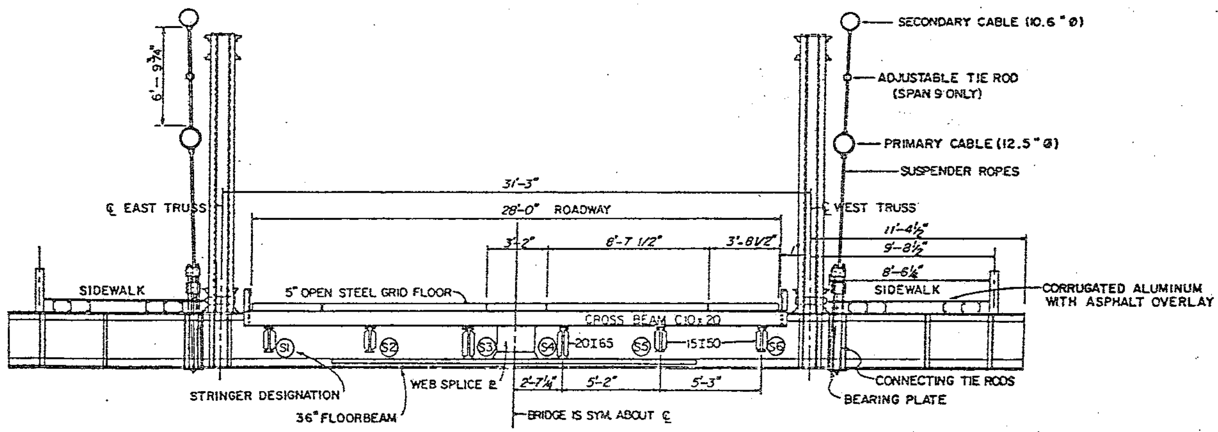
DIAMETER - 12 1/3 INCHES
NO. STRANDS - 7
NO. WIRES - 5180
WIRE SIZE - NO. 9 GAGE IRON WIRE
ULT. STRENTH OF ONE WIRE - 1620 LBS
ULT. STRENGTH OF ONE CABLE - 8,391,600 LBS

SECONDARY CABLES

DIAMETER - 10 1/2 INCHES
NO. STRANDS - 21
NO. WIRES - 2226
WIRE SIZE - NO. 6 GAGE UNGALVANIZED STEEL WIRE
ULT. STRENTH OF ONE WIRE - 5400 LBS
ULT. STRENGTH OF ONE CABLE - 12,000,000 LBS

STAY CABLES

DIAMETER - 2 1/4 INCHES
ULT. STRENGTH - 180,000 LBS.



TYPICAL SECTION

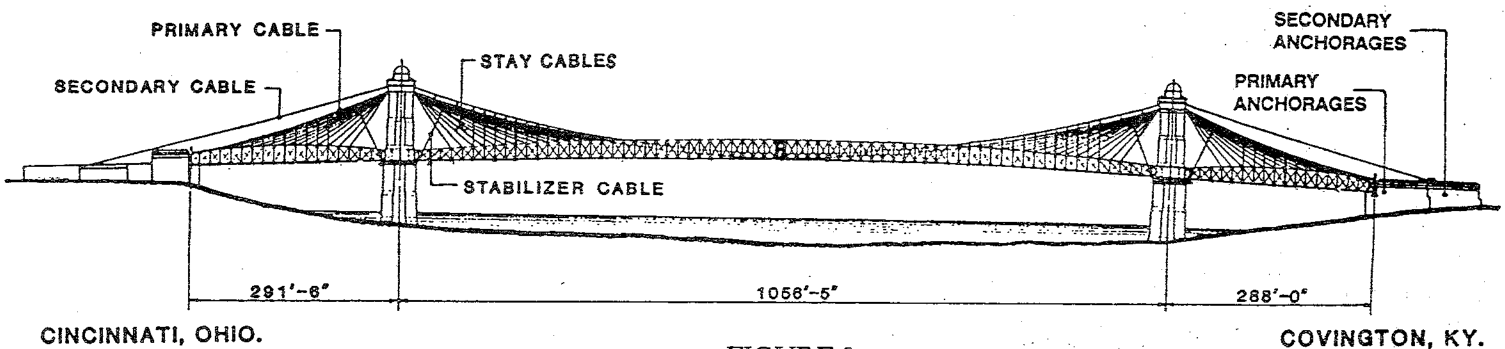


FIGURE 3
THE JOHN A. ROEBLING BRIDGE
(1987)

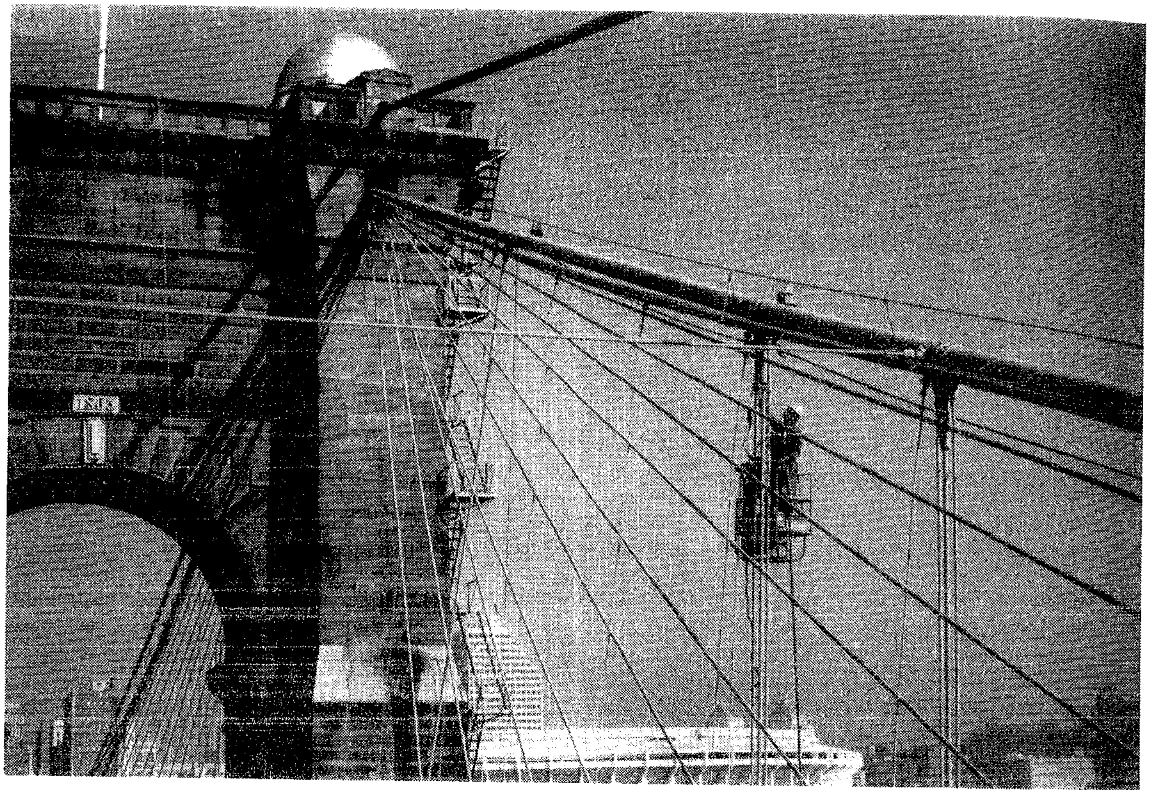


FIGURE 4. CABLE RIGGING FOR HIGH LEVEL CABLE INSPECTION

To document the inspection findings, a comprehensive report complete with 150 color photographs and 48 sketches was prepared. The report recommended specific repairs for the bridge, and outlined a plan for future maintenance inspection.

1987 INSPECTION SUMMARY

- The Ohio Approach deck was in poor condition. There were numerous areas of corrosion of the steel trough and buckle plate floor system caused by stormwater percolating through the thick, concrete fill deck.

- The primary and secondary suspension cables were in fair condition. The areas of greatest deterioration were in the masonry anchorages. Twenty-one broken wires were counted in the south anchorage for the east secondary cable. Several strands were also bulging due to internal corrosion caused primarily by leakage of water through the roof. A report prepared by the Kentucky Department of Highways, Division of Maintenance, suggests that this cable has lost 35% of its ultimate strength. The paint system on the primary cable wrapping was in poor condition, and the paint system on the secondary cable wrapping was in fair condition. There was also a heavy accumulation of pigeon waste on the cables in the towers.

- The suspension cable and stay cable saddles in the towers were in fair condition, but they appeared to be frozen due to heavy debris accumulation and corrosion. This condition causes the towers to rock on their timber mat foundations during temperature changes and other load applications.

- The suspenders and stays were in fair condition. Some of the suspender to floorbeam bearings in the main span had shifted laterally, shearing off the restraining angle. Some suspenders exhibited below average tension as compared with other suspenders on the bridge. The stays were embedded in heavy pigeon waste accumulation in the towers.

- The Ohio approach girders were in poor condition. Pack rust had developed between the bottom tension flange cover plates causing them to spread apart by 1/2" to 1". The diaphragms and crossframes were in poor condition at the ends of Spans 6 and 7 at the anchorages.

- The suspension spans' stringers were in poor condition. There were many unseated stringers at expansion joint locations. This condition caused cracks to develop in the webs of four stringers. Fifty percent (50%) localized pitting section loss of the top flanges was common. Pack rust had developed at the stringer to floorbeam connections.

- The Ohio approach floorbeams were in poor condition. The floorbeams were mostly damaged beneath leaking expansion joints and the steel plate deck adjacent to Anchorage 1.

- The suspension spans' floorbeams were in fair condition. The floorbeam to truss bearing connection angles were cracked in six of eight locations at the towers. The top flanges were heavily pitted. The top flanges of three floorbeams were cracked.

- The stiffening trusses were in fair condition. Ten pins were loose and had moved 1/4" transverse to the bridge. There were two cracked pin nuts. Pins suffer from pitting corrosion. Most of the truss member corrosion was confined to the lower chord joints, where there was up to 50% section loss of diagonal eyebar heads. There were numerous locations of traffic impact damage to truss verticals.

- The north abutment was in poor condition. It had tilted, causing the girder bearing pads to spall severely.

- Anchorage 1 was in poor condition because of masonry deterioration, cracks, and open joints beneath the floorbeams of the adjacent spans.

- Anchorages 2, 3 and 4 were in fair condition, but there was heavy spalling of stones above the sidewalk and roadway elevations, which was hazardous to both pedestrians and vehicular traffic. There were large pieces of stones missing from Anchorage 2, causing a visually offensive appearance. Some of the foil roof material on the cable housings had peeled, allowing moisture to seep into the cable rooms. Cracks were observed inside the cable housings of Anchorages 3 and 4.

- The towers were in fair condition. The main problem with the domes and cable housings was that pigeons had penetrated through protective wires, depositing waste on the cables and floor to a depth of six inches. There were several areas of loose and missing joint material and bricks, with a hole through the wall of the east dome of the North Tower. The wooden cable housings were in poor condition. The most serious problem discovered, in terms of immediate traffic safety, was heavy layering and spalling of large blocks of stone above the roadway level. There was severe loss of joint material and vegetation growth in these areas.

PHASE II - REHABILITATION

The 1987 Phase I in-depth inspection of the John A. Roebling Bridge identified numerous areas in need of repair and conditions which warranted further study. In Phase II, the Kentucky Department of Highways embarked on a program of rehabilitation and restoration of the historic bridge. The consulting engineering firm of Parsons Brinckerhoff was again retained to provide the engineering services for the restoration effort, working under the direction of the Division of Maintenance. Plan review is being provided by engineers from the Divisions of Maintenance and Bridges.

RELATIVE AGES OF BRIDGE COMPONENTS

In formulating the plan for rehabilitation and restoration, the project team gave careful consideration to the relative ages of the various bridge components. The reader will recall that the bridge underwent a major reconstruction in the mid-1890's and various other alterations throughout the twentieth century - one as recent as the 1950's. These alterations have created a medley of structural elements, each representative of the state-of-the-art of civil engineering and construction technology of its time. The comparative ages of the various elements of the bridge are:

- Original Construction by John A. Roebling (1856 to 1867):
  - Timber mat foundations for both towers
  - Masonry towers, except for alterations to the roadway-level sidewalk, the balustrade at the tops of the towers, and the brick dome turrets and wooden sheds at the tower tops which protected the cable saddles
  - Primary cable anchorages except for alterations to the masonry surfaces in some locations
  - The pair of primary (lower) suspension cables
  - Certain suspender cables and stay cables reused in the 1890's reconstruction

  The above items range in age from 125 to 136 years as of 1992.

- Mid-1890's Reconstruction by William Hildenbrand:
  - Secondary cable anchorages
  - Secondary (upper) suspension cables
  - Additional suspender cables
  - Floor system of the suspended spans
  - Stiffening truss of the suspended spans
  - Ohio approach spans
  - Tower stairways
  - Tower-top brick domes and wooden sheds which protect the cable saddles
  - Sidewalk around the perimeter of the towers

These items are about 98 years old as of 1992.

- Mid-1950's Reconstruction:
  - Abutment 1
  - Steel grid deck on the suspension spans

Based on this comparison of the relative ages of the bridge elements, one can see why greater emphasis is directed toward maintaining the authenticity of the original elements than on those items which are of more recent construction. In certain cases, this project provides an opportunity to actually restore some of the more recent elements with reproductions of original designs.

HISTORIC RESEARCH

Rehabilitation efforts have been hampered throughout Phase II by the lack of as-built drawings from the various stages of reconstruction. Since the bridge was privately-owned by the Covington and Cincinnati Bridge Company until 1953, the Kentucky Department of Highways files contain scant information in the form of original drawings made prior to that date. However, other documents were available for use during the Phase I inspection such as Roebling's report to the C&C Bridge Company upon completion of the bridge, E. F. Farrington's similar description, and various technical articles describing the 1890's reconstruction. A complete bibliography was included in the Phase I Bridge Inspection Report, and that bibliography is also included with this report for convenience.

The lack of plan data for the Roebling Bridge created an additional level of difficulty for the engineers designing the rehabilitation. These difficulties have been overcome by - 1) making extensive field measurements of those items to be repaired or replaced and 2) by searching for additional historical information. One aspect of the document search that has been particularly helpful was a visit by one of Parsons Brinckerhoff's engineers to the Roebling Library at Rensselear Polytechnic Institute located at Troy, New York. This library search uncovered a wealth of valuable information including:

- Sketches of proposed alternative bridge designs which were not constructed

- Detailed drawings of railings, masonry, turrets, stiffening truss, anchor chain and plates, and falsework and mechanical devices used during the original construction of the bridge

- Calculations and estimates of quantities.

Many of the drawings have been initialed and dated by John A. Roebling. Unfortunately, since many of the elements shown in the sketches have been removed, it cannot be determined in many instances which, if any, of the proposed alternate designs were actually constructed. Only those items which have either survived unaltered or were photographed in the period from 1867 to 1893, prior to reconstruction, can be said with any certainty to have been part of Roebling's original intent.

RESTORATION METHODS

Throughout Phase II, particular attention was given to the restoration methods used on the bridge. Rehabilitation methods and materials were selected with regard to the present level of deterioration of each element.

Cleaning was used to remove industrial, organic, and corrosion residue that promotes further deterioration or detracts aesthetically. Methods used range from water jet cleaning of masonry surfaces to vacuum cleaning of delicate cable wires to power wire brushing and grit blasting of structural steel. Paint and sealers were applied, as required, to protect these elements from further deterioration.

Repairing was the method chosen when the bridge element or nearby elements were in a sufficiently reliable condition to provide continued service after repair. A wide range of repair methods were required, from welding of structural steel to pointing of masonry joints. Repaired areas were also protected, as required, using paints and sealers.

Replacement of elements was required when present conditions did not allow the element to fulfill its intended function after repair. Examples of this situation are steel members that are severely corroded, severely spalled masonry blocks, roofing materials that permit damaging entry of water, etc. The replacement process included careful attention to specifying components that were similar in appearance and composition to the original material. Occasionally, a different material was substituted when improvement could be gained in strength or durability without sacrificing the authentic appearance of the piece.

SUSPENDER REPLACEMENT PLANS (CONTRACT I)

On the Roebling Bridge, wire rope suspenders and steel tie-rods transmit dead and live load forces from the floorbeams to the primary or lower set of suspension cables. In the mainspan, tie-rods located between the primary cables (1865) and upper, secondary cables (1895) transmit a portion of the same forces to the secondary cable system. The condition of the suspenders and tie-rods is obviously an important factor in determining the overall strength and condition of the suspension spans. Unfortunately, little information can be gained from visual observation alone. Testing of representative suspenders and tie-rods is the only certain method of evaluating the ultimate strength of these members.

The first set of plans prepared during Phase II dealt specifically with the removal of four sets of suspenders and tie-rods from roughly the third points of the mainspan (panel points L40 and L'40). Suspenders and tie-rods were removed intact by using floorbeam hangers to temporarily sustain the loads usually carried by the suspenders and tie-rods (Figure 5). Four tie-rods and twelve suspenders were shipped for testing to Construction Technology Laboratories and Fritz Engineering Laboratory at Lehigh University for modal analysis and destructive testing, respectively. Results of the modal analysis of the tie-rods enabled non-destructive testing of any number of similar tie-rods on the bridge to determine actual loads in those members. Results of the destructive testing were used in determining the ultimate strength of these members, the mode of failure, and the extent of internal deterioration of the wire rope and sockets.

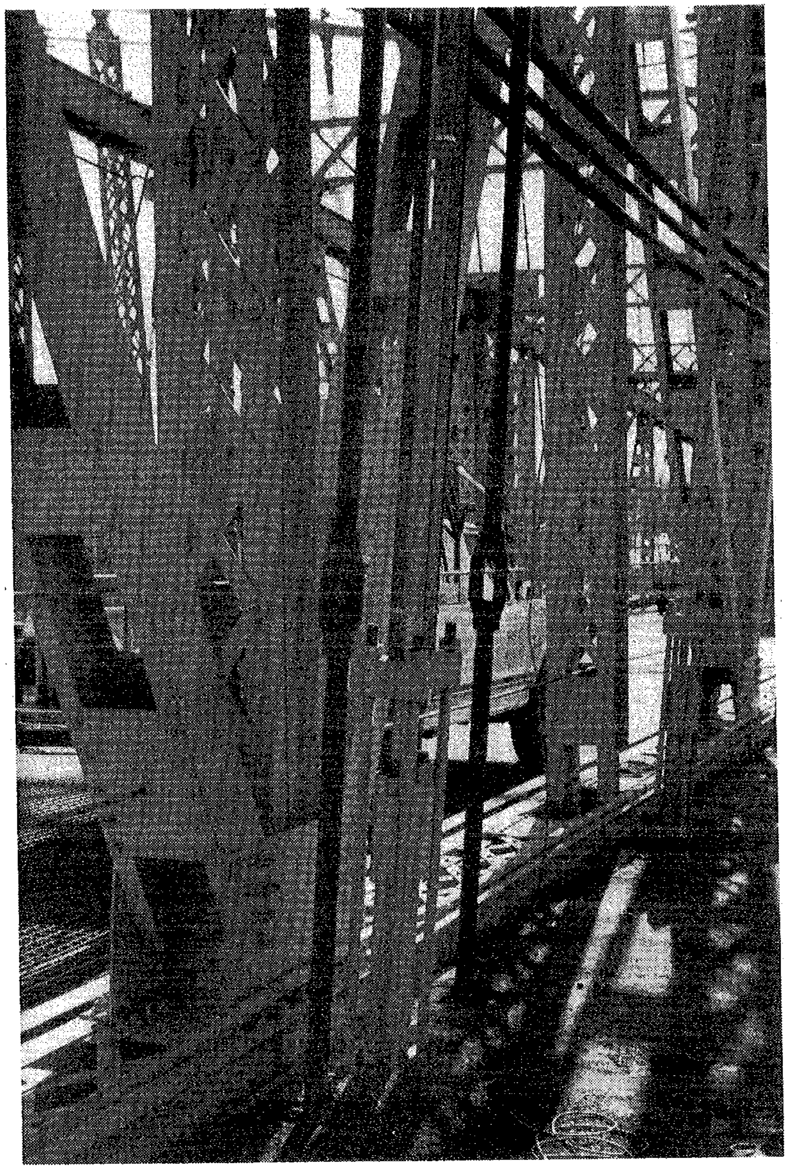


FIGURE 5. TEMPORARY FLOORBEAM HANGER IN POSITION, READY FOR REMOVAL OF SUSPENDERS

Once the suspenders and tie-rods were removed, the cable bands that attach these elements to the suspension cables could be removed along with four-foot sections of the wrapping wire to reveal the massed individual wires of the suspension cables. The eight unwrapped locations (four primary and four secondary) permitted an examination of the exterior surfaces and a portion of the internal wires surfaces by wedging apart the wires with plastic or wooden wedges (Figure 6). This was the first such examination conducted on the suspension cables, outside of the anchorages and tower housings, perhaps since the cables were originally wrapped. The findings of these investigations were of primary importance in evaluating the overall condition of the suspension cables.

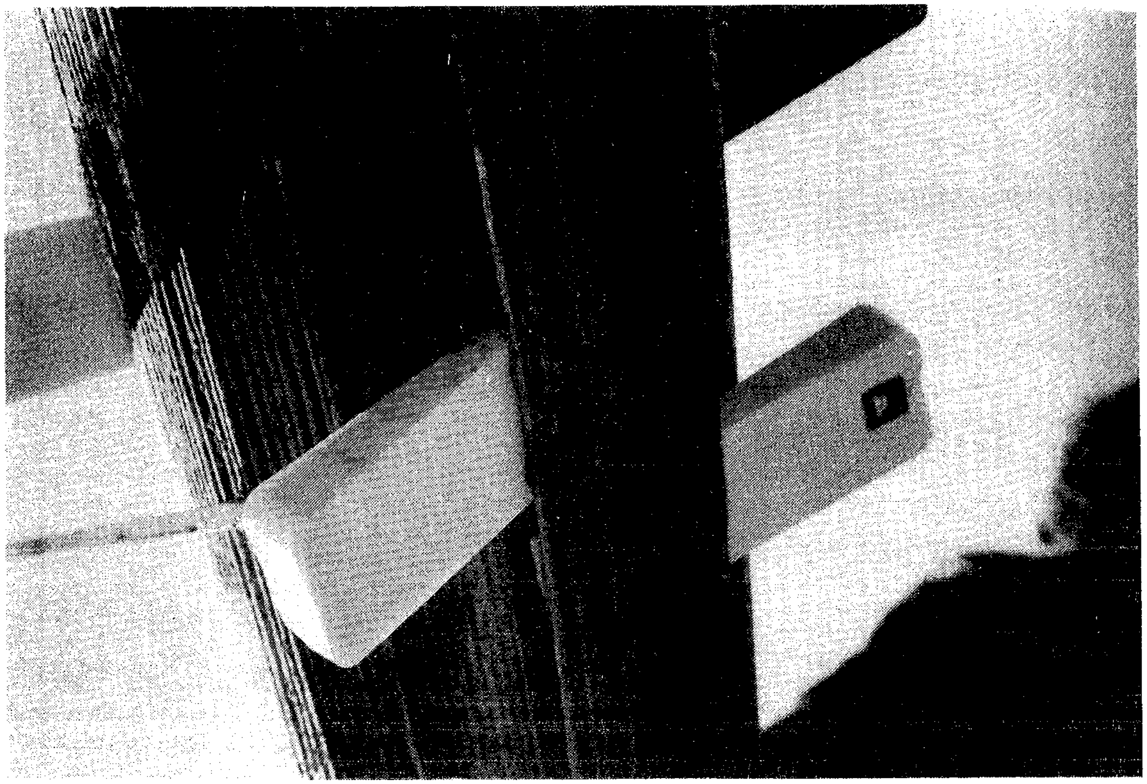


FIGURE 6. PLASTIC WEDGES USED TO EXAMINE THE INTERNAL WIRES OF THE SECONDARY SUSPENSION CABLE

Once the investigations were completed, the suspension cables were rewrapped with galvanized steel wire. Replacement components for the suspender ropes, sockets, tie-rods and cable bands have been designed similar to the original elements based on exact field measurements of the original pieces. The replacement components were installed and the temporary floorbeam hangers removed. The newly installed elements were painted to match the adjacent color, and are indistinguishable from the other elements to the untrained eye.

This set of plans was let for bids by the Transportation Cabinet on May 19, 1989. The successful bid for this work was $222,184, and the Contractor for this portion of the project was Judy C. Harp Co., Inc. of Frankfort, Kentucky.

REPAIR PLANS (CONTRACT II)

Unlike the Suspender Replacement Plans, which focused on only a specific location on the bridge, the Repair Plans addressed repair of a variety of elements located throughout the bridge. The types of repair and the historic aspects of each is discussed below.

Abutment 1 Repairs included removal and replacement of loose and spalling concrete on the abutment breastwall and concrete bearing pads. A sliding bearing was installed under each of five girders to prevent recurrence of the problem. Since the original construction of Abutment 1 dates only to the mid-1950's, this repair was of little historical significance.

Tower Stairways attached to the southeast corners of the masonry towers and extending from the sidewalk to the tower tops were removed and replaced in this plan set. The stairways date from the 1890's reconstruction. Prior to that time, access to the tower tops was achieved by climbing a wire rope ladder to an opening at the base of the arch above the roadway and thence to the roof via a narrow masonry stairway and wooden ladders. Over nearly one hundred years, the exterior stairways had deteriorated to the point where they were hazardous to use and, therefore, were an obstacle to routine maintenance of the rooftop and cable saddles.

In the early development of this plan set, consideration was given to various means of replacing the exterior metal stairways with other less conspicuous means of access. Ladder systems, original wire rope ladders, winches, etc. were all considered, but a similar exterior stairway system was viewed as the most effective way of moving maintenance personnel and materials to the roofs.

A similar system of stairways and landings was designed based on extensive field measurements (Figure 7). Certain safety improvements were made, such as the replacement of steel plate treads and landings with an open grid design for better traction and less retention of water, the addition of toeboards to the landings, and the use of steel tubing in the handrails for appearance and more comfortable gripping.

Upon removal of the existing stairways, old anchor bolts were removed, and the voids were filled with a non-shrink grout. The new stairways were anchored by stainless steel threaded anchor rods. Upon completion, the new stairways were painted with an earth-tone color to blend with the color of the sandstone masonry. From a distance, the towers do not appear materially different, but their graceful form is enhanced by the subdued appearance of the stairways.

Sidewalks resurfacing, originally included in this plan set, was deferred to a later phase.

Structural Steel Repairs were performed at approximately 150 locations scattered throughout the suspension spans. These repairs included:

- three types of repairs for cracks and section losses in floorbeams
- installation of new bearing plates on certain stringers to prevent vertical movement
- complete replacement of four stringers due to extreme corrosion and cracking
- plating and welding of cracked crossbeams
- three types of repairs to the steel grid deck
- welding of cracked teeth in the finger-type expansion dam located at midspan of the mainspan
- welding of truss pins at problem locations to prevent shifting
- two types of lateral bracing repairs and installation of new bracing at 16 locations.

This extensive list of repairs might cause concern to one unaccustomed to bridge maintenance; however, these repairs are considered quite typical for a bridge of this age, complexity, traffic volume, and elapsed time since the last major repair effort.

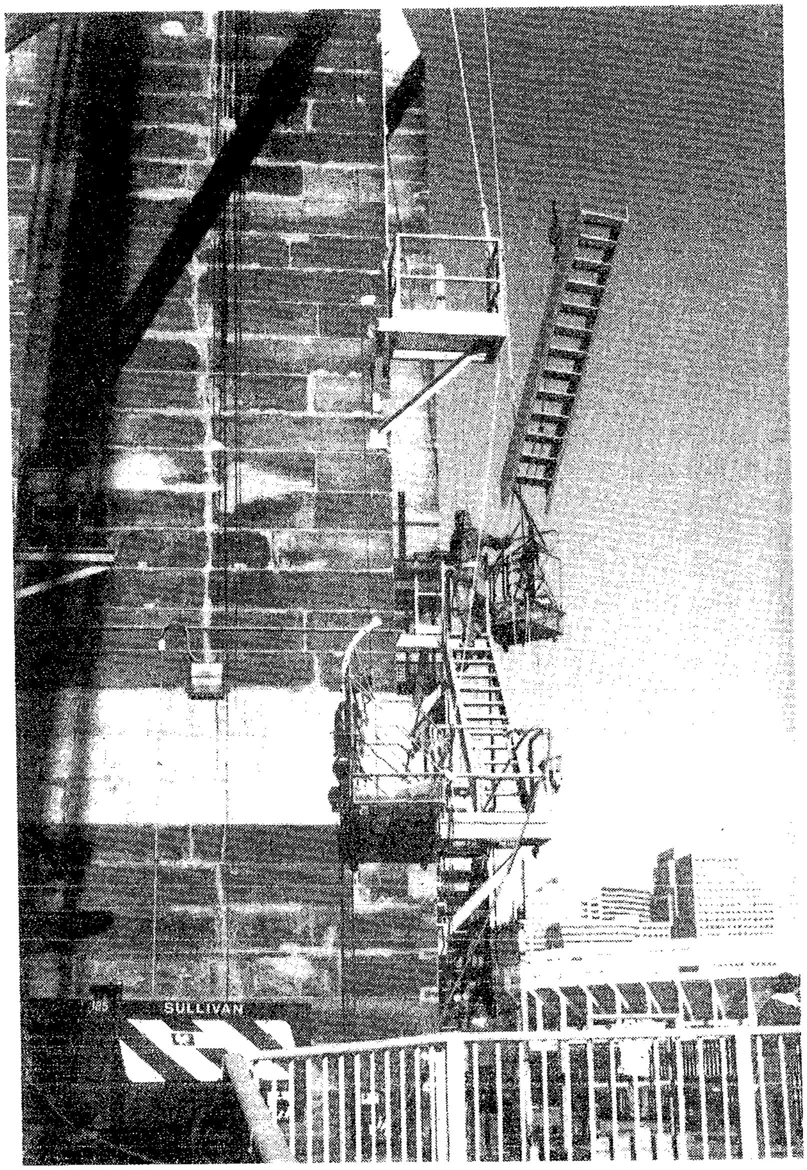


FIGURE 7. INSTALLATION OF THE NEW STAIRWAY ON THE COVINGTON TOWER

Steel repairs were accomplished using a variety of methods. Welding, addition of plates, and drilling of holes were methods used to deter crack propagation. Certain clip angles, stringers, and bracing were replaced with new members of the same sizes based on actual field measurements. One major difference is that original rivets were replaced with high-strength bolts at repair locations. Today, riveting is essentially a lost art. Most of the structural steel repairs are within the floor system below deck level and are not noticeable by motorists or pedestrians. All repairs were painted to match the adjacent color.

The Transportation Cabinet accepted bids for the completion of this repair work on November 17, 1989. The contract was awarded to Kay & Kay Contracting, Inc. of London, Kentucky with a low bid of $838,410.

MASONRY RESTORATION PLANS (CONTRACT III)

This effort was perhaps the most significant of the rehabilitation effort in terms of historic preservation. The rehabilitation efforts of this set of plans covered two main categories of restoration - 1) complete reconstruction of the turret housings and rooftops of the masonry towers and 2) cleaning and restoration of the exterior masonry surfaces of the towers and anchorages.

Turret Housings and Rooftops

In 1867, in "A Full and Complete Description of the Covington and Cincinnati Suspension Bridge," E. F. Farrington, Master Carpenter of the original construction described the tops of the newly-completed towers as :

> "finished with a paneled (sic) stone balustrade, 4 feet high, above the cornice. Two brick turrets, covering the saddles which support the cables, are carried up on each tower 30 feet high, and surmounted by a galvanized iron ball and a Greek cross, of the same material--making the full hight (sic) from foundation to the top of the cross about 240 feet."

The tower tops lasted in this configuration for less than 30 years, when, in the 1890's, the brick turrets and ornamental spires were removed to accommodate an additional pair of suspension cables. After recabling, the tower saddles were protected with brick domes and wooden sheds.

Severe deterioration of the domes, wooden sheds, tower roofs, and cornices was discovered during the 1987 inspection. The brick domes and wooden sheds were of such dilapidated condition that pigeons had converted the housings into rookeries which had a detrimental effect on the suspension cables therein.

The sandstone and cement mortar roofs were also showing signs of spalling. Of greater concern was the extensive delamination of the masonry blocks below the cornice and above the roadway. A decision was made to replace the domes, repair the masonry deterioration, install a roof drainage collection system, and seal the roof from damaging water as much as possible.

Replacement of the existing domes presented an opportunity to return a portion of the bridge to its more elegant, pre-reconstruction appearance. It was felt that a historically accurate reproduction would enhance the appearance and awareness of the historic landmark. Fortunately, among the sketches discovered in the Roebling Library was a rough sketch, with dimensions, of the original brick turrets (Figure 8). Based on examination of old photographs of the bridge, the design in the sketch appears to be the design actually used on the bridge. The sketch and dimensions have been reproduced in this plan set for comparison to the proposed design. The design for the new turrets was necessarily modified to accommodate the secondary cables--just as was necessary in the 1890's.

Prior to removal of the existing domes, which were nearly 100 years old, their appearance was documented in a detailed series of drawings showing the interior and exterior features of the domes and housings (Figure 9). That sheet was included in the plan set and was used to indicate those items to be removed.

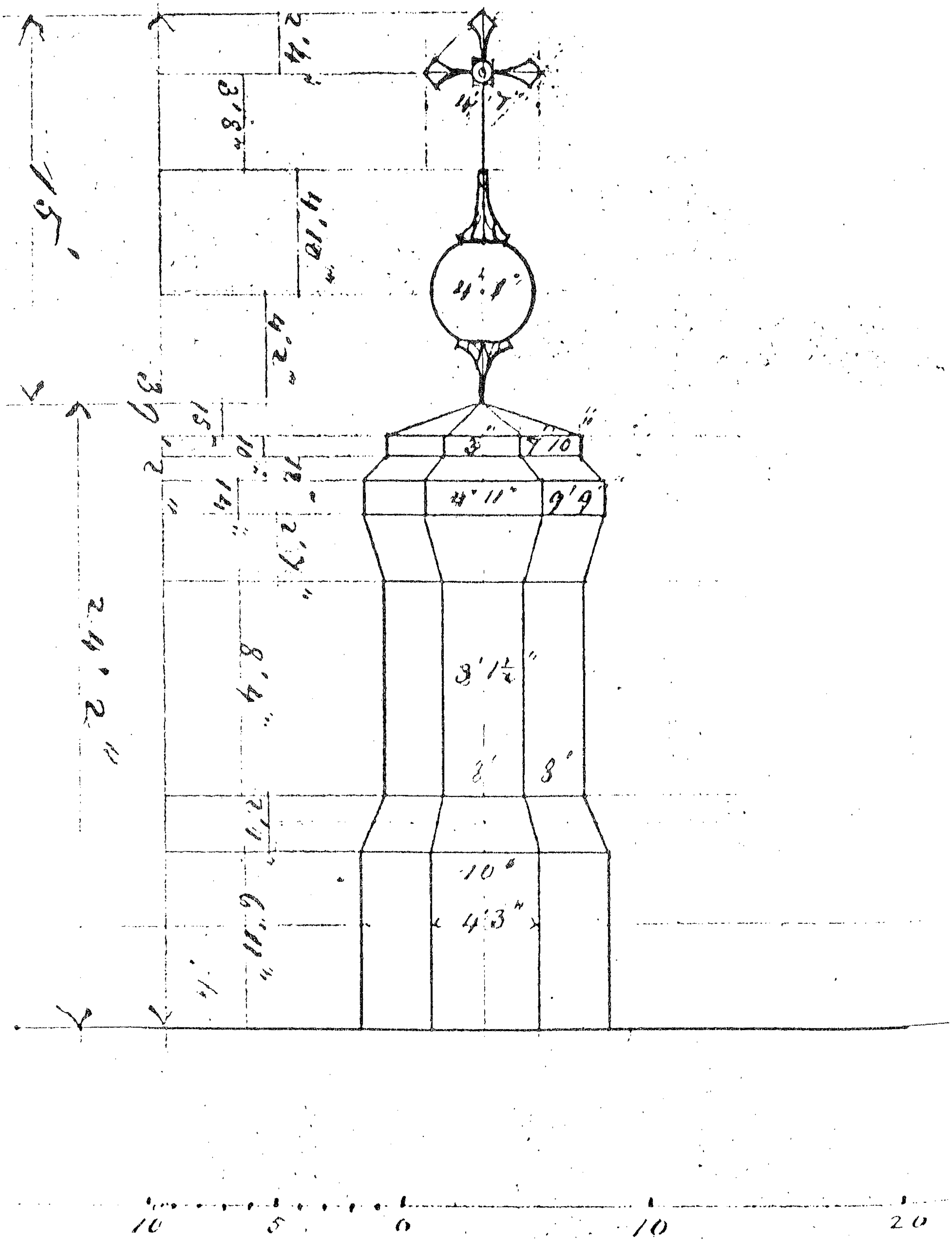


FIGURE 8. DIAGRAM OF ROEBLING'S ORIGINAL TURRET DESIGN

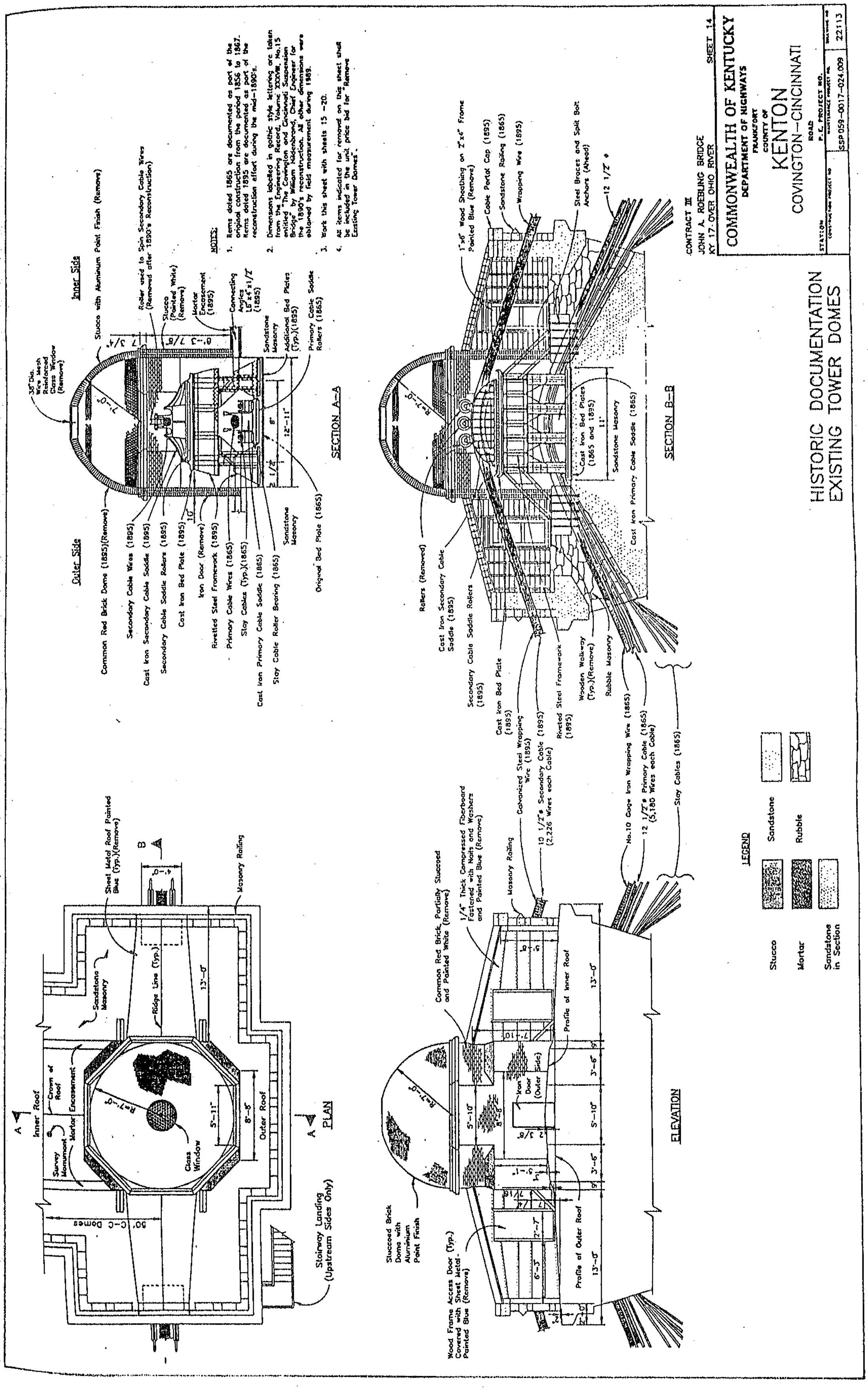


FIGURE 9. HISTORIC DOCUMENTATION PRIOR TO REMOVAL OF THE EXISTING TOWER DOMES

During construction, the existing domes and housings were removed first. At the same time, the cement encasement on the floor between the domes was removed along with loose sandstone near the railings. All surfaces were then thoroughly cleaned of pigeon waste and other residue by vacuuming, water jets, and sandblasting as appropriate. At this time, additional photographic documentation was obtained for the rooftop and saddles in their uncovered and cleaned condition. Many parts indicated in old drawings were previously unseen due to encasement, inaccessibility, or coverings of debris.

Once removal was complete, the center portion of the rooftop was protected with concrete encasement formed to the same lines and grade as the original encasement. Metal gutters, similar in design to another sketch found in the Roebling Library files, were inserted into the sandstone near the railing above the roadway and grouted into place. Gutter flumes extend through the masonry railing to direct the runoff away from the cornice. This drainage system should be effective at reducing the rate of deterioration of the masonry below the cornices. The entire roof was then given an application of waterproofing material.

The turret housings were reconstructed with an octagonal structural steel frame, covered with composite brick and concrete block walls that extend longitudinally to go from railing to railing. The structural steel frame was topped with an octagonal brick chimney (Figure 10). Improved lighting (both natural and artificial) and access for maintenance personnel were provided in the new design. Roof areas were covered with standing seam copper roofing. Walls were constructed of bricks, selected to mimic the appearance of the existing sandstone. Holes were plugged at the cable entrances to prohibit entry of pigeons. The new turrets were crowned with a gilded stainless steel ball and Greek cross representative of the original design. Stainless steel was selected in lieu of the original galvanized iron for reasons of weight, ease of erection, and minimal maintenance. It was theorized that from the ground, stainless steel with a brushed finish would be indistinguishable from galvanized iron. This theory was never tested, since funds were raised to further enhance the ornaments by gilding.

The contractor elected to fabricate and gild the ball and Greek cross as one unit in the shop. The octagonal steel frame bases clad in copper were also shop assembled. The individual units were trucked to the site, where the ornaments were mounted on the bases (Figure 11). Final touch-up gilding was done while the assemblies rested in the parking lot adjacent to the Ohio approach. The next day, March 7, 1992, the bridge was closed to traffic, and the ornament assemblies were lifted one by one using a heavy-duty helicopter and positioned on the finished turrets (Figure 12).

Exterior Masonry Surfaces

The other major restorative effort in this set of plans consisted of selective replacement of damaged masonry blocks, repairs to prevent further deterioration, and general overall cleaning of the entire masonry surfaces of the two towers and eight anchorages. A series of ten typical repairs for damaged, missing, and delaminated masonry was developed to include:

- installation of new masonry blocks or portions of blocks
- reattachment of delaminated and spalling masonry using epoxy injection techniques
- grouting of cracks
- pointing deteriorated joints
- patching deteriorated masonry areas with colored concrete
- refacing intact but weathered blocks by bushhammering
- resetting loose blocks

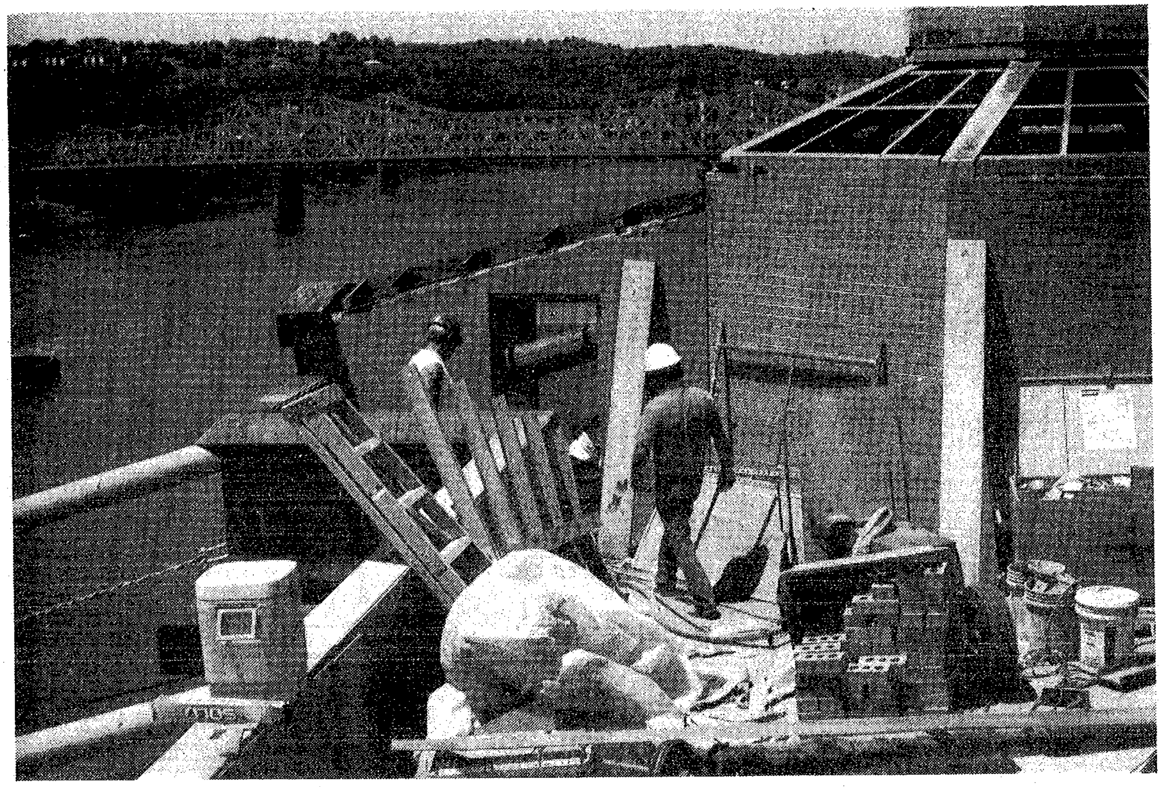


FIGURE 10. NEW TURRET HOUSINGS UNDER CONSTRUCTION

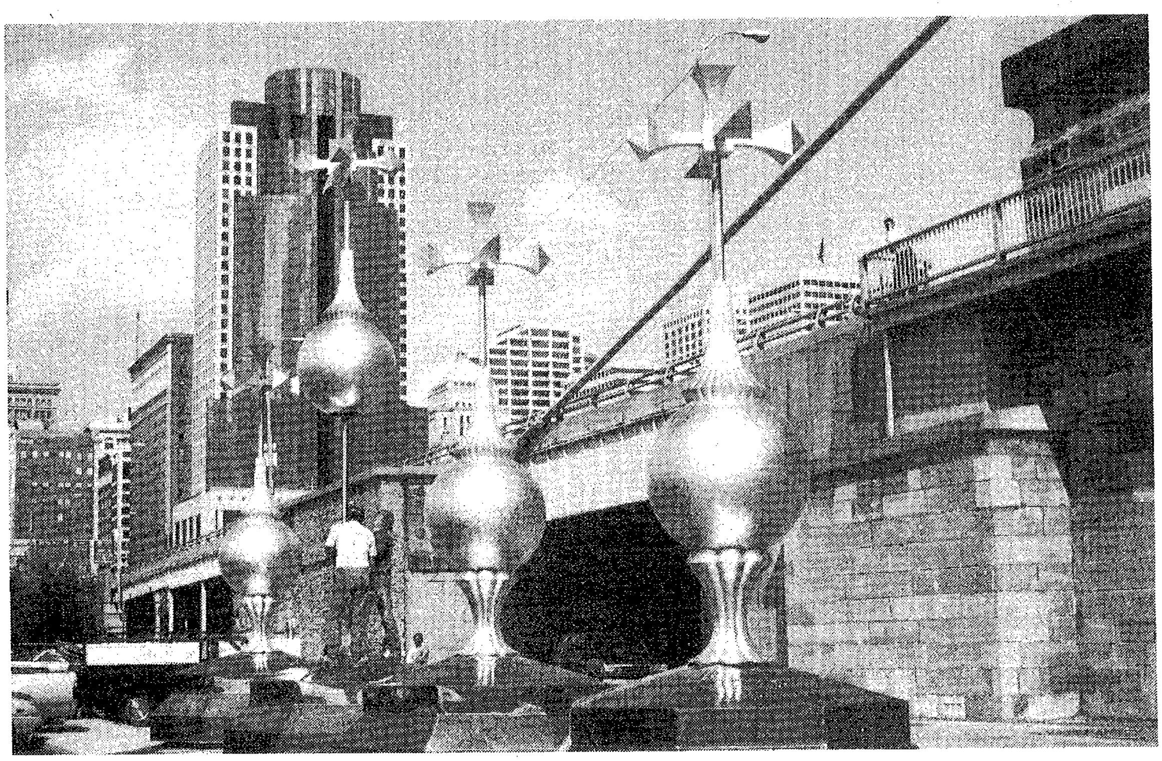


FIGURE 11. ATTACHING THE GILDED BALL AND GREEK CROSS ORNAMENTS TO THE PEDESTALS

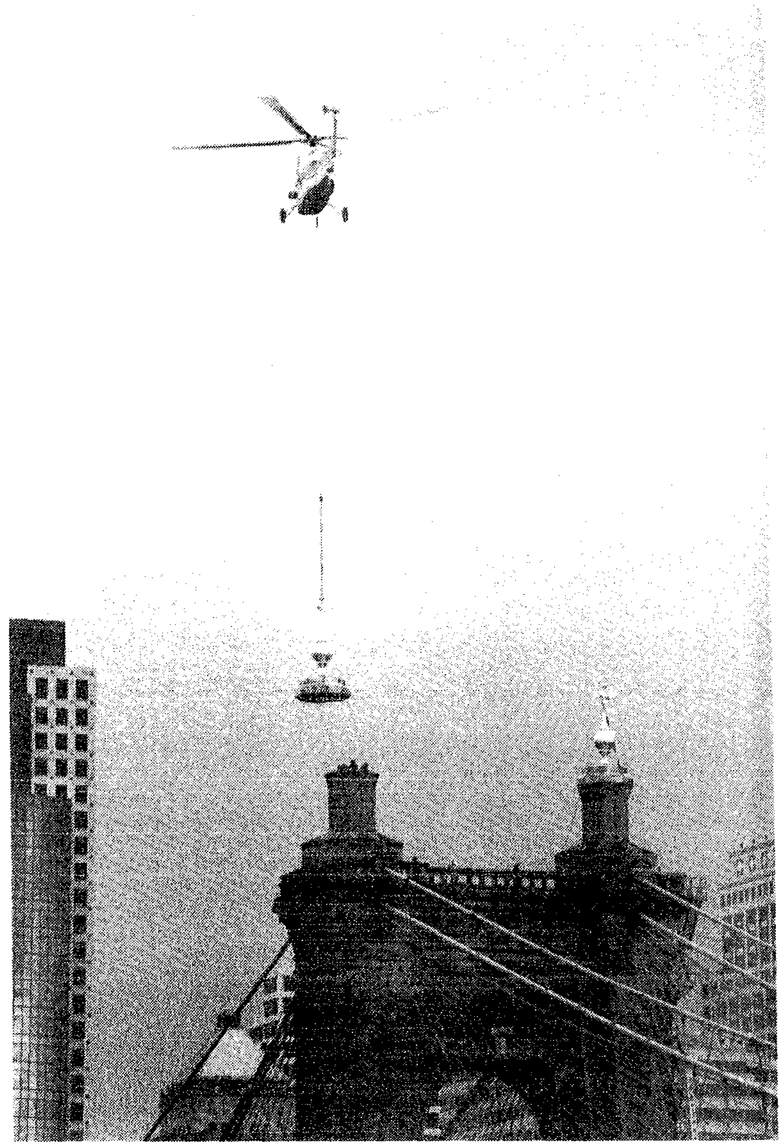


FIGURE 12. LIFTING THE ORNAMENTS IN PLACE BY HELICOPTER

New sandstone and limestone blocks used in the various repairs were selected to match the existing blocks in color and texture (Figure 13). The original stones were obtained from quarries in Buena Vista, Ohio (sandstone) and North Vernon, Indiana (limestone). The source of replacement sandstone, found near the bridge site, was one of the old unused Ohio approach piers of the L&N Railroad Bridge located about 4,000 feet upstream from the bridge site. These stones were of similar size and texture to the stones in the Roebling Bridge.

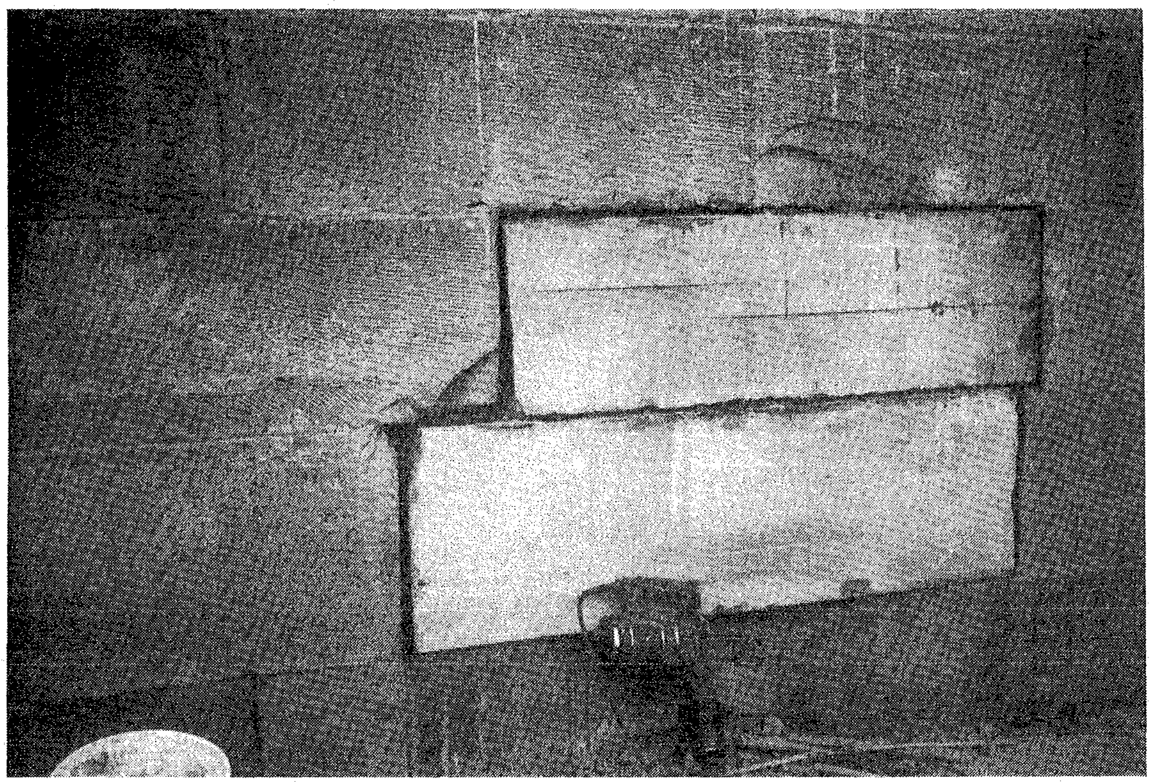


FIGURE 13. NEWLY INSTALLED MASONRY BLOCKS PRIOR TO APPLICATION OF A BUSHHAMMERED FINISH

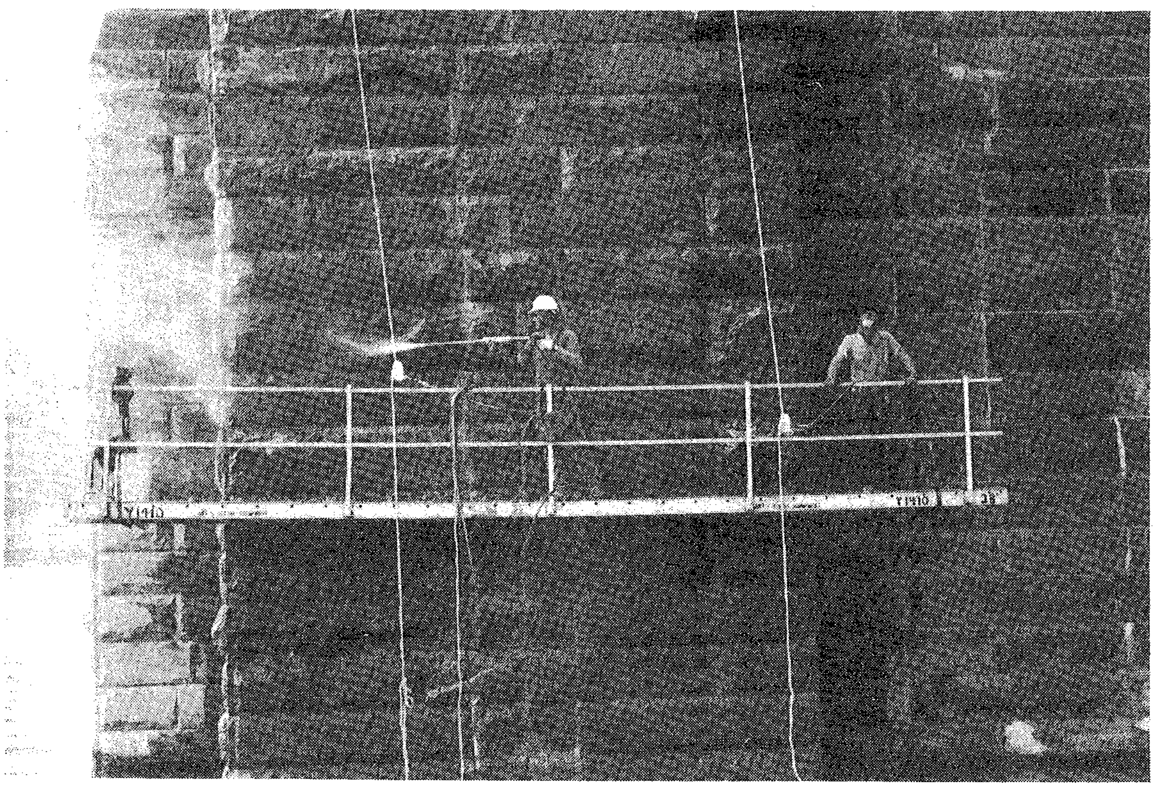


FIGURE 14. CLEANING TOWER MASONRY WITH WATER JETS

After the masonry repairs were completed, the entire surface of the towers and anchorages were cleaned from the top down to the river or ground level. Cleaning entailed a variety of methods including removal of tar with solvents, removal of spattered paint using paint stripping agents, and general washing of the entire surface with water jets and hand scrubbing with brushes (Figure 14). Prior to the use of any of these methods, test cleaning was performed on a representative area in an inconspicuous location. The most effective methods that removed accumulated grime yet did not damage the surface texture of the masonry blocks were employed. Sandblasting of sandstone was not permitted. The intent was to retain the mottled appearance of the sandstone masonry blocks caused by the variation in sandstone color and the natural crust that develop on the petroleum impregnated stones. Light sandblasting of limestone surfaces was permitted due to its greater degree of hardness.

Abandoned Utility Removal

Abandoned Utilities were identified for removal. Utility companies were contacted to determine which unused lines were candidates for removal. Certain telephone cables on the bridge were removed once installation of a new fiber optic cable was complete. This much smaller cable greatly reduced the visual clutter caused by the utility conduits on the bridge.

The Transportation Cabinet accepted bids for the Masonry Restoration Plans on July 27, 1990. The contract was awarded to H. G. Mays Corp. of Frankfort, Kentucky with a low bid of $3,005,503.

REPAIR PLANS (CONTRACT IV)

This set of Repair Plans includes a variety of repairs similar to Contract II. These repairs, however, were of a lesser degree of urgency than the earlier repairs, so they were grouped together in this set for letting after the Masonry Restoration Plans. The various repairs are described below.

Ohio Approach Deck Replacement is the most significant effort in this plan set. The 1987 inspection noted a poor condition of the concrete deck and associated deterioration of the structural steel below. The deck in this location is composed of a concrete fill on a steel trough plate and buckle plate floor. The steel plates date back to the 1890's reconstruction. Concrete sidewalk and curbs were added in 1971 along with a sand asphalt overlay.

The concrete fill and steel plates will be removed from the approach spans. Prior to removal, the steel trough plates and buckle plates will be photographed, since this type of deck support system has been replaced by other, more modern stay-in-place form systems. The structural steel supporting members will be modified to support a thinner, 8" concrete deck. Deteriorated structural steel will be replaced with new stringers, floorbeams, and crossframes. Steel shapes will be matched where possible, but connections will be either welded or bolted in lieu of riveting. Spalled concrete pedestals at the bases of the supporting columns will be replaced with new concrete and reinforcement to the same shape as the originals. All new structural steel will be painted to match the adjacent color. This rehabilitation will reduce the dead load weight of the spans, and will protect the elaborate steelwork below from further deterioration caused by surface runoff.

Cable Repairs will be performed on tie cables, stay cables, stabilizer cables, lower lateral cables, suspenders, and their associated components in a variety of locations. All tie cables, which are connected to the stays for dampening of harmonic motions, will be replaced due to excessive section losses and breaks at the contact points with the stays. The wire tie cables will be replaced in kind and will be painted to match the adjacent color. Stabilizer cables, lower lateral cables and fasteners will be replaced at all locations in a manner similar to the tie cables.

Sidewalks of the suspension spans will be resurfaced with the same sand asphalt surface used since the 1930s. The most recent prior resurfacing was completed in 1971 on the east sidewalk. The existing support system of aluminum corrugated sheets supported by six-inch deep stringers was found to be in good condition and was retained in the resurfacing design.

The design for these repairs is scheduled to be completed by the end of July 1992. The project will be advertised for bids sometime around September of 1992.

ANCHORAGE RESTORATION PLANS (CONTRACT V)

As its name suggests, this set of plans deals exclusively with rehabilitation of the eight anchorages that house the primary and secondary cable wires as they splay apart to connect to the eyebar chains that descend to the massive anchorage plates that restrain the cables. During the inspection significant internal corrosion was discovered in bulging strands caused by moisture leaking through the roofs. Broken wires were found in several locations. The repairs in the plan set fall into three major categories.

Cable Strand Restoration

Cable Strand Restoration procedures were developed for each of the eight anchorage chambers. First, the exposed metal surfaces were cleaned of all corrosion, and the interior masonry surfaces of the anchorages were cleaned of all debris. Each of 21 cable strands in the secondary anchorages and 28 strands in the primary anchorages were wedged apart row by row starting from the top (Figure 15). Once wedged apart, the strands were cleaned internally and broken wires were repaired using a system of press-on wire ferrules and new sections of wire. Each new section of wire was tensioned using a central, threaded ferrule that tensioned in a manner similar to a turnbuckle. After all repairs and cleaning were complete, the wires within the strand were painted and the strand rewrapped with seizing wire.

Anchorage Roofs

To prevent recurring damage to the cable strands, it was decided to cover the existing tar and foil-coated masonry roofs with a more watertight and aesthetically pleasing roof material. Because the new tower top turret roofs had been specified as a standing seam copper roof, the anchorage roofs (except for Anchorage 1 which has a concrete roof) were designed as copper roofs also. Prior to installation of the new roofs, the existing rooftop utility conduits were removed and any holes grouted closed. Treated wood and redwood were used as a permanent base for attaching the copper roofing.

Maintenance Enhancements

To encourage and facilitate future inspection and maintenance activities within the anchorages, several enhancements were made in the Anchorage Restoration Plans. Access ladders were added to the interiors of the secondary cable anchorages to allow direct access from the access passageway to the anchorage floor. Previously, an inspector or maintenance worker would have to clamber over the secondary cable strands to reach the anchorage floor. Another maintenance enhancement was the installation of from four to nine light fixtures in each anchorage chamber

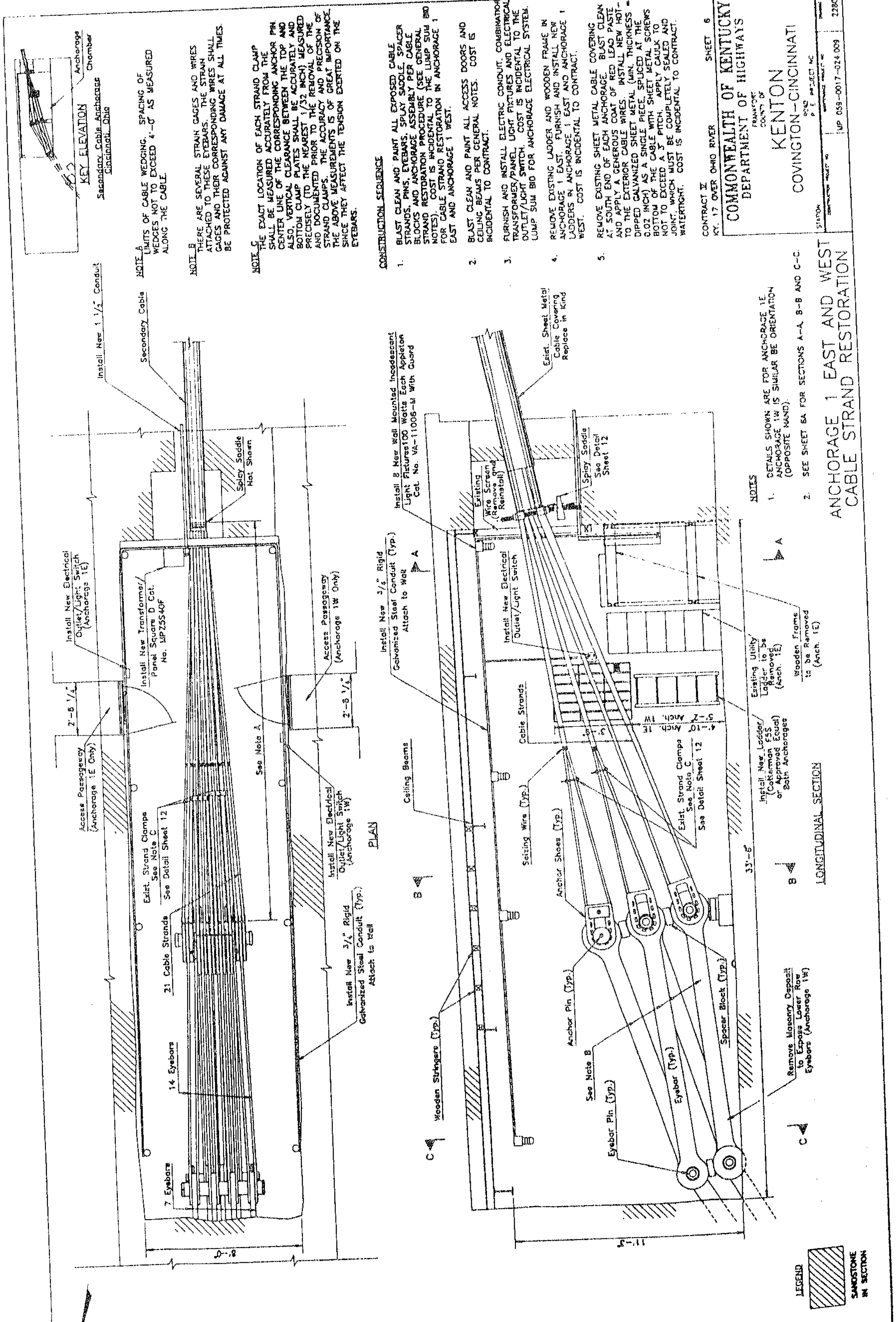


FIGURE 15. CABLE STRAND RESTORATION IN A TYPICAL ANCHORAGE CHAMBER

along with electrical outlets for power equipment. Previously, inspection and maintenance activity within the anchorages depended upon light and power supplied by portable generators.

The Anchorage Restoration Plans were bid on January 17, 1992. The Kentucky Transportation Cabinet awarded the project to H. G. Mays Corp. of Frankfort, Kentucky with a low bid of $894,725.

DRAMATIC TURRET LIGHTING AND ORNAMENTAL FENCING PLANS (CONTRACT VI)

Three major categories of work were accomplished in this set of plans - 1) dramatic lighting of the newly-installed tower-top turrets and ornamental spires, 2) replacement of existing fencing along the sidewalks at the towers with ornamental fencing, and 3) construction of a new stairway for pedestrian access.

Dramatic Turret Lighting

Decorative lighting of the bridge has existed since 1984, when funds were raised by the Covington-Cincinnati Suspension Bridge Committee to pay for the lighting installation. The new lighting, named the Julia E. Langsam Lights in honor of the late wife of a President Emeritus of the University of Cincinnati, included necklace lighting of the primary cables and lighting of the towers both above and below deck. One of the most noticeable features of the new lighting was the illumination of the flags positioned on tall flagpoles at the centers of the tower tops.

Installation of the new turrets and new ornamental spires created the need for compatible dramatic lighting. A new dramatic lighting system for the turrets was created to blend with the existing decorative system. The new system provided a series of four floodlights mounted on the diagonal faces of the octagonal brick walls of the lower turrets. These floodlights are pointed upward to illuminate each gilded ball and Greek cross ornament. To avoid the creation of shadows caused by the high angle of the lower lights, additional lights were specified -- two roof-mounted lights to highlight the interior face of each ornament and two mast lights to highlight the outward face. In addition, four floodlights mounted on the lower, interior surface of each turret barrel shines upward into the white-washed barrel to create an internal glow from the eight glass block window slits spaced around the turret barrels.

Ornamental Fencing

When originally constructed in the 1860's, the Covington-Cincinnati Suspension Bridge had a narrow walkway around the outside roadway level of each tower. Pedestrians were protected by an ornamental fence set into the masonry ledges surrounding the towers. The locations of the old railings where they connected to the masonry are still viable to anyone willing to crawl below the existing sidewalk. At some point in time, the sidewalks were widened to their present configuration consisting of a concrete deck with aluminum handrails cantilevered away from the tower. Apparently, criminal activity perpetrated from the sidewalk corners away from the traffic flow created the need for fenced enclosures of these corners. The existing chain link and barbed wire fencing had fallen into disrepair and was an eyesore. It was decided to replace the existing fencing with new ornamental security fencing. Although design of the fencing could not conform entirely with earlier design by Roebling for security reasons, the lattice and rosette pattern illustrated in his original design (Figure 16) was used as a decorative aspect of the new design.

New Stairway

> Construction of a new stairway for the west side of the Ohio Approach was included in this plan set. This additional stairway was needed to provide safer access and to balance pedestrian flow across the bridge during Riverfront Stadium events. The design of the new stairway closely conforms to the design of the existing stairway constructed in 1971 on the east side of the bridge.

The Kentucky Transportation Cabinet opened bids for the Dramatic Lighting and Ornamental Fencing Plans on April 10, 1992 and awarded the contract to H. G. Mays Corp. of Frankfort, Kentucky with a low bid of $191,757.

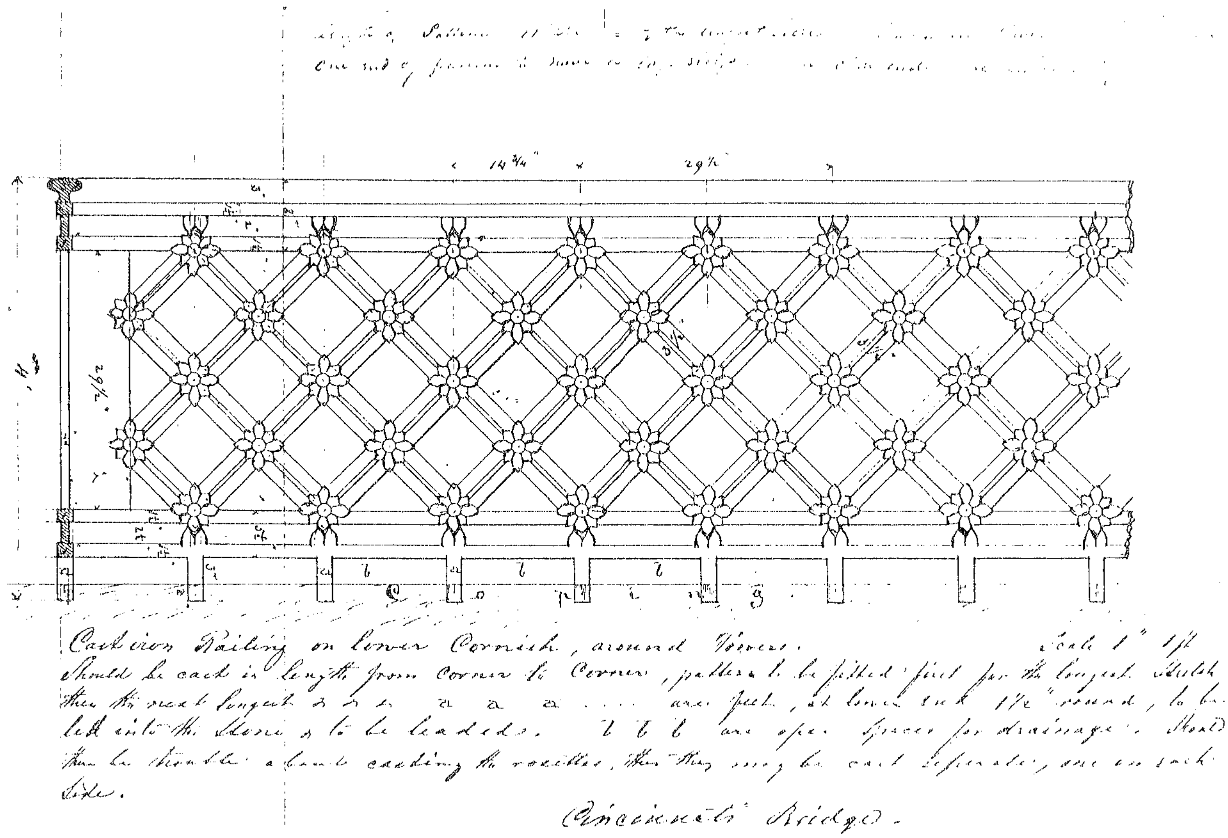


FIGURE 16. ORIGINAL RAILING DESIGN BY JOHN ROEBLING, 1865

STRUCTURAL RATING ANALYSIS AND SURVEYING

Though not having a direct effect on the historical character of the Roebling Bridge, the structural rating analysis and surveying performed in Phase II played a great part in further understanding of the response of the structure to load, temperature, and deterioration. The rating analysis used live load testing, modal analysis, manual calculations, and a computer model of the unique cable system to identify crucial elements in the overall structural system of the bridge. The field surveying effort provided much needed data for design and established a system of permanent monuments for continued monitoring of bridge motions. Results of the surveys were used for comparison of predicted behavior to actual live load response. The results of these analyses are beyond the scope of this report, but have been documented elsewhere.

CONCLUSION

At the time of this writing, the Suspender Replacement Plans (Contract I and the Repair Plans (Contract II) are completed. The Masonry Restoration Plans (Contract III) is nearly finished (Figure 17); and the Anchorage Restoration Plans (Contract V) and Dramatic Lighting and Ornamental Fencing Plans Contract (Contract VI) are well underway. The second set of Repair Plans (Contract IV) will be bid in late summer.

Although much of the rehabilitation work on the bridge remains to be done, the efforts completed thus far have gained recognition. The organization Cincinnati Beautiful has given an award to the Covington and Cincinnati Suspension Bridge Committee for their involvement in the preservation of the John A. Roebling Bridge. Since the installation of the new turrets and spires, the local citizenry has developed a renewed interest in their landmark bridge. We believe that John Roebling would also be pleased, as one can detect the pride which he felt in his greatest achievement up to that time in his report to the stockholders of the Covington & Cincinnati Bridge Company, 1867:

> "It is scarcely deemed necessary to say to you that the bridge is a complete success; perhaps no work of its magnitude has ever been more so--the wonder and admiration of all who cross it--and in the future there will doubtless few visit the city of Cincinnati, or its vicinity, who will not cross this magnificent structure.
>
> The final completion of the bridge will still require some two or three months, the finishing of the sidewalks, the ornaments on the tops of the towers, and the necessary offices for the company's use remaining yet to be completed.
>
> In finishing this great work we feel warranted in saying that it must ever remain an ornament to both cities, and the chief point of attraction in the locality to visitors from the vicinity or from abroad."

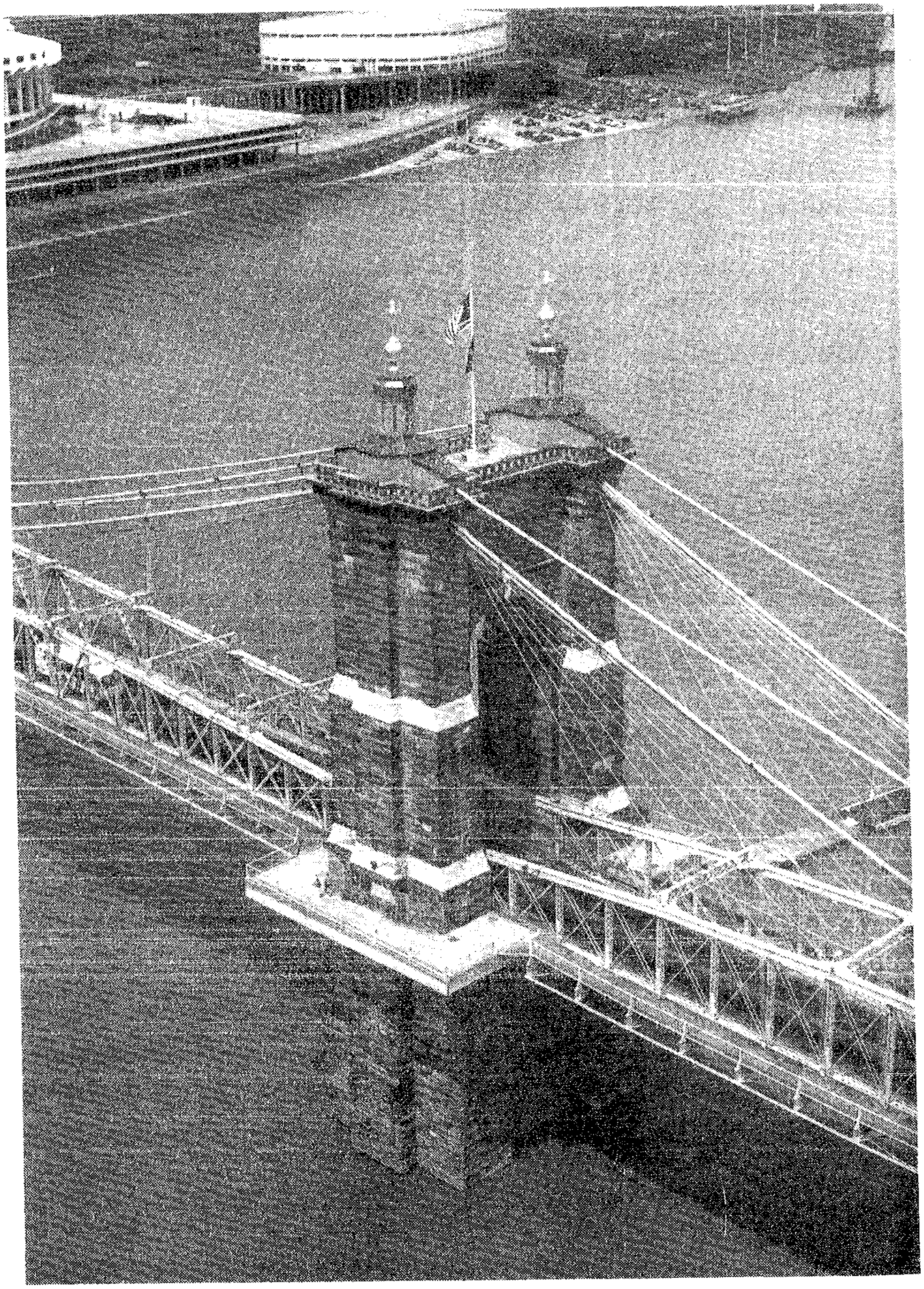


FIGURE 17. AERIAL VIEW OF THE RESTORED COVINGTON TOWER, JUNE 12, 1992

CONTRIBUTORS TO THE RESTORATION EFFORT

The following persons have made key contributions to the design and management of the repairs and rehabilitation of the John A. Roebling Bridge:

Kentucky Transportation Cabinet, Department of Highways:

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- William A. Crace, P.E., Bridge Inspection Program Engineer
- Glenn A. Givan, P.E., L.S.,
- Donald R. Herd, P.E.,

Division of Bridges:

- Stephen E. Goodpaster, P.E.
- William J. Lynch, P.E. (Retired)

Parsons Brinckerhoff Quade & Douglas, Inc.:

- William H. Allen, P.E., Principal-in-Charge
- Frank P. Balsamo, P.E., Project Manager
- William F. Hollingsworth, P.E., Technical Director
- Raymond G. Robison, Jr., P.E., L.S., Deputy Project Manager
- Richard M. Drewery, P.E.
- Masoud H. Taheri, P.E.
- Jeffrey L. Arnold, P.E.
- Michael A. Hudson, P.E.
- James O. Polley, L.S.
- K. Darrell Bolin

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