

HISTORIC AMERICAN ENGINEERING RECORD

FREMONT BRIDGE

HAER No. OR-104

Location: Spanning the Willamette River, carrying Interstate 405 northbound and southbound, Multnomah County, Oregon

Date of Construction: 1969-1973

Design Engineers, Tied Arch Structure Including Piers: Parsons, Brinckerhoff, Quade & Douglas, New York, with Architectural Consultant, Harrison & Abramovitz, New York

Public Involvement Design Team: Portland Art Commission, with Werner Storch & Associates And C.B.A. Engineering, Vancouver, B.C., Canada

General Contractor and Steel Erector, Tied Arch Structure: Murphy Pacific Corp., Emeryville, Ca., with erection consultants, Earl and Wright Consulting Engineers, San Francisco

Steel Fabricators, Main Girders/Arch: Other Components: Murphy Pacific Corp., fabrication yard, Richmond, Ca. American Bridge Division, United States Steel, South San Francisco and Gary, Indiana plants

Pier Construction: Peter Kiewit Sons' Co., Omaha, Nebraska

Design Engineers, East and West Approaches: Contractors, West Approaches: Howard, Needles, Tammen & Bergendoff, Kansas City, Missouri
Anderson-Hannan, Portland, a joint venture (Contract 1);
Drake-Willamette, Portland, a joint venture (Contract 2);
Willamette Western Corp., Portland, sub-contractor for steel erection

Contractors East Approaches: Drake-Willamette (Willamette River Contractors), a joint venture;
E. Carl Schiewe, Portland (buildings)

Owner: Oregon Department of Transportation

FREMONT BRIDGE
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Present Use: Vehicular traffic only

Significance: Opened in 1973, and the epitome of high-tech, the graceful Fremont Bridge is still both the longest bridge (main span) in Oregon and the longest tied arch bridge in the world. Its 6,000-ton center span lift was the heaviest anywhere, accomplished with techniques and technology never used before at that scale. This erection method was selected because it had the least impact on navigation and the lowest cost. Innovative features include a weight-saving orthotropic deck and welded box girder and welded arch rib sections, with the arch ribs fabricated from high-strength quenched and tempered (T-1) steel. Fremont is one of only about eighty steel tied arch bridges in the U.S. Of the lower Willamette River bridges in Portland, Fremont is the only arch, with its unusual three-span tied arch design inspired partly by European engineers as a solution to site conditions. Fremont's final form was the result of unusual collaboration between the Oregon Department of Transportation; Parsons, Brinckerhoff, Quade & Douglas (Parsons Brinckerhoff, Inc.), the largest transportation design consulting firm in the U.S.; Portland Art Commission; and, because it was financed for the national system of interstate and defense highways, the Federal Highway Administration.

Historian: Sharon Wood Wortman, HAER Historian, 1 September 1999.

Project Information: Documentation of the Fremont Bridge is part of the Willamette River Bridges Recording Project, conducted during the summer of 1999 under the co-sponsorship of HAER and the Oregon Department of Transportation in cooperation with Multnomah County. It extends preliminary work conducted under the Oregon Historic Bridge Recording Project with the same co-sponsors in the summer of 1990.

Introduction

Portland, Oregon is a major port for ocean-going ships although it is located one hundred miles upriver from the Pacific Ocean. This makes Portland one of a handful of U.S. cities located on a river well inland, a geography shared with a few cities, such as Savannah, Sacramento, Philadelphia, Baltimore, New Orleans, Wilmington and Baton Rouge. Due to recreational gentrification during the past thirty years, little remains along the downtown waterfront to show why Portland, incorporated in 1851, succeeded because of its primary location between valley crops and the Willamette River waterfront. Physical reminders of a more industrial past are limited to five large movable bridges, two grain elevators, a barge builder and remnants of public docks and wharf walls.¹

A century before Fremont Bridge, an enabling act by Congress, passed 2 February 1870, allowed bridges to be built for the first time across the Willamette River in Portland.² However, no street bridges of any type were built until 1887. Beginning that year, and until 1973, twenty-one bridges of all three main bridge types and all three main movable bridge types were erected and re-erected between river mile 0 and river mile 26, from the confluence of the Willamette and Columbia rivers upriver to Oregon City. A total of fourteen spans, two of them railroad-only, and one a combined railroad and highway bridge, remain at the end of the twentieth century.³ (See Appendices 1)

When it opened 11 November 1973, planners said that Fremont would not solve Portland's inner city traffic woes, "but it should help ease them."⁴ Fremont was the second downtown Portland Bridge designed to be part of the national system of interstate and defense

¹ Nearer the confluence of the Willamette and Columbia, the river tells a different story. The port of Portland is Oregon's largest and most diversified port, exporting the second largest volume of goods on the West Coast in 1997. In addition to five marine terminals, the port leases the 125-acre Portland Ship Repair Yard. The ship repair yard handles more than 45 percent of all commercial repair work done on the West Coast. *Oregon Blue Book 1999-2000*, (Salem: Office of the Secretary of State, compiled and published by Phil Keisling, 1999), p. 194. All this activity is out of sight from Burnside Bridge, the city's geographic center and where east is divided from west, and north from south.

² George P. Sanger, ed., *Statutes at Large and Proclamations of the United States of America, from December 1869 to March 1871, and Treaties and Postal Conventions*, (Boston: Little Brown, 1971), vol. 16, p. 64.

³ Sharon Wood Wortman, "Portland's Bridges, Including Railroads & Interstate Highways, Willamette River Mile 0 to 26," (Portland: 1995 to 1998).

⁴ "Stadium Freeway 1-405" (Salem: Oregon State Highway Division), an undated brochure, ca. 1973, panel 6. On its first full day after opening, Fremont carried 35,350 vehicles. A 1997 Average Daily Traffic (ADT) count shows 57,650 vehicles a day crossing Fremont eastbound and 64,250 crossing westbound, for a total of 121,900 vehicles, second only to Marquam Bridge. ADT for the eight downtown core bridges is approximately 438,000 vehicles; with Sellwood and St. Johns, the total ADT come to 495,000. "Portland, Oregon Traffic Flow Map," City of Portland, Bureau of Traffic Management, 20 April 1998 (data collected 1993-August 1997)

highways, behind Marquam Bridge, opened in 1966.⁵ Fremont completed the inner city freeway beltway, or "loop" pattern designed to carry through traffic around the core Central Business District.⁶ The Eastbank Freeway and Marquam Bridge carrying north-south Interstate 5 were completed by the Oregon State Highway Department (renamed the Oregon Department of Transportation) in 1966, with the west side Interstate 405, also known as the Stadium Freeway, finished in 1968.⁷ The full stadium Freeway is 3.4 miles in length and was completed at a total estimated cost of \$129 million.⁸ Fremont Bridge carries I-405 over the Willamette River in Northwest Portland, the finishing touch in this 6.2 mile urban loop.⁹

During Portland's bridge building spree of the 1920s, a regional civil engineering journal described Portland's physical challenges:

⁵ On the lower twenty-six miles of the Willamette River, ODOT owns and maintains Oregon City Bridge, Abernathy (I-205), Ross Island, Marquam, Fremont and St. Johns, and maintains the highway deck on the double-decker Steel Bridge. Also across the water in the Portland area, ODOT co-owns and maintains Interstate Bridge and Glenn L. Jackson Bridge between Oregon and Washington States across the Columbia River. In all, the State owns and maintains about 6,500 bridges.

⁶ Several studies in the early part of the twentieth century proposed a bridge near Fremont's location between St. Johns and the Broadway Bridge, with an inner freeway loop configuration illustrated by Robert Moses in his comprehensive planning study for the City of Portland in 1943. City of Portland, Oregon, Robert Moses, et al, "City of Portland, Oregon Map Showing Portland Improvement," *Portland Improvement* (New York City: 10 November 1943). In 1927 the City Planning Commission issued a "Major Traffic Street Report," which proposed, among other projects, that a bridge be built in the general location of the present Fremont Bridge. The year before, New York bridge engineer Gustav Lindenthal, as a design consultant to Multnomah County for Burnside, Ross Island and Sellwood bridges and the Lovejoy Viaduct, proposed that an Interstate (Avenue) Bridge be built just down river of Fremont's location without piers in the river as deference to river traffic. *Multnomah County Bridge Journal*, "Record of the Proceedings of the Board of County Commissioners Pertaining to the Construction, Repair, Maintenance, Improvement and Reconstruction of the Broadway Bridge," 1 December 1926, p. 9. Also see Oregon State Transportation Committee Minutes, "Fremont Street Bridge Across the Willamette River Construction with Federal Funds Suggested, 4 November 1933," Oregon State Archives, p. 4448, par. 2. In a paper dated 28 March 1968 Edwards refers to a State study of 1955 that finally selected Fremont's site. Copies of Lindenthal's drawings for various never-built cantilever, suspension and arch bridges at three different sites on the lower Willamette are in 2'x2' binder at Multnomah County Central Library Wilson Room, Portland.

⁷ Larry W. Price, ed., *Portland's Changing Landscape*, Occasional Paper No. 4, April 1987, Portland, Oregon (Department of Geography, Portland State University and Association of American Geographers, 1987), p.43. Oregon was the first state to complete a toll-free interstate from border to border. Tom Lewis, *Divided Highways: Building the Interstate Highways*, (New York: Viking, 1997), pp. 211-212.

⁸ "Stadium Freeway I-405," panel 6

⁹ The author often takes school groups on urban field trips, with one exercise a circumnavigation of the inner city freeway loop by vehicle, timed with a stop watch. During non-rush hours and traveling at or below the speed limit, average time to complete the 6.2-mile circle, from Marquam Bridge to Fremont Bridge, is seven minutes, fifteen seconds.

Portland is so situated that traffic congestion is a serious problem. The business center is on the west side of the Willamette River while more than three-fourths of the people reside on the east side, thus necessitating many bridges. The city is hemmed in immediately west of the business district by a north and south ridge about a thousand feet high, known as Portland Heights, where many of the most attractive homes are located. The ridge¹⁰ is such a barrier that the city has rapidly extended easterly across the river for five or six miles, thus bringing about a peak-load congestion on the bridges of 100,000 autos per day and 5500 street cars.¹¹

The construction of Fremont's approach cleared a landscape, especially in Northeast Portland, but its main impact was along the waterfront. With Fremont opened, traffic could be diverted farther west, thus six-lane Harbor Drive closed and was replaced by Governor Tom McCall Waterfront Park.¹² Fremont's west interchange provided one-way eastbound access across Fremont's bottom deck from NW Glisan Street from the south, and NW Yeon Avenue and NW Vaughn Street from the north. When ODOT proposed Fremont Bridge in the mid-1960's, it was assumed that ramps planned for the east-end interchange would be connected with the Minnesota Freeway (I-5) and, eventually, with the planned east-west Rose City Freeway. The Rose City plan was abandoned, with Fremont's northwest exit ramp still used as exit to N. Kerby Avenue only.¹³ The simple connection that extended to NW 21st Street was reconfigured as part of an Interstate 505 extension project, with egress reworked and rebuilt to make a straighter, more direct connection to NW Yeon Street, St. Helens Road and U.S. Highway 30.¹⁴

Willamette River

¹⁰ The ridge is actually the fifteen-long Tualatan Mountain Range.

¹¹ Melville E. Reed, "The New Burnside Bridge, Portland, Oregon," *Western Construction News*, 10 July 1926, 20.

¹² *Changing Landscape*, 42 Harbor Drive dominated the city's western waterfront from 1942 to 1974.

¹³ "Fremont Bridge Access Study." Draft Environmental Impact Statement, City of Portland, November 1976, 9. The study proposed four alternatives but in the end status quo prevailed.

¹⁴ For a broad overview of Portland past and present, the author suggests *The Growth of a City, Power and Politics in Portland, Oregon 1915 to 1950*, E. Kimbark MacColl (Portland: Georgian Press, 1979); *Fares Please! Those Portland Trolley Years*, John T. Labbe (Caldwell: Caxton Press, 1980); *Portland, Planning, Politics, and Growth in a Twentieth-Century City*, Carl Abbott (Lincoln: University of Nebraska Press, 1983); *Cornerstones of Community: Buildings of Portland's African American History*, rev. and expanded (Portland: Bosco-Milligan Foundation Architectural Heritage Center, 1997); and *Frozen Music, A History of Portland Architecture*, Gideon Bosker and Lena Lencek (Portland: Western Imprints, 1985). Also see *Oregon Blue Book 1999-2000*, especially the section on Oregon History, by Terence O'Donnell.

The Willamette River basin covers 11,200 square miles, with the semi-wild Willamette River beginning its journey in the Cascade Mountain Range. It is first called the Willamette near the city of Eugene, Oregon's second largest city and located 110 miles south of Portland. Tamed from the way European explorers found it 200 years ago, the ancient river is rain-driven rather than snow-driven, and changes with each season, and in the lower twenty-six miles, with the daily tides. It flows northward the length of the Willamette Valley, until joining the Columbia River at Kelley Point Park at Willamette River mile 0. Fremont Bridge, at river mile 11.7, is the third bridge upriver and is situated upstream of Burlington Northern Railroad Bridge 5.1. and downstream Broadway Bridge. Before 1941, bridge building was hampered by uncontrolled spring freshets, but beginning that year the U.S. Army Corps of Engineers began regulating the Willamette with multi-purpose dams and reservoirs. In 1999, eight power projects and five non-power dams control water levels.¹⁵ The main channel from Sellwood Bridge to the Broadway Bridge self-scours to about 30' deep, with the river width between St. Johns and Sellwood ranging from less than 700' at Steel Bridge to 1,400' at Ross Island. The entire channel down river from Broadway is dredged to 40' deep, including that area below and near Fremont, where the river width runs about 1,000' wide.¹⁶ Alluvial river bed conditions, clearance requirements for river traffic, sharp bends, and right-of-way available for approaches all affected planning for all Portland's bridges, true especially at Fremont's location.¹⁷

Name

Fremont Bridge takes its name from Fremont Street, which at one time was slated to be the east side approach to the bridge. The street was named for John Charles Fremont (1813-90), explorer and army officer, the man, as did the bridge, benefitted from federal money. After serving as a railroad surveyor in the army, Fremont obtained federal aid and permission for a western journey to Oregon. In 1842 Fremont surveyed the Oregon Trail, and in 1843, he entered Oregon and, subsequently, opened a route to California from the Dalles, Oregon. His travels earned him a nickname "The Pathfinder."¹⁸

Arch Type

Arch bridges are particularly adapted to architectural treatment. As noted in *Historic Highway Structures of Oregon*, "Unlike other bridge types, arch structures are typically ornate. It is arch bridges which seem to generate recognition and local pride. Where the truss can evoke

¹⁵ Blue River, the last dam, opened in 1969. *Willamette River Basin reservoir System Operation*, U.S. Army Corps of Engineers, Reservoir Regulation and Water Quality Section, Portland District

¹⁶ Sounding maps, "Columbia and Lower Willamette Rivers below Vancouver, Washington and Portland, Oregon," February 2 - 24 June 1999, U.S. Army Engineering District, Portland Construction Operations Division.

¹⁷ "Fremont Bridge Access Study," 1.

¹⁸ Wood Wortman, *The Portland Bridge Book* (Portland: Oregon Historical Society Press, 1989), 10.

nostalgia from the engineer, it is invariably the arch structures which seem able to stimulate such feelings in the remainder of the community."¹⁹ The ancient Egyptians employed the arch as an architectural rather than a structural element, with the arch construction used in the Pyramids at Gizeh (3000 to 4000 B.C.) being the type commonly designated as the "corbeled arch." This is not an arch at all, as Conde B. McCollough (1887-1946), a former Oregon State Bridge Engineer, pointed out, "but rather a series of superimposed cantilevers with a simple slab closure." In his opinion, the modern period in arch bridge building began with the formation (in 1716) of the French Department des Ponts at Chaussees.²⁰

An arch bridge is a bridge type in which a curved structure spans an opening and provides support for the roadway. Arch bridges have been made of wood, cast iron, reinforced concrete, and steel. They come in tied, two-hinged, three-hinged, and stiffened varieties. Location of the roadway in relationship to the arch results in either a deck arch, a through arch or a half-through arch. Of the arch bridges in Oregon, the majority are reinforced concrete deck arches, some of the most esteemed located on the Oregon Coast. Fremont is unique as the only half-through tied arch in the state.²¹ Half-through means the roadway crosses through the arch at mid-height. In a tied arch, the arch's horizontal-push is resisted by foundations in the ground. In a tied arch, the arch's horizontal-push is resisted by a straight tie running to the other end of the arch, similar to a string in Sagittarius's bow.²² A theoretical tied arch appears in Faustus Verabtius's *Machinae Novae* sometime between 1595 and 1617.²³ Probably the first tied arch bridge in the U.S. was

¹⁹ Dwight Smith, James Norman and Peter Dykman, *Historic Highway Bridges of Oregon*, second edition, revised (Portland: Oregon Historical Society Press, 1989), 86, 298. As far as truss bridges evoking nostalgia for highway engineers, first-hand experience with designing and erecting truss bridges is going the way of steam-powered derricks, wooden bridge decks and riveting guns. The last big truss built in Oregon was the Peyton Bridge over the Rogue River in Southern Oregon, opened in 1975. Before that, major trusses erected in Oregon in recent decades are Astoria-Megler (1966), Marquam (1966), and Thomas Creek Bridge (1961) and the Oregon coast.

²⁰ Conde B. McCollough and Edward S. Thayer, *Elastic Arch Bridges* New York: John Wiley & Sons, 1931, 5-6. McCollough, former Oregon State Bridge Engineer, is best known for his Oregon Coast bridges, which include a reinforced concrete tied arch at Alsea Bay (replaced in 1991). McCollough also designed the McLoughlin Bridge across the Clackamas River south of Portland on the Pacific Highway, which consists of three independent steel tied arches. McCollough's opinion of the tied arch is "...as a matter of fact, this type of structure can hardly be classified as a true arch type." *ibid.*, 2. McCollough's definition of a true arch might be that the arch must thrust sideways into the ground. The arch, however, doesn't know any difference, i.e., whether its being held in place by rock or by a tie girder.

²¹ Smith, *Historic Highway Bridges*. 259-260.

²² See appended transcript 17H in field notes, slide presentation "Fremont Bridge Construction," by Ed Wortman, Fremont Bridge field engineer for contractor Murphy Pacific (December 1970 to December 1973), presented to HAER architects at University of Oregon Yamhill Center, 21 July 1999, 20.

²³ David J. Brown, *Bridges* (New York: Macmillan, 1993) 35.

built over the Delaware River, at New Hope, Pennsylvania, in 1812 by Lewis Wernwag.²⁴ Even more exotic, are three-span tied arches like Fremont. The oldest known extant three-span steel tied arch, a footbridge, is located next to the Eiffel Tower in Paris. The Passerell de Billy opened in 1899 for the Exposition of 1900.²⁵ Of the more than half-million highway bridges in the U.S., only about eighty are steel tied arches.²⁶ Part of this paucity is due to the Federal Highway Administration's advisory issued in 1978 for steel tied arch bridges. Since then, FHWA has not participated in funding for this bridge type.²⁷ Steel arch bridges, and especially steel tied arches, do not fit a niche. In almost all cases, steel arch bridges are more expensive to build than other bridge types of comparable size. Shorter bridges tend to be designed as girders, while mid-length spans are usually designed as trusses, with longer spans (up to 2,000') designed as cable-stays. In most cases, the widest bodies of water are reserved for suspension designs.²⁸ Arch designs typically are selected only in cases where aesthetics are particularly important, or where site conditions make other bridge types difficult to build (such as over deep canyons). Fremont's bridge type was selected for both reasons. The three-span tied arch suited Fremont's site, and the

²⁴ Carl W. Condit, *American Building Art the Nineteenth Century* (New York: Oxford University Press, 1960) 88, 295.

²⁵ Robert Cortright, *Bridging* (Tigard, Oregon: 1998), 88.

²⁶ Fax to the author dated 17 August 1999, titled "Tied Arch Bridges," from the Federal Highway Administration, Washington, D.C., faxed to FHWA, Oregon Division, Salem, Oregon. FHWA compiled the list in 1978, and has monitored additions to the list since then. These are all the steel tied arch highway bridges that FHWA knows about on any highways in the U.S. There are only sixteen steel arch highway bridges in the thirteen western states, one in Idaho, six in Oregon and nine in Washington state. Oregon's steel arch bridges, of all types, are Crooked River (High) Bridge, Willamette River (Oregon City) Bridge, Yaquina bay (Newport) Bridge, Clackamas River (McLoughlin) Bridge, South Umpqua River (Winston) Bridge, John Day (Clarno) Bridge, Pudding River (99E) Bridge, Clackamas River (Baker's Ferry Road) Bridge, and Fremont Bridge. All but Clarno, Pudding River, and Baker's Ferry Road are in *Historic Bridges*.

²⁷ "Technical advisory," Subject tied Arch Bridges, Classification Code T5140.4, U.S. Department of Transportation, Federal Highway Administration, 28 September 1978. The advisory was issued, "because tied arch bridges are inherently not 'load path' redundant, that is if the tie girder failed the entire bridge may fail." Although FHWA's position has not changed, two new arch bridges have been approved since 1997, Goff Bridge on U.S. Highway 95, owned by Idaho Department of Transportation, and Blue Water Bridge, between Ontario, Canada and Michigan. Both Goff and Blue Water were designed with "redundant member" features. Bruce Johnson, Pacific Northwest Region Bridge Engineer, Federal Highway Administration, Salem, telephone interview by the author, 18 August 1999.

²⁸ See appended transcript 17D in field records, oral history telephone interview by the author with Louis G. Silano, principal designer and project manager at Parsons for Fremont Bridge, 5 August 1999, 21. Silano states that the tied arch was a popular bridge type beginning in the 1930s and 1940s for spans up to 600'-700', anything longer competing with cantilever trusses. Also see appended transcript 17A, oral history telephone interview by the author with Gerrit Hardenberg, lead designer for NEDECO (Netherlands Engineering Consulting), assisting C.B.A. Engineering on its consulting contract for Port Mann Bridge, 13 August 1999, 4.

premium paid for the aesthetics was estimated to be approximately twenty percent above the cost of its conventional competitor. Design modifications made in the final phases of engineering reduced this premium by an estimated \$2 million over earlier estimates.²⁹ The responsible city, state, and federal officials concurred that this was a desirable investment, and the tied arch design was adopted.³⁰

Fremont's total cost, including approaches and construction repairs (see "Fracture in West Side Span Tie Girder" section below) was \$82 million.³¹ Part of the national system of interstate and defense highways, the bridge was financed under the Interstate Highway Act, with the Federal Highway Administration providing ninety-two percent of the funds.

Design Concept and Background

Fremont's rare three-span tied arch form is attributed to Port Mann Bridge in Vancouver, British Columbia.³² Also a three-span tied arch, Port Mann's configuration originated from Europe and European design engineers.³³ Opened in 1964 in Vancouver, B.C., the Port Mann

²⁹ "The Fremont Bridge, Portland's Arch of triumph," *Notes*, (New York: Parsons, Brinckerhoff Quade & Douglas), Spring 1974, 4. Also see Silano oral history (Appendices 17D in Field Records) 14-15.

³⁰ "The Fremont Bridge," 5. Also see appended transcript 17B in Field Records, oral history interview by the author with Walter Hart, Oregon State Bridge Engineer (1971-1988) at Multnomah County Central Library, 10 August 1999.

³¹ News release 73-47-Se, 7 March 1973, Oregon State Highway Division, Public Affairs Office. Fremont's \$82 million price tag converts to about \$180 million in 1999 dollars. "Building Cost Index History (1916-1999)," *Engineering News-Record*, 22-19 March 1999, 99.

³² R.O. Cunningham, H. Erzurumla, and R.A. Leber, "Construction of the Fremont Bridge," American Society of Civil Engineers Meeting Preprint 1968, ASCE National Structural Engineering Meeting (April 1973, San Francisco, California), 3. Also see Hart oral history (Appendix 17B in Field Records), 8.

³³ See Gerrit Hardenberg oral history (Appendices 17A in Field Records) p 3-5. In an effort to determine the origin of Port Mann's form, thus the first prototype for Fremont's design, the author located Hardenberg, who was living in the Netherlands. Hardenberg was senior designer for Port Mann Bridge, working for NEDECO at the time. NEDECO, the Dutch shareholder and European consulting consortium, was advising C.B.A. Engineering in its contract with the Canadian Government for C.B.A.'s design of Port Mann. When asked whether a bridge like Port Mann had ever been built before, Hardenberg said, "yes and no." Prior to Port Mann, NEDECO had submitted the three-span tied arch design once before, that time for a bridge in the Netherlands that was not built. Unlike the U.S., tied arch bridges were common in the Netherlands and the rest of Europe, but adding a side half arch to the center arch was required. "A span of 1,200' was most economical, but since the navigable channel in the river is not 1,200' wide, but only 800'...there was no point in having an arch of 1,200' going from one pier to another in a single span. It was more economical for the arch to come down almost to water level...because the deck level cuts across the arch (through-arch), it's a natural consequence to have the arch come up again, the side spans, and to have them join up with the tension girders where they take the arch's thrusts." See Hardenberg's illustration in letter to the author dated 20 August 1999, attached as page 18 to oral history. Hardenberg's tied arch design across the Fraser

Bridge is a steel, single deck, three-span tied arch that provides a clearance over the Fraser River of 145'. It was also the first bridge built in North American with a lightweight orthotropic steel deck.³⁴

Fremont for an aesthetically-pleasing arch for Portland came as a result of public reaction to the form of the functional Marquam Bridge. During Fremont's nascent stages, Marquam's river piles were being driven. It was during this time that the Portland Art Commission formally objected to Marquam's design, calling it, "an erector set bridge."³⁵ Although Portland had almost an eighty-year history with truss-style bridges, Marquam was its first interstate-style double-deck truss, and the Portland Art Commission, under the direction of Chairman Douglas Lynch, was not impressed. The State's design engineers countered that Marquam was an example of simplicity and economy of design.³⁶ Efforts to stop Marquam's construction were to no avail, since State Bridge Engineer Ivan Merchant had announced that the \$2.8 million contract for Marquam's superstructure had already been awarded to U.S. Steel Corporation. Governor Mark Hatfield approved Marquam's design; however, Portland's Mayor Terry Schrunk and Glenn L. Jackson, head of the State Department "to work out the type of design which will meet both the functional and aesthetic requirements" for Fremont, which was being planned for the site two miles down river.³⁷ City Commissioner William Bowes requested that a nationally

River worked for exactly the same reasons Fremont's tied arch design worked across the Willamette. Both were the right bridges for their sites in terms of soil conditions and navigational clearances. Additionally, the three span form at Fremont allowed the west side span to clear Front Avenue and several railroad tracks without intermediate piers. Also see Silano oral history (Appendix 17D in Field Records) 25-26.

³⁴ Port Mann's main span is 1,200', flanked by soan spans of 360'. The tied arch structure is shorter than Fremont's by 232'. For a web image of Port Mann Bridge, see Backband and Taylor, Ltd., website www.b-t.com. Backband and Taylor studied Port Mann in 1995 for seismic upgrading and widening. Principal Peter Taylor worked for C.B.A. Engineering testing piles during Port Mann's construction in 1960. See appended transcript 17F in Field Records, oral history telephone interview with Peter Taylor by the author on 30 July 1999. Also see George W.C. Lake, "The Port Mann Bridge," 1964 Annual Meeting Paper, Engineering Institute of Canada E.C.-64-BR and STR 6; G. Hardenberg, "Design for the Superstructure of H.Q. Golder and G.C. Willeumier," "Design of the Main Foundations of the Port Mann Bridge," *ibid.*, August 1964; W.G.F. Davie, "The Construction of the Foundation of the Port Mann Bridge," *ibid.*, September 1964; N. Hilton, "A Two-Inch Bonded Concrete Overlay for the Port Mann Bridge," 1964 Annual Meeting Paper, Engineering Institute of Canada E.C.-64-CIV 10; and Hilton, "The Lighting and Pavement Design of the Port Mann Bridge," *The B.C. Engineering News-Record* 16 June 1960, and "Canadians Build a Tied-Arch," *ibid.*, 11 July 1963, 29.

³⁵ Douglas Lynch, former chairman of the Portland Art Commission, telephone interview by the author, 15 August 1999. Letter dated 24 September 1963 to Portland's Mayor Terry Schruck from Lynch, with carbon copy to News Media, in which Lynch also protests Marquam Bridge being designed "without provisions for pedestrian traffic."

³⁶ Wood Wortman, *Bridge Book*, 43.

³⁷ "Marquam Bridge Foe Plans for Future

known bridge, designer be employed to help in the selection process. The State hired Parsons, Brinckerhoff, Quade & Douglas, of New York as consulting engineers for preliminary design studies, with a contract signed 10 October 1963.³⁸

Parsons submitted a report for seven alternative designs for Fremont on 10 August 1964. The Art Commission asked Werner Storch & Associates of Portland to review the designs. Storch, an engineer specializing in industrial structures, thought the proposed designs too much like Marquam and the Astoria-Megler Bridge, another truss bridge then also under construction. At the time Storch was in the process of writing about the Port Mann Bridge for a German engineering journal. Requirements for Fremont called for a double-deck bridge with a vertical navigation clearance of 167', the only specification criteria.³⁹ At the time, Roland Haertl was working for Storch as a structural engineer.⁴⁰ At some point, Storch teamed up with the consulting engineers for Port Mann's design, C.B.A. Engineering, and using a rendering by Portland architect David Soderstrom, submitted it to the City Council, who approved it.⁴¹

Storch et al had hopes of participating in the Fremont design contract, but that did not come to pass. Parsons served as sole design consultant, delivering on the request by the public and the State for a three-span tied arch. Prior to proceeding with final plans, Parsons further developed the tied arch concept, submitting additional studies to ODOT. A contract between ODOT and Parsons for final design was signed on 21 September 1966.

Tied Arch Superstructure

Fremont Bridge, ODOT structure No. 2529, is a steel, double-deck, continuous three-span stiffened tied arch. The superstructure consists of a 1,255'-4" long main span (as measured between four bearings, two on each river bank) plus two side spans measuring 448'-4" each, for a total length of 2,152'. (East and west approaches add another 5,153', making the bridge's total length 7,312'.)⁴² The main span over the river is in the shape of a full arch, while each side span

³⁸ Wood Wortman, *Bridge Book*, 43.

³⁹ "Marquam Bridge Foe Plans for Future," *The Oregonian Journal*, 29 August 1963. Also see Hart oral history (Appendix 17B), 40. Nearly thirty-five years later, Hart recalls, "I think of all the problems that this type of bridge (Fremont) presented, it did accomplish the one purpose that the Art Commission and the City of Portland wanted, was an aesthetically dominant feature on the Portland skyline."

⁴⁰ Contract dated 10 October 1963, for "no more than \$87,500" for preliminary design on microfilm at ODOT Records Center, Salem. Also see Silano oral history (Appendices 17D in Field Records), 12. At the time of Fremont's construction, Parsons was one of the largest consulting engineering companies in the country.

⁴¹ See appended transcript 17C in Field Records, oral history telephone interview with Roland Haertl, engineer in Werner Storch offices in 1960s., 15 August 1999, 3.

⁴² Fremont contract plans.

is in the shape of a half arch, with the entire 30,000-ton weight of the three-span superstructure supported and balanced on four bearings located on the river banks. On the west side, 15,000 tons is conveyed to ground in a grassy area of an office complex parking lot located between the Willamette Greenway Trail and N.W. Front Avenue. Two east side bearings support the remaining 15,000 tons near an asphalt recycling plant located between the Willamette River and Union Pacific Railroad's Albina Yards. A stiffened tied arch is similar to a self-anchored suspension bridge, both being closed structural systems; that is, they rely on their foundations only to support the structure, but not to maintain their shape). Fremont's double-deck structure has an orthotropic steel upper deck and a conventional reinforced concrete lower deck supported on stringers and floor beams. The columns and hangers connecting the arch rib to the tie girder at each panel point are spaced at 44'-10" intervals. There are forty-eight panel points in all.⁴³

Sixteen miles of traffic lanes in the approaches and the bridge make Fremont Complex the largest structure in the Oregon state highway system. The roadway width of 68' provides four 12' travel lanes on each deck with 10' shoulders on either side. The upper deck carries four lanes of westbound traffic and the lower deck carries four lanes of eastbound traffic.⁴⁴ The two decks are spaced apart at a vertical distance of 34' from grade to grade to permit adequate space for signs and lighting. Minimum clearance at harbor line above low water is 167' while clearance at the center of the bridge is 175'. The top of the arch rib projects above low water.

The two tie girders are 4' wide and 18' deep. The bottom 6' of each girder is fabricated of American Society for Testing Materials (ASTM) A588 steel while the top 12' is ASTM A36. The arch ribs are 4' square and fabricated of ASTM A 514 steel.⁴⁵ (See section below, "T-1 Steel in the United States.") Tie girders in the center portion of the main span are suspended from the arch ribs with eight 2-5/16" diameter bridge strands at each panel point. In contrast, box columns sitting on the arch ribs support the tie girders where the girders are above the arch in the side spans and portions of the center span.⁴⁶

The 7' wide by 39' to 56' long panels of the orthotropic upper deck were shop-welded in South San Francisco and shipped to Portland by barge. After erection, prefabricated panels were

⁴³ Elevation drawing of Fremont emphasizing panel point designations, an attachment to report "Fremont Bridge Crack at Panel Point 3," sent to the author 9 November 1988, by Jerald E. Backstrand, ODOT Assistant Bridge Engineer. Notice panel point 3, the site of the tie girder fracture.

⁴⁴ Fremont was actually designed for each roadway to carry five lanes of traffic "in order to accommodate future traffic needs." Alfred Hedefine and Louis G. Silano, "Design of the Fremont Bridge," American Society of Civil Engineers, Meeting Preprint 1210 (April 1970, Portland, Oregon), p. 2. Also see Silano oral history (Appendices 17D in Field Records), 6-7.

⁴⁵ Fremont contract plans, "Truss Detail drawings Nos. 25240-25253."

⁴⁶ Cunningham, "Construction of the Fremont Bridge," 3.

connected, transversely and longitudinally by bolted splices. The connections in the transverse direction were accomplished by using 7/8" diameter ASTM A-325 high-strength bolts, while in the longitudinal direction the panels were lap spliced to the top flange of the tie girder with 1" diameter high-strength bolts. Due to the complex erection procedure and resulting stress patterns, orthotropic deck panels were erected and bolted according to a predetermined sequence. Each prefabricated orthotropic deck panel was provided with lifting lugs to permit its handling and erection by means of a gantry mounted on special dollies which traveled longitudinally on the top flange of the main girders.⁴⁷

Fremont was painted green in 1973 as part of construction and has not been repainted since.

Driving Surface for Orthotropic Deck

To provide a driving surface on the steel orthotropic deck, 2-1/2" of epoxy asphalt were applied in two layers. This work was done by a subcontractor, Adhesive Engineering. Difficulties were encountered with the performance of the original epoxy asphalt surface. One contributing factor was the fact that the surface was applied during cool fall weather and did not have time at higher temperatures to cure properly before heavy traffic began regular use.⁴⁸

Construction Contracts

Construction proceeded in eight major contracts. Principal contractors included:⁴⁹

Contractor	Date
Peter Kiewit Sons' Co. Pier Construction	27 February 1968
Anderson-Hannan West Fremont Interchange, Unit 1, \$20,868,475	29 April 1969
Murphy Pacific Corp. Tied Arch Superstructure, \$28,686,705	3 July 1969

Willamette River Contractors

⁴⁷ Cunningham, Construction of the Fremont Bridge," 4.

⁴⁸ Letter dated 9 May 1994 from Terry Shike, ODOT Bridge Engineer, Australian Road Research Board, Victoria, Australia.

⁴⁹ "Stadium Freeway I-405" brochure. This is the most complete reference for amounts, dates, and names for Fremont's eight primary construction contracts.

East Fremont Interchange, Unit A, \$14,120,100	11	September 1969
E. Carl Schiewe		
East Fremont Interchange, Buildings, \$141,990	9	September 1969
Willamette River Contractors		
East Fremont Interchange, Unit B, \$9,472,330	11	September 1969
Willamette River Contractors		
East Fremont Interchange, Unit C, \$2,215,785	11	September 1969
Drake-Willamette		
West Fremont Interchange, Unit 2, \$3,699,335	26	August 1971

Piers for Tied Arch Structure⁵⁰

The four piers supporting the three-span tied arch structure were built by Peter Kiewit Sons' Co. Two of the four are the main low-level piers supporting the arches next to the river. The other two are the tall and massive approach span piers where the approach spans meet the tied arch structure. The approach span piers primarily carry the weight of the approaches. If these [piers were removed, the tied arch structure would still stand, as the half tied arches that extend from the main span arch are "cantilevered" out. The approach span piers keep the cantilever arms, or half arches, from moving up and down relative to the approaches, especially in hot and cold weather when the steel expands and contracts.⁵¹

All four piers are founded on steel piling driven into the gravel that underlies the site. Kiewit built concrete footings on the piling. They then built the reinforced concrete piers on the footings. Materials required for the four piers included approximately 38,000 cubic yards of concrete and 1,900,000 pounds of reinforcing steel.

Kiewit began pier construction in March 1968 and finished in 1969. Construction features for the main piers included the following"

- * Kiewit drove 672 steel H-piles for the west pier and 360 piles for the east pier (larger

⁵⁰ "Works Starts on the Fremont Bridge," *Western Construction*, January 1969, 88-92.

⁵¹ "The behavior of the bridge is more dependent on temperature than on traffic. Temperature differentials between the top and bottom flange plates of 50 degrees Fahrenheit and between the outside and inside web plates to 20 degrees Fahrenheit were measured in the tie girders." Kamal Kamadoli, P.E. principal structural design engineer, bridge design section, ODOT, "Thermal Stresses in Fremont Bridge Superstructure," a paper presented at the 7th Annual Meeting of the Northwest Bridge Engineers' Seminar, Olympia, Washington, October 1983.

piles were used on east pier).

- * The west pier is located a short distance from the edge of the river. Kiewit installed a sheet pile cofferdam and dredged soil out before driving the piling. With the piling in place, a concrete seal was poured before footing construction started. Dimensions of the seal were 101' x 117' x 10' deep.⁵²

- * The east pier was built in water at the edge of the river. To allow work to be done "in the dry," Kiewit built a dike and a cofferdam along the river side of the pier.

- * Footing concrete was placed in large blocks, in depths up to 9'. To avoid development of shrinkage cracks at vertical joints between block, heat measuring devices were installed to monitor concrete temperatures prior to pouring adjacent blocks.

Construction features for the approach piers include:

- * 160 steel H-piles per bent
- * 40' x 80' x 12' high footings on the piles
- * 111' tall pier shafts flaring out at the top on north and south sides. The shaft concrete was cast in custom-built steel forms.

Under plans submitted by Murphy Pacific, the superstructure was to be built and erected in three distinct phases: 1) Construction of the cantilevered west bank and east bank side spans 2) assembly of the center span in Murphy's yard at Swan Island, a 22-acre site 1.7 miles downstream from Fremont's location and 3) moving assembled tied arch upriver by barge and lifting the arch in place between the half arches, or side spans, using hydraulic jacks.

Tied Arch Superstructure Fabrication and Shipment

The three-span tied arch superstructure was built by Murphy Pacific and subcontractors. First step in the process was to fabricate the structural steel. All members of the bridge were fabricated in the San Francisco Bay area by either Murphy Pacific or the American Bridge Division of U.S. Steel Corporation, except the lower deck system which was fabricated in Gary, Indiana, by American Bridge. The four large bearing "shoes" supporting the arch structure on the main piers next to the river were cast at National Forge Co. in Pennsylvania and finished by Bethlehem Machining.

Most of the fabricated steel components from the Bay Area were shipped to Portland on Murphy's Pacific's derrick barge *Marine Boss* and stored there until used.

Erection of Superstructure Side Spans

⁵² The contractor's original plan was to construct the pier using a dike between the work and the river and to complete the excavation by "glory holing." The Willamette River wouldn't cooperate and breached the dike, forcing use of the conventional cofferdam. Eric Bolton, "Portland's Triumphant Arch," *Constructor*, October 1975 16.

First step in on-site construction of the tied arch superstructure was to erect the east and west side spans. From the bearing shoes on the main piers at the river's edge, these units extended 450' back over land to the monumental concrete approach span piers; in the other direction, each side span extended about 180' out over the river where the curved arch intersected the tie girder at roadway level.

Murphy Pacific began erection of the west side span in April of 1971. Side span erection was a slow and difficult process due to the complexity of the structure and the large size of many of the pieces. Lifting the pieces one at a time, the field crews had to carefully interweave the many components of the giant three-dimensional jigsaw puzzle: arch sections, arch bracing, arch-to-girder posts, tie girder sections, lower deck floorbeams and stringers, and—finally—the orthotropic upper deck panels.

Due to the long 450' clear span of each side span, it was necessary to use two falsework towers to provide temporary support for the pieces as they were assembled. Erection started at the main pier shoes and worked section-by-section back toward the approach span piers. The falsework tower supported each partially-assembled side span until its far end landed on the approach span pier. Each falsework tower was equipped with 400-ton and 200-ton capacity hydraulic jacks to allow for adjustments in elevation of the steel pieces as they were fitted together.

Murphy Pacific used three large cranes to lift the side span pieces into place. The 500-ton capacity of crane on the *Marine Boss* was used for erection operations over and near the river. For the portion of the side spans away from the river, erection lifts were made by two 200-ton capacity crawler cranes. The orthotropic deck panels presented a special challenge. They were too wide and heavy to be set in place by the crawler cranes. The contractor's solution was to set each deck panel onto the river end of the end of the partially-built side span. The crews then used a custom-built "gantry" outfitted with airplane tires to roll each deck panel down along the tie girders to its final location. Hydraulic jacks then lowered the panel into place on the tie girders.

Side span components were permanently connected together using high-strength bolts. The bolt holes in the arch and tied girder connections had been pre-drilled full-size at Murphy Pacific's fabrication yard in California with the pieces temporarily assembled in proper relation to each other. However, holes for connecting the orthotropic deck panels to the tie girders had to be drilled in the field.

Because of the complex structural interrelationship of the arches, the tie girders and the orthotropic decks, Murphy Pacific was required to follow a detailed pre-engineered procedure for pushing, pulling and lifting various components with hydraulic jacks before bolting the components together. Purpose of this elaborate procedure was to ensure that the final stresses in all components after erection would be as required by Parsons Brinckerhoff's design.

Center Span Assembly

As described in the next section, Murphy Pacific chose to erect the 900'-long center section of the tied arch by assembling it off-site, floating it to the bridge and lifting it into place. Accordingly, the contractor assembled the center span section on falsework in the river alongside their yard at Swan Island.

The center span section consisted of the 900' portion of the bridge between the arch-tie girder intersections. The section included the two tie girders, arches, orthotropic deck panels, and suspender ropes between arches and tie girders. Center span assembly began late in 1971 and was finished prior to being moved to the bridge site in March of 1973.

Prior to starting center span assembly, Murphy Pacific installed eighteen falsework towers in the river near shore; steel piles were driven into the river bottom through bracing templates. As for side span erection, hydraulic jacks on the falsework were used to adjust the elevation of components during assembly.

Erection work for the center span was straightforward since the *Marine Boss* derrick barge could set all pieces into place while anchored just outside the span. First step was to place girder sections on the falsework and bolt them together with high-strength bolts. Next, the crews set the orthotropic deck panels on the girders and bolted them into place. Falsework bents were then set on the girders to support the arches during assembly. Finally, when the arches were finished, the suspender ropes were pulled up into place one-by-one and fitted into receptacles in the arches and girders.

From an engineering point of view, the most interesting aspect of the center span assembly was the requirement to "camber" the tie girder-deck unit before erecting the arch. Purpose of the operation was to bend the girder-deck unit upward temporarily so that it would be in the proper position when it later bent back down under full weight of the finished bridge. The girder-deck unit was bent upward approximately 18". Murphy Pacific accomplished the cambering by simultaneously pushing upward with hydraulic jacks on fourteen of the falsework towers (the four end towers stayed at initial elevation). After center span assembly was completed, the four end falsework towers were removed to permit access by the barges that would transport the section to the bridge site.

Center Span Erection

The most spectacular phase of construction of the Fremont Bridge was the record-setting lift of the 6,000-ton center span section. The lift employed a hydraulic jacking system, placed on the completed side spans, to lift the 900' unit 160' from the transport barges to its final position in the bridge. The river was closed for navigation for only three days during the lifting operation.

Before selecting the "float-in, lift-up" erection method, Murphy Pacific considered two other approaches. One method would have been to install falsework in the river, then assemble

the center span unit in place piece-by-piece much as it was assembled at Swan Island. However, this method was not feasible because of the major impact on river traffic. Another alternative method, frequently used for arch bridges (including the similar Port Mann Bridge in Canada), would have used an overhead tieback cable system to support the arch during assembly. This method was considered to be more difficult and expensive than the lift-up method finally selected.

The "float-in, lift-up" erection method has been used on many bridge projects in the past, including the Quebec Bridge, Carquinez Strait Bridge in California, and the Chesapeake Bay Bridge. However, no span nearly as heavy as Fremont's 6,000-ton section had ever been lifted this high in the air. To accomplish this feat, Murphy Pacific had to acquire a custom-built jacking system consisting of 32 special 200-ton capacity hydraulic jacks and several thousand feet of 4" diameter threaded high-strength rods. The method used was as follows: The jacks were mounted in structural frames at the outer ends of the side spans. Each jack lowered down through its jacking cylinder. The 24'-long rod sections were coupled together and lowered down through the jacks to reach the center span at river level below. The jacks lifted the rods by pushing up on nuts on the rods. After each 24" stroke of the jacks, other nuts on the rods below the jacks were tightened down to hold the rods while the jacks were retracted for their next stroke. The top nuts were also run down as the jacks retracted.

Design of the record-setting jacking system was a joint effort of Murphy Pacific working with their erection consultants, Earl & Wright, and the jack manufacturer, the William S. Pine Division of Templeton-Kenly & Co. In addition to the jacks and rods, other essential custom-designed components were the "split-nuts" used on the rods above and below the jacks. These highly-machined nuts consisted of two C-shaped halves held together with retainer rings. Whenever one of the rod couplers came up to a nut during the lift, it was necessary to disassemble the split nut to let the coupler pass, then reassemble the nut around the rod below the coupler. With eight rods lifting each corner of the span, this made the span lift a labor-intensive operation.

Prior to the span lift itself, Murphy Pacific had to move the center span from Swan Island to the bridge site. Two large barges were used, one under each end of the span. *Marine Boss* was used for one of the barges, and a cargo barge was used for the other. Both barges were outfitted for the transport operation. Extra pumps were added to pump water in and out for ballasting when the span was lifted off the falsework at Swan Island. Steel and timber cribbing was installed to support the bridge span on the barges. It was also necessary to install an extra stiffening in the span tie girders to avoid buckling of the girder webs under the transport loads.

The center span was lifted off the Swan Island falsework for the trip to the bridge site on the day the lift commenced. Some difficulties were encountered due to the fact that the river elevation was a few feet below normal for early march. Extra timber cribbing had to be added on both barges to reach up to the span where it sat on the falsework. Also, with the low water, the

river depth at the span assembly location proved to be barely sufficient for the barges to fit in under the span. In fact, Murphy Pacific employed a land crane with clam shell bucket for a night-long operation to dredge out high spots to allow the barges to move in. Finally, the barges were ballasted down, moved under the span, then deballasted to lift the span off the falsework. The last step prior to leaving for the site was to tie the span to the barges with a series of wire ropes and turnbuckles to prevent the span from sliding on the cribbing while moving.

Early on the morning of 14 March 1973, a fleet of six tugs moved the barge/span unit lengthwise up the river approximately two miles to the bridge site. Upon reaching the site, the *Marine Boss* set anchors in the river and the tugs swung the span 90 degrees into position for the lift. Once in place, the 32 jack rods were connected to steel frames bolted to each end of the span. The final step in preparation for the lift was to test each rod up to 300 tons, fifty percent more than the 200-ton load that would be on the rod during the lift. This overload testing also provided confidence that the jacks and hydraulic systems would function well during the lift.

The actual lift began near midnight of 14 March. Once begun, it proceeded at a steady rate of four feet per hour for the next forty hours. No serious difficulties were encountered during the lift. To avoid overstressing the floorbeams in the orthotropic deck, the span was kept level within 1-1/2" side-to-side. It was not critical to keep the span exactly level from end-to-end; however, the crews kept it level within two feet from end to end to avoid unforeseen difficulties.

Final elevation was reached on 16 March 1973. Construction operations were then suspended for the weekend before starting span-completion tasks the following week.

Tied Arch Completion Operations

Once the center span was lifted into place, Murphy Pacific carried out several operations to complete tied arch structure. In summary, these were:

1. Make up bolted connections between the center span and the east side span. Approximately 4,600 bolts were required for these connections.
2. Push the east side span/center span several inches to the west to fit the center span to the west side span. Note: The east side span had been deliberately built a few inches too far east to leave room for the center span lift. It was pushed into final position with four 400-ton hydraulic jacks, then pins were installed in field-machined holes to lock the shoes into place.
3. Bolt-up connections between the west side span and the center span. Once again, 4,600 bolts were installed. The first attempt at "trapping" the bridge at this connection failed, with a number of temporary bolts shearing off as the bridge

lengthened due to expansion in the sun.⁵³ The attempt on the following morning succeeded.

4. Install cross-girders and final orthotropic deck panels at the gaps between center span and side spans.
5. Bolt the final deck panels into place. Before the bolting was finished, special operations were required to assure that the deck system would participate with the tie girders in carrying the longitudinal tie force from one end of the arch system to the other. This was done in two ways: (1) the far ends of the tie girders were jacked up at the approach span piers to minimize stress in the tie girders at the points where the final deck panels were being bolted; (2) several of the span lift jacks and jack rod assemblies were attached to the deck panels, then activated to pull the deck panels together before the final seam between them was bolted.

Lower Deck Construction

The lower traffic deck on the Fremont tied arch structure is a conventional composite concrete-on-steel-stringer bridge deck. Other than adding weight to the bridge, it does not participate in the overall arch-girder structural system. For the side spans, the steel floorbeams, stringers and lateral bracing were erected after the center span was in place. First step in this sequence was to lift each floorbeam, together with vertical hangers, up from a barge using two mobile cranes positioned on the top deck. Crews then connected the hangers to the tie girders and disconnected the cranes. Stringers and bottom lateral braces were installed by a small crane working in front of itself as it moved across the span over the river.

The contractor used stay-in-place metal forms for the lower deck concrete. The concrete itself was delivered to the top deck by readi-mix trucks, then chuted down to placement equipment on the lower level.

All lower deck work was done by the prime contractor, Murphy Pacific. One of their last operations in this portion of the bridge was to install piping for draining rain water off the bridge decks.

Approaches

Nearly as massive in scale as Fremont's superstructure, the east and west approaches for Fremont set records. The initial contract for west approach was then the largest contract ever let

⁵³ See appended transcript 17G in Field Records, oral history telephone interview by the author with Thomas Worley, ironworker and general foreman during Fremont Bridge erection, 28 August 1999. After the bolts sheared, ironworkers had to wait until next morning's sun to make a second and successful attempt at bolting the final joint. "Metal expands a quarter-inch for every 100', for every ten degrees of temperature," Worley said.

in Oregon, only to be superseded by Fremont's three east approach contracts.⁵⁴

Approach work began on the west side with the first structural steel, a 20-1/2 ton bottom section of a ring girder, placed on 21 July 1970.⁵⁵ In a paper for the 1968 Oregon Building Congress held 28 March 1968, Tom Edwards, Assistant Oregon State Highway engineer wrote:

"After finalizing the type selection for the main span, it became time then to consider the problem of the approaches. The firm Howard, Needles, Tammen and Bergendoff was retained to make those designs. Due to their complexity and interlacing, these portions of the structure could only be simple span type construction; hence, the alternatives could only be in kinds of materials (either steel or concrete) and in configuration. The consultants were given very simple instructions, namely 1) that their designs must be in keeping with the type selection for the main structure, 2) that they should avoid a trestle-like appearance, and 3) the designs should not be exotic to the point of pricing themselves out of the market. "To have given any further instructions to a firm of this stature would have been somewhat in the class of telling a bee how to make honey. Their analysis and recommendation developed structural types, basically with single stem piers, having a rectangular shape with rounded corners. Where double-decking is necessary, the upper deck is supported by columns, extending upward from the crossbeam of the lower roadway. For want of a better name, I have been referring to them as 'tennis rackets,' or 'banjos.' Even though unique, this configuration is not new or original. Some time prior to giving this assignment to HNTB, the *Engineering News-record* carried an article of a double-deck structure being built in Tokyo, using the same 'banjo'-type piers for double-deck configurations."⁵⁶

West Approaches

Construction for the west approaches was let in two contracts. The first contract, dated 29 April 1969, for \$20,868,475, was awarded to Anderson-Hannan, a joint venture. Willamette Western became the subcontractor for steel erection on the west approaches. A second west approach contract dated 26 August 1971 was awarded to Drake-Willamette, also a joint venture, for \$3,699,335. (All contractors for both east and west approaches were Portland-based general contracting companies.)

The west approach consists of two elevated curved double-deck roadways that wye onto

⁵⁴ "On Oregon Bridge Approach Jobs—Counterweights Eliminate Shoring," *Western Construction*, April 1971, 45-51.

⁵⁵ Caption, "Milestone," *The Oregonian*, 21 July 1970.

⁵⁶ Tom Edwards, Assistant State Highway Engineer, Oregon State Highway Department, "The Fremont Bridge," Oregon Building Congress, 28 March 1968.

the main tied arch structure. Main structural elements include concrete piers, steel box girders and concrete decks. The west approach contains 8,200 tons of steel, and 60,000 cu. yards of concrete.⁵⁷ Either three or two lines of trapezoidal box girders are embodied in the design for spans ranging from 161' to 192'. The box girders, 6'8" to 8' deep, were fabricated at Canron Steel, Vancouver, B.C., in sections weighing 30 to 45 tons each. Two girder sections were spliced on the ground to make up each erection section. The erection sections, weighing up to 75 tons, were placed by two crawler cranes, a Manitowoc 4000 (125-ton capacity) and an American 9299 (165-ton capacity). Booms frequently adjusted in length up to 190' were fitted with 40' jobs. An erection with each crane crew made up of two operating engineers and five ironworkers.⁵⁸

East Approaches

The state divided the eastern approach job into three separate contracts, with the low bidder for all three turning out to be a venture of Donald Drake Co. and Willamette Western. Total amount for three contracts, all let on 11 September 1969, was for \$25,808,325.⁵⁹ For their work on the east approaches, the joint venture assumed the name Willamette River Contractors, with Drake constructing the piers and Willamette Western erecting the steel.

The eastern approach, also a two-deck elevated structure, connected with I-5. Elevated ramps cross I-5 and merge with streets on rising ground beyond. East approaches included eighty footings and piers to support a five-level "stack" over Interstate Avenue.⁶⁰ The tallest pier was 140' and flared from a bottom of 60'. About 13,000 tons of steel were used in the east side, with spans between piers ranging from 125' to 240' and lengths of girders varying from 60' to 216' with weights of from twenty-five to ninety-five tons. Most of the steel for the eastside interchange was fabricated in Japan.⁶¹ Support of the two deck levels on each pier is accomplished by a steel box member, termed a "ring girder." The approach structure was designed so that the traffic on the lower deck runs through the "ring," the upper deck being supported by the top of the ring. The ring girder has a component anchored to the pier cap but which does not extend the full width of the cap. This is identical in function to the cross girder on piers supporting single decks. Heights of piers vary from 20' to 156'. With ring girders 30'

⁵⁷ "The Bridge," *Oregon -Columbia Constructor*, Summer 1990, A-4.

⁵⁸ "Big Box Girders Posted Unloading Problem," *Roads and Streets*, December 1971, 36.

⁵⁹ Drake-Willamette was next low bidder for the steel arch construction contract, at \$22,755,000, still nearly \$6 million above the successful Murphy-Pacific bid. *The Oregon-Columbia Constructor*, A-4.

⁶⁰ "Portland's E. Fremont Interchange off on a Good Footing," *Pacific Builder & Engineer*, 19 June 1970, 35.

⁶¹ "Canada, Japan Mills to Provide Majority of Fremont Bridge Steel," *The Oregonian*, 15 January 1970.

high, lifts for the top deck were as high as 186'. Lifts were made by two 165-ton capacity 9299 American crawler cranes (on tracks).⁶²

East approach construction methods hanging counterweights from one side of a cross-girder on a pier so that a pier, instead of falsework, could bear the asymmetric action of the weight of the girder on the other shoulder until placement of the second girder restored the balance.⁶³ Girders were placed in double normal lengths, which halved the number of joints that had to be made aloft. Fixed connections were made with high-strength bolts.⁶⁴

Fracture in West Side Span Tie Girder

On 28 October 1971, while the center span was still at Swan Island, release of load by the contractor on the falsework under the west side span triggered a brittle crack at Panel Point 3 in the south tie girder. The crack occurred in the joint between the arch and the bottom flange of the tie girder. The tie girders are 18' deep by 4'2" wide box sections. The crack started in the 66" x 3-1/4" bottom flange of the girder and proceeded upward through the 24" x 2-3/4 and 48" x 1" web plates.⁶⁵ The fracture propagated upwards 6' in one side web, but only 2' in the other web. Both cracks stopped at welded splices between plates.⁶⁶ The girder came to rest on the falsework, still in place, thus avoiding complete failure of the side span. Workers standing on the falsework at the time, located about 300' from the shore and 160' above N.W. Front Avenue, feared the entire span was going to fall.⁶⁷

Murphy Pacific halted construction work on the side spans after the crack while

⁶² *Western Construction* 46.

⁶³ *ibid.* 45. Also see Silano oral history (Appendices 17D in Field Records)

⁶⁴ Fremont contract plans.

⁶⁵ Fremont Contract Plans, Drawing No. 25240. None of the plates that cracked were T-1 steel.

⁶⁶ Fremont Bridge contract drawing "Truss Details P.P.-3," Drawing No. 25240.

⁶⁷ See appended transcript 17I in Field Records, slide presentation "Fremont Bridge Crack," by Ed Wortman, presented to HAER architects at University of Oregon Yamhill Center, 21 July 1999. Wortman was one of those people standing on the falsework at the time of the fracture. Walt Hart later assessed, "If that fracture hadn't occurred, it might have just been on the ragged edge, but if it hadn't occurred and the erection of the structure went off and then they tried to lift that twelve million pound center span and that weakness in that back span had occurred, had fractured then, the implications are just unbelievable. There would have been, undoubtedly been fatalities associated with it. You would have had twelve million pounds of steel, plus any of the approach spans dumped into the Willamette River, you would have blocked the ship's channel. It's not appropriate to say that it was a fortunate event, but when you look at what potentially could have occurred if that fracture hadn't happened, and the problem came to light, it's frightening." See Hart oral history (Appendix 17B in Field Records), 22-23.

investigations were carried out and decisions were made on how to handle the situation. Independent consultants were brought in to help determine the cause of the failure and make recommendations. Murphy Pacific hired Richardson Gordon Bridge Engineers of Pittsburgh and the State hired HNTB and MEI Charlton metallurgical engineers. On 21 March 1972, the State issued an official statement:

"The multi-million dollar Fremont Bridge being constructed over the Willamette River in Portland is a one-of-a-kind structure designed by the firm of Parsons, Brinckerhoff, Quade & Douglas of New York. This form is recognized as one of the outstanding bridge design consultants of the world. During erection of the Fremont structure, a crack occurred in the main tie girder where it intersects the arch support. The crack is at a joint incorporating a connection piece in the south girder. The north girder did not crack even though it is of the same design. The State and the contractor both immediately called in separate independent consultants to investigate the reason for the crack. The design was rechecked, using space frame and finite analysis techniques. Adequacy of the erection procedure was analyzed. A metallurgical consultant was retained to check the steel for compliance with specifications. The results indicated that the crack should not have occurred. In spite of this, the girder did crack. The enormous size of the steel plates, combined with the magnitude of the welding required may have built up locked-in stresses which could not successfully be relieved using conventional techniques. The arch-type erection, which is delicate and difficult at best, may have caused additional stresses to be induced by the erection procedure required. A combination of these factors may have induced stresses causing failure...."⁶⁸

After the fracture, the bonding company stepped in and took over the project's finances.⁶⁹ Murphy Pacific hired Alpo Tokola to take over the job as Project Manager. Tokola was a bridge engineer from California who had worked on Glen Canyon, Hood Canal, Richmond-San Rafael and other large bridge projects for Murphy Pacific between 1955 and 1963. He led the investigation for the contractor's team.⁷⁰ Tokola recommended the repair method that was used,

⁶⁸ "Statement by Tom Edwards, State Highway Engineer, Concerning the Cracked Girder in the Fremont Bridge," News Release 72-71-S (Oregon State Highway Division: Public Information Office), 21 March 1972.

⁶⁹ From a financial standpoint, the insurance company was running the project after the crack occurred and work was stopped. Interview with Alpo Takola, 4 November 1993. Also see Walt Hart oral history (Appendix 17B in Field Records) 25.

⁷⁰ Alpo Tokola, interview by the author in Portland, 4 November 1993. As part of his research into the Fremont crack, Tokola traveled to Port Mann Bridge. He noticed that in the same area where Fremont had its failure, the Port Mann Bridge was not built as shown in contract plans. Tokola's subsequent investigation revealed that Port Mann Bridge originally had the same design as Fremont, but during its construction period, the Port Mann engineers had modified its design. Ironworker Thomas Worley is emphatic that Port Mann suffered the same cracking as Fremont, in the same area. See Thomas Worley oral history (Appendix 17G in Field Records), 6. Port

and negotiated the financial settlement with the state and federal agencies. MEI Charlton of Portland was one of the consultants hired to make studies of the crack. Contracted by ODOT, MEI Charlton conducted fractography, fracture toughness measurements, analysis of stress-concentration factors, and other advanced procedures/ MEI Charlton's findings about Fremont's fracture resulted in revisions to the American Association of State Highway Officials standard specifications for bridge design, including revisions to design practices, material specifications and fabrication procedures.⁷¹

In a later report, the State notes, "The study indicated that the failure of the juncture piece in the girder may have been contributed by one or a combination of the design detail fabrication and material deficiency. The stress concentration in the complex juncture piece along with locked-in stresses from the heavy welding and the low fracture toughness of the material compounded to cause the crack. The juncture piece was fabricated and installed into the structure such that its weaknesses were orientated in the direction of the stresses."⁷² Parsons denied that design error was a factor.⁷³

Crack Repairs and Modification of Arch-Tie Girder Joints

As noted above, the south tie girder in the west span cracked at Panel Point 3 where the arch connected to the bottom of the tie girder. Based on investigations and recommendations by several consultants and agencies, the State decided to redesign the arch-to-girder joints in both side spans. Parsons finalized the redesign as agreed to with the State. In the original design, the arch was welded to the bottom of the flange of the tie girder via machined junction plates built into the girder flange.⁷⁴ In the new design, this detail was eliminated, instead, continuous heavy web plates were called for in order to transfer loads from arch to girder. This revised design

Mann's Hardenberg states he knew of no cracking on Port Mann. See Hardenberg oral history (Appendix 17A in Field Records), 15. Both design and fabrication drawings for Port Mann Bridge's arch to tie girder connection in the backspan are available from the Canadian Highway Department, Bridge Branch, in Victoria, B.C. Plan numbers are available in HAER No. OR-104 Field Notes.

⁷¹ "Outstanding Oregon Engineering Projects," reprinted from *The Oregon Consulting Engineer*, vol. 19, no. 9, April 1977.

⁷² Kamal Kamadoli, "Fremont Bridge Crack at Panel Point 3," undated attachment with letter to the author from Jerald E. Backstrand, Assistant Bridge Engineer, ODOT, dated 9 November 1988.

⁷³ In response to the question, "Did Parsons Brinckerhoff have an official position on causes of the girder crack in 1971? Do you have any comments on that subject now?", Silano replies in his e-mail to the author dated 24 August 1999. "The crack that occurred at this critical juncture was due in part to a metallurgical stress raiser. The fracture occurred during a critical stage of erection which put undue stresses on the joint. Subsequent investigations revealed that high preheat temperatures during welding caused a stress raiser which amplified the actual stresses." Silano oral history (Appendix 17D in Field Records), p 28.

⁷⁴ Fremont Contract Drawing No. 25240.

avoided heavy welds and potential stress configurations in the original design.⁷⁵

At the time of the crack, Murphy Pacific had already fabricated and shipped all four Panel Point 3 (PP-3) tie girder sections with the arch-girder joints as originally designed. The two sections for the west side span had been erected and bolted into place, including the south section that cracked. The two east side span sections were waiting to be erected. Changing to the new design for the arch-girder meant rebuilding all four PP-3 girder sections. For the west side span, it also meant removing the two PP-3 sections, modifying them on the ground, then reinstalling them.⁷⁶

To carry out the girder modification program, the Murphy Pacific team took the following steps:⁷⁷

1. Four new arch-girder intersection pieces were fabricated. Each new piece would replace the lower 6' of a PP-3 girder section.
2. When the new pieces were finished, they were shipped by rail to Murphy Pacific's Swan Island yard in Portland.⁷⁸
3. Meanwhile, Murphy Pacific prepared to remove the two PP-3 tie girder sections from the west side span. This required: (a) installing a new falsework bent between railroad tracks to support the west portion of the side span; and (b) removing two top deck panels and one lower deck floorbeam that were connected to PP-3 sections.
4. Murphy Pacific then unbolted the west side span PP-3 sections one-by-one from adjoining girders. Each 90-ton section was lowered to the ground with two crawler cranes.
5. Wilhelm Trucking of Portland transported the PP-3 sections on its heavy-haul truck "Enormous" to the *Marine Boss* for transport to Swan Island for unloading

⁷⁵ "Advance Print, for Information Only," Fremont Bridge, Details of Panel Point 3, 21 April 1972.

⁷⁶ Kanadoli, "Fremont Bridge Crack."

⁷⁷ Ed Wortman interview

⁷⁸ Photo, ODOT files.

in Murphy Pacific's yard.⁷⁹

6. Murphy Pacific crews cut the lower 6' off each PP-3 section, then bolted on one of the new pieces.
7. When complete, the modified PP-3 sections were transported back to the side spans.
8. All four modified tie girder sections were set in place with the two crawler cranes.
9. Finally, each modified section was bolted to the adjoining tie girder sections and arch. It was necessary for the crews to filed-drill a portion of the bolt holes to connect the new pieces to old.

Repairs totaled \$5.5 million, with the federal government paying 92 percent of the cost.⁸⁰

Opening Ceremony

An opening ceremony called "People's Day" on the Fremont Bridge was the idea of Joan Campf, head of public affairs and promotion at Portland radio station KGW. ODOT agreed to allow KGW to sponsor the party, under certain conditions.⁸¹ The public bus company provided free transportation. Vendors signed up to provide food and music. Schools sent track teams, musicians and dancers. The celebration was held on 11 November 1973. The public, estimated between 25,000 and 30,000, arrived on roller skates, unicycles, crutches, skateboards, bicycles and in wheelchairs.⁸²

⁷⁹ "Wilhelm's on the Beam," *The Wilhelm Driver*, newsletter of Wilhelm Trucking Co., Portland, vol. 7, no. 2, Fall 1972, 1-2.

⁸⁰ "Fremont Span Repair May Cost \$5.5 million," *The Oregonian*, 22 August 1972. The \$5.5 million covered cost of changes made in the bridge and the additional cost of equipment rental, labor and other expenses incurred because of the delay. State and federal interstate funds were used to cover the repair cost as it was used concluded that 96.3 percent of the responsibility was attributable to the bridge's design, approved by both state and federal highway officials. Remaining responsibility for the crack was attributed to the contractor's construction procedures.

⁸¹ Joan Campf, "Wings and High Places," an essay written 1 March 1999 for "BridgeStories," an exhibit about Portland Bridges at the Oregon Historical Society, 15 March 1999 to 1 March 2000. OHS also mounted a photo exhibit called "People's day on the Fremont Bridge," in March 1974. The exhibit, representing the images of 32 people who had attended the People's Day Party, was created by OHS "to stimulate the collection of materials pertinent to contemporary history." From a news release titled, "Information from the Oregon Historical Society," March 1974.

⁸² Nelson Pickett, "People," *The Oregon Journal*, 12 November 1973.

Post-Opening Changes⁸³ (See Appendices, 2)

U.S. and Oregon Bicentennial flags were installed by helicopter on top of the bridge in a public ceremony on 17 May 1976. The epoxy asphalt on the orthotropic deck fared poorly, replaced by conventional asphalt overlay on 29 August 1978.⁸⁴ In 1981, due to the orthotropic's deck tendency to ice easily, eight ice detector sensors were installed on the bridge's upper deck and approach spans, with the monitoring unit operated from the Interstate Bridge.⁸⁵ Access and inspection lighting was installed in 1983.⁸⁶ Peregrine falcons began investigation the Fremont Bridge as a place to call home in 1993, with the endangered raptor actually nesting and hatching on Fremont since 1994.⁸⁷

Post-Opening Studies and Inspections⁸⁸

There has been a continuing series of inspections and upgrading projects on Fremont since it was opened. The high-level of activity has been prompted largely by concerns over the possibility of cracks developing in key structural members. Other concerns have been raised about corrosion of structural members due to water seeping in and damage to the wire rope suspender cables due to vibration from the wind.

⁸³ See Appendices, 16, "Condensed Event Time Line (1963-1997)." Also refer to HAER No. OR-104 Field Notes, and author's "Complete Fremont Bridge Time Line (1963-1998)."

⁸⁴ Letter dated 11 September 1978, from Edward L. Hardt, ODOT Region Bridge Engineer, to Adhesive Engineering Co., San Carlos, California.

⁸⁵ Memos to file date 13 May 1983 and 16 June 1982, from M.W. Stovall, Region Maintenance Engineer. The ice detector system operated so well that it convinced the State to install a similar system on the Glenn L. Jackson I-205 Bridge across the Columbia.

⁸⁶ Letter dated 13 June 1983 from H.S. Coulter, State Highway Engineer to Oregon Transportation Commission.

⁸⁷ In March 1993, the author, on a research trip, climbed through the arch ribs of Fremont Bridge on the top of the arch. A catwalk 77' long stretches between the U.S. and Oregon flags. As our group crossed this walkway (about 380' in the air), two peregrine falcons began diving on us. We had inadvertently interrupted lunch or the mating season, perhaps both, as the peregrines have hatched babies on Fremont since 1994. A bridge can provide two factors critical to peregrine nest site selection: High, inaccessible location and abundant prey in the form of rock doves (city pigeons) and starlings. What bridges don't possess, however, are updrafts that help keep young peregrines airborne as they learn to fly. Because of this, young peregrines raised on the Fremont Bridge tend to end up spending several hazard-filled days on the ground while they perfect their flying skills. Each year a dedicated group of Audubon Society and Oregon Department of Fish and Wildlife volunteers give their time during the fledgling process to help keep the fledges from straying into trouble. ODOT assists in the peregrine effort. In 1997, the agency delivered 200 pounds of gravel to the bridge to help the peregrines better their rocky nests.

⁸⁸ Contracts and reports are on file at ODOT Records and Bridge Section offices, Salem. Also see Appendices 16, "Condensed Event Time Line." Also refer to HAER No. OR-104 Field Notes, and "Complete Fremont Bridge Time Line (1963-1998)."

The concerns about possible cracking were based on several factors: 1) a series of failures in welded steel box bridges around the world in the late 1960s and 1970s; 2) existence of high-strength steels in the Fremont Bridge that are known to be susceptible to cracking under certain conditions; 3) the extensive use of welding in the fabrication; and 4) the effect of strengthening members that were added by the contractor to take erection forces.

Based on available information, there have been no significant cracks found in the bridge during its life. Efforts taken to monitor the bridge and improve its performance include the following: 1) post-construction studies by consulting engineers and materials testing companies; 2) detailed inspections by ODOT and consultants on a regular basis; and 3) modification work at critical locations, carried out primarily by a contractor between 1984 and 1987.

Engineering Advances

T-1 Steel in the United States

After the turn of the century, alloying such as nickel, chrome, and silicon were used to change the crystal structure of steel. This made the steel stronger and allowed engineers to design for longer spans. For example, nickel steel had been used in the stiffening trusses of the Manhattan Bridge in New York and in the truss members of the Quebec Bridge. About the time of Fremont Bridge, American steelmakers began producing extra high strength structural steel by adding certain alloys and treating with heat and quenching ("quenched and tempered"). These were called heat treated constructional alloy steels. In the early 1950's American steelmakers began producing extra high strength structural steel by adding certain alloys and treating with heat and quenching ("quenched and tempered"). These were called heat treated constructional alloy steels.⁸⁹ The most prominent of these steels was ASTM's grade A514. U.S. Steel produced and patented A514 under the brand name T-1. Desirable for its high strength, T-1 steel was used in Fremont's arch rib. "At the time [T-1] was probably the highest strength steel manufactured...for commercial use," recalls Louis Silano. T-1 was extensively used and allowed the designers to bring down Fremont's arch size to a 4'x4' box, which provides the bridge with one of its main features, a very slender arch.⁹⁰ T-1 would eventually fall out of favor, as it was found to be susceptible to cracking, particularly at welds. It was later determined that its high boron content contributed to the formation of stress-relief cracks. In 1973, U.S. Steel recommended changing T-1's formula.⁹¹

Orthotropic Decks in the United States

⁸⁹ R.L. Brockenbrough, "Properties of Structural Steels," *Structural Steel Designers' Handbook* (New York: McGraw-Hill), 1-5.

⁹⁰ Silano oral history (Appendices, 17D in Field Records) 25.

⁹¹ Staff reporter, "How U.S. Steel Reassured Customers Even While It Reformulated T-1 Steel," *Wall Street Journal*, 16 January 1984, 14.

When it opened, Fremont Bridge was the sixth major orthotropic plate bridge in the United States. Orthotropic is a hybrid name for a stiffened plate steel deck. In such decks, the metal is used in two directions, one along the length of the bridge deck and the other cross-ways of the bridge deck, thus "orthogonal." In a typical orthotropic steel deck, the top deck plate serves three functions: 1) as a short beam carrying vehicle wheel loads to the vertical or hatshaped (trapezoidal) stiffener plates running lengthwise to the floorbeams; 2) as the top flange for these lengthwise stiffener plates; and 3) as the top flange of the floorbeams, which run cross-ways to the main trusses or girders. In Fremont Bridge, the deck plate also serves another function as part of the tension tie that carries tension load from one end of the arch to the other. The deck and the two tie girders form one big tension tie, thus "tie arch."⁹²

The orthotropic upper deck, an innovative design feature of Fremont Bridge, was used because it decreases the dead load of the bridge. Orthotropic decks have been widely used in Europe and Japan during the past four decades, with their first use in Germany after World War II to replace a large number of bridges destroyed in the war. This design used steel more efficiently than other bridge types, important in a country faced with serious shortage of steel and other construction materials. During the two decades after the war, more than forty orthotropic bridges were built in Europe. The first major orthotropic-deck highway bridge in North American was the Port Mann Bridge, in British Columbia, Canada, opened in 1964. The first major orthotropic highway bridges in the United States were the San Mateo-Hayward Bridge across the San Francisco Bay and the Poplar Street Bridge in St. Louis, opened to the public in 1967 and 1968, respectively. Major U.S. bridges that followed were Creyt's Road Bridge, on Interstate 496 near Lansing, Michigan, San Diego-Coronado, Queensway Bridge in Long Beach, California, Luling Bridge near New Orleans and Fremont Bridge.⁹³

Despite early interest in this type of bridge in the United States, several factors contributed to limiting its widespread use, the most important being that deck fabrication was labor intensive and the initial cost was generally higher than the cost of the traditional concrete decks in use.⁹⁴ On the other hand, orthotropic decks are popular for replacement of old decks, since they can be installed quickly and reduce dead weight of the bridge. Several large U.S. bridges have had their deteriorated concrete decks replaced with orthotropic steel decks;⁹⁵ among

⁹² Ed Wortman interview by the author, Portland 21 August 1999. Also see Silano oral history (Appendices 17D in Field Records) 5-7.

⁹³ Ali Touran and Alex Okereke, "Performance of Orthotropic Bridge Decks," *Journal of Performance of Constructed Facilities*, American Society of Civil Engineers, vol. 5, no. 2, May 1991, 134.

⁹⁴ Ali Touran and Alex Okereke, "Performance of Orthotropic Bridge Decks," 137.

⁹⁵ Gustav Lindenthal's Smithfield Bridge in Pittsburgh was refurbished with an aluminum orthotropic deck in 1967, and then this aluminum deck was replaced with another deck type in the early 1990s. See "Aluminum Orthotropic Bridge Deck, *Civil Engineering-ASCE*, November 1967, 65.

them are Golden Gate Bridge in San Francisco, Ben Franklin Bridge in Philadelphia, and Throgs Neck Bridge in New York.⁹⁶

During the 1990's, several monumental bridges were built in Europe and in Asia with record breaking spans that would not have been feasible without steel orthotropic decks. In the U.S., the new East Bay section of the San Francisco-Oakland Bay Bridge is scheduled to open after the millennium. Designed with an orthotropic deck system, the East Bay section's estimated cost is \$1.5 billion.⁹⁷

In order to improve structural efficiency and provide guidelines for fatigue design of orthotropic decks, theoretical and experimental studies were started in the 1970's and intensified in the 1990's in several research centers.⁹⁸

Computer Use for design of Fremont's Superstructure

The first use of computers in design of Willamette River bridges was in 1961 when the Oregon State Highway Department used them for structural analysis during design of Marquam Bridge's river pier shafts.⁹⁹ Between the time Parsons signed an agreement with the State to design Fremont Bridge in 1966, and the pier construction began in 1969, the capability of computers for analyzing bridge designs had progressed, with the time-consuming preliminary analysis "vastly improved upon" for Fremont's final design. Solutions to analysis of Fremont's statically indeterminate form, with its arch, deck girder and suspender ropes all interdependent members, were provided by the "Structural Engineering System Solver" or "STRESS" computer program. At the time of Fremont's final design, this revolutionary program was in its infant

⁹⁶ Touran and Dennis Ladick, "Application of Robotics in Bridge Deck Fabrication," *Journal of Construction Engineering and Management*, American Society of Civil Engineers, vol. 115 no. 1, March 1989, 35.

⁹⁷ Caltrans plans to keep spending big in the Bay Area in 2000. It is set to advertise an estimated \$180 million contract for a parallel structure to Benicia-Martinez Bridge carrying Interstate 680, and also in 2000 it wants to seek bids for the \$1.5 billion replacement of the San Francisco Bay Bridges east span. "Bid After Planned This Year to Renovate Bay Area Spans," *Engineering News-Record*, 19 July 1999, 11.

⁹⁸ For an overview of new developments in orthotropic decks, see Roman Wolchuk, "Steel Orthotropic Decks, Developments in the 1990's," a paper presented at the 78th annual meeting of the National Academy of Sciences Transportation Research Board, Washington, D.C., 8-14 January 1999.

⁹⁹ Walter Hart, telephone interview by the author, 20 August 1999. On this same date, Hart researched and interpreted Marquam Bridge Calculation Book No. 636, designer F. Herb Mingle, to determine extent of computer use on Marquam. Hart recalls that ODOT developed one of the first, if not the first, Continuous Bridge Program in the U.S. The computer program's development, by State Bridge Section designer Larry Bush, probably was funded by the U.S. Bureau of Public Roads, renamed the Federal Highway Administration.

stages of development by the Massachusetts Institute of Technology.¹⁰⁰ Fremont was the first use of "STRESS" by Parsons and allowed the design team to create a 3-D model of the deformed shape of Fremont under wind load, something Parsons had never been able to visualize before in long span bridges.¹⁰¹

Engineers, Contractors and other Participants Engineers

Resident engineers for ODOT during construction were Robert O. Cunningham, tied arch; Robert Shotwell, main piers and east approaches; and John Howard, west approaches. Ivan Merchant was State Bridge Engineer during Fremont's design process, succeeded by Walter Hart in 1971. George M. Baldwin was Administrator of Highways, and Tom Edwards was Assistant State Highway Engineer and State Highway Engineer.¹⁰²

Parsons Brinckerhoff, Inc., New York City, employed 8,000 people in 1999. In 1998, they were ranked number one in the U.S. (in dollar volume) for design of transportation, highway and mass transit/light rail, and number two for bridge design.¹⁰³ Founded in 1895, Parsons employed 2,000 at the time of Fremont Bridge construction, designed the Tylon and Perisphere, them structures of the 1939 World's Fair, and was chief designer for the Newport Bridge crossing Narragansett Bay, Rhode Island as well as many other structures.¹⁰⁴ Other Parsons' designs include Bay Area Rapid Transit, San Francisco, and New York City Transit (NYCT) Subway System. Louis Silano served as Fremont's project manager and chief designer. Harrison & Abramovitz architectural firm had a minor involvement in Fremont's early stages.

¹⁰⁰ "Design of the Fremont Bridge." 4. Also , see Silano Oral History (Appendices 17D in Field Records), 15-16.

¹⁰¹ Also see Silano oral history (Appendices 17D in Field Records). Parsons use the UNIVAC computer in Washington, D.C. for Fremont, which ran for "twenty-one hours" before providing results. Ed Wortman recalls the MIT "STRESS" program as "a huge step forward in bridge design that totally changed engineering. This was the first time engineering firms had a program that allowed them to solve their own problems. "STRESS" was to engineering what Word Perfect was to typists." Wortman interview 21 August 1999. Port Mann Bridge, commissioned in 1957 and opened in 1964, was designed during a time that there were no suitable ready-made computer software programs such as Algol or Fortran. Calculations were made with use of the ALWAC computer, installed in 1957 at the University of British Columbia, with the program laboriously written especially for Port Mann in machine code. Hardenberg oral history (Appendices 17A in Field Records), 16-17. See "<http://www.cc.ub.ca/campus-computing/mar97/fortyago.html>" for more about ALWAC.

¹⁰² Handout as part of information packet distributed by ODOT, 1973.

¹⁰³ "The Top 25 in Transportation," "The Top 10 in Highways," "The Top 10 in Mass Transit/Light Rail," "The Top 10 in Bridges," *Engineering News-Record*, September 1998, 57-58.

¹⁰⁴ Benson Bobrick, *Parsons Brinkerhoff, The First 100 Years* (New York: Van Nostrand Reinhold, 1985).

They went out of business in the seventies.¹⁰⁵

Howard Needles Tamman & Bergendoff (HNTB), Kansas City, Mo., was design consultant for Fremont's approaches. Later ODOT contracted with HNTB to study and report on Fremont's side span erection procedures and crack in November 1971, and to carry out post-construction studies in 1982 and 1987.¹⁰⁶ In 1998, HNTB was ranked fourth in U.S. transportation and highway design projects, and third in bridge design. One of the descendant firms of Waddell and Harrington, Kansas City, Missouri, HNTB designed the Alsea Bay Bridge on the Oregon Coast, opened in 1992, and also redesigned Burlington Northern Bridge 5.1, across the Willamette River, from a swing bridge to vertical lift in 1989.¹⁰⁷

Earl and Wright, San Francisco, were consultants to Murphy Pacific for Fremont Bridge's tied arch engineering, with Richard A. Leber, Earl and Wright's project engineer. Earl and Wright were consulting engineers specializing in marine construction, design of docks and wharfs, and bridge construction. They were one of the world's leading designers of offshore oil platforms from the 1960s to the 1980s. They are no longer in business on the West Coast.¹⁰⁸

Contractors

Murphy Pacific Corp., Emeryville, Ca., was prime contractor, primary fabricator and steel erector for Fremont's tied arch. The company and its predecessor firms were leading West Coast builders from the 1940s to the 1970s. Projects included steel fabrication and erection of the Dallas and Interstate (1958) bridges across the Columbia River. Murphy Pacific dominated welded box girder construction on the West Coast in the 1960s for at least two reasons: 1) The firm built and operated the first big West Coast-based derrick barge for large construction projects (*Marine Boss* was the Derrick barge that erected much of Fremont's steel and helped float in the center span), and 2) the firm owned and operated its own fabrication plant (Emeryville) and assembly yard (Richmond). In addition to Fremont and other bridges, Murphy Pacific was prime contractor for San Mateo-Hayward Bridge in San Francisco Bay, San Diego-Coronado Bridge in San Diego, and Queensway Bridge in Long Beach, California. William Choate was project superintendent of construction throughout Fremont's construction, and was also project manager before the tied-girder failure. Alpo J. Tokola served as project manager after the crack. Jack Geer was project engineer for the planning process, with Ed Wortman on-site project engineer during construction. J. Phillip Murphy, president of Murphy Pacific, dies

¹⁰⁵ E-mail to the author from L.G. Silano, 30 August 1999, address Corpins@pbworld.com.

¹⁰⁶ See "Condensed Event Time Line."

¹⁰⁷ See Condensed Event Time Line. Also see Kathi Ann Brown, *Diversity by Design, Celebrating 75 Years of Howard Needles Tamman & Bergendoff, 1914-1989* (Kansas City: HNTB).

¹⁰⁸ Interview with Ed Wortman.

just before Fremont's construction commenced, with his son, Jay P. Murphy taking over as president. The company stopped building bridges shortly after Fremont Bridge opened.¹⁰⁹ Takola formed Takola Corp. in 1973, designing bridges, buildings and off-shore platforms from offices in Portland. Ed Wortman was vice-president for Takola from 1973 until 1994. In 1989 Wortman served as construction engineer for reconstruction of Burlington Northern Railroad Bridge 5.1 across the Willamette River from a swing bridge to a vertical lift. In 1994, he was hired by Multnomah County where he worked as an engineer full-time until 1999.

Peter Kiewit Sons' (renamed Kiewit Group), Omaha, was contractor for Fremont's piers. Kiewit was ranked number one contractor in transportation, highways and bridge construction in the U.S. in 1998.¹¹⁰ Long active in the Portland area, Kiewit was also the contractor for Marquam Bridges's substructure, and during the 1990's, contractor for widening of Interstate 84 east of Portland and for Crooked River Gorge Bridge near Bend, Oregon, to name just a few projects.

Andersen-Hannan were two Portland general contracting companies that formed a joint venture for the west approaches, sub-contracting with Willamette Western for the steel erection. For Andersen-Hannan, Ralph Hannan served as project manager, with Bob Meadow as Willamette Western's erection superintendent. John Howard was resident engineer for the State. H.A. Anderson Co. has been a Portland-area general contractor since the 1950s. Major Portland-area Anderson projects have included the Portland Hilton Hotel, Textronix campus, and in 1999, St. Vincent Hospital additions. Henry and Ralph Hannan, principals for Hannan Brothers Construction Co. of Southeast Portland, are deceased.¹¹¹ Both Henry Hannan and H.A. Anderson were presidents of the Associated General Contractors of America, Oregon-Columbia chapter, Anderson in 1968 and Hannan in 1970.¹¹²

The Donald M. Drake Co. and Willamette Western joint ventured for three of the four prime contracts for the east approach construction, and also for a second, smaller contract for the west approach after Anderson-Hannan finished its larger contract. The Drake-Willamette joint venture operated under the name "Willamette River Contractors" for the east approach work. Project manager for Willamette River Contractors on the east approach was Bill Bugge. Robert Shotwell was resident engineer for the State.

¹⁰⁹ Jay P. Murphy, telephone interview by the author, 5 November 1993.

¹¹⁰ "The Top 50 in Transportation," "The Top 25 in Highways," "The Top 25 in Bridges," *Engineering News-Record*, November 1998, 51-54.

¹¹¹ H.A. (Andy) Anderson, telephone interview by the author 24 August 1999.

¹¹² "The Bridge," *Oregon-Columbia Constructor*, Summer 1990 A-2.

Drake has been a long-time Portland general contractor. In the early 1990s, Drake joint ventured with Turner Construction Co. of New York as prime contractor for the Portland Trail Blazer basketball team's Rose Quarter Arena. Willamette Western was a division of the Portland-based Reidel family enterprises, which were active in general contracting, marine and bridge construction, dredging, barging, tug operations, sales of the sand and gravel, and production of readi-mixed concrete. The Reidel enterprises went out of business in the 1980s. In all, Willamette Western shared in four of the five prime approach span contracts for Fremont (three east, one west), and in one contract as a sub-contractor for steel erection (west).

E. Carl Schiewe Co., another Portland general contractor, moved buildings and preformed other site preparation work for the east approaches. Schiewe Company was still in business in 1999, with Carl Schiewe retired.¹¹³

Public Involvement Design Team

At the time of Fremont Bridge, the Portland Art Commission board members were appointed to serve in a volunteer capacity to advise in matters of civic arts. Each member represented a category of fine art, such as music, or theater, for example. Chairman Douglas Lynch, a graphic artists credited with design of City of Portland's flag, represented visual arts. Lewis Crutcher, A.I.A., Portland chapter, represented architecture, and about the time of Fremont's design selection was selecting colors for the downtown Willamette River bridges to be painted by Multnomah County. Although the other members of the commission wanted Fremont to be a suspension bridge or an arch, Lynch would have preferred a different approach, "a design that was a ribbon, without any visible supports."¹¹⁴ The Portland Art Commission evolved to be the Regional Arts and Culture Council, so-named in 1995.

Werner Storch of Storch Corporation Engineers began business in Lake Oswego, moving to Portland and eventually to Vancouver, Washington. Specializing in industrial structures, Storch provided design and 85 percent construction for Valdez Grain Export Terminal in Veldez, Alaska, erected after the 1964 Alaska earthquake. Storch also designed the original melt shop at Oregon Steel Mills on Portland, finished during the time of his involvement with Fremont Bridge. Storch's article about Fremont Bridge was published in the book, *Triump der Spannweiten*, ed. Dr. Ing. hans Wittfoht (Dusseldorf: Beton-Verlag GmbH, 1972) 52.¹¹⁵ At the time of Fremont's design collaboration, Roland Haertl was employed as an engineer in Storch offices. Haertl Development Co. lists an address at N.W. Cornell Road.

¹¹³ Carl Schiewe, telephone interview by the author 24 August 1999.

¹¹⁴ Douglas Lynch interview 8 August 1999.

¹¹⁵ Storch interview by the author at Vancouver, Washington 18 August 1999. See also Storch oral history (Appendices 17E in Field Records).

David Soderstrom's name appears on a rendering of a proposed Fremont Bridge that survives as an 11"x17" framed image hanging at Storch offices in Vancouver, Washington. This undated drawing was used to promote the idea of a three-span tied arch as adapted from the Port Mann Bridge to the Portland Art Commission.¹¹⁶ An architect, Soderstrom formed Soderstrom Architects P.C. with eight partners in 1984 in Southwest Portland where he was doing business at the time of the study for HAER No. OR-104. The company specializes in designs for educational institutions. During the 1970s, Soderstrom was chairman of the Portland City Planning Commission, and helped draft the Portland Downtown Plan guidelines, adopted by Portland City Council in 1972.

C.B.A. Engineering, Vancouver, British Columbia, was successful for a number of years after partnering with NEDECO for design of Port Mann Bridge. In 1981, C.B.A. joint ventured downstream of Port Mann Bridge, the Alex-Fraser Bridge opened as the longest cable-stayed bridge in North America. When the founders of C.B.A. got to the end of their careers, the company never made the transition to the new generation. C.B.A. was bought by a company called Crippen, which was bought by still another company, which eventually went out of business.¹¹⁷

About the time Fremont Bridge was under construction, Gerrit Hardenberg, chief designer of Port Mann bridge and engineer for NEDECO, was chief engineer for the Engineering Directorate of the West Gate Bridge in Melbourne, Australia after the West Gate Bridge collapsed in 1970.¹¹⁸ This box girder bridge failed during erection, killing 35 engineers and construction workers. Hardenberg was also responsible for the design and contract supervision for the Willems Bridge in Rotterdam, a cable-stayed bridge with a main span of 900'. For a large part of his career he worked with a fabricator and built bridges with designs prepared by others.¹¹⁹ Hardenberg was 72, retired, and living in Dordrecht, Netherlands at the time of the HAER No. OR-104 study.

Craft Workers

Craft workers on Fremont Bridge included carpenters, ironworkers, laborers, pipefitters, and operating engineers. On the west approach steel erection work, sub-contractor Willamette

¹¹⁶ David Soderstrom interview 18 August 1999. Also see Storch oral history (Appendices 17E in Field Records).

¹¹⁷ Peter Taylor oral history (Appendices 17F in Field Records) 7.

¹¹⁸ "Report of Royal Commission into the Failure of West Gate Bridge," (Melborne: R.H. Rixon, Government Printer, 1971), presented to both houses of parliament pursuant to sec. 7 of the West Gate Bridge Royal Commission Act 1970, No. 7989, 3; letter from Gerrit Hardenberg to the author 20 August 1999.

¹¹⁹ Hardenberg oral history (Appendices 17A in Field Records), 16-17.

Western had a total of about 35.¹²⁰ On the toed arch superstructure, the largest labor force was used during the center span lift when the ironworkers worked around-the-clock in twelve-hour shifts for 54 hours.¹²¹ There was one fatality on the project. Construction worker Leo Marmolaja, an employee of Anderson-Hannan joint venture, fell approximately 45' when scaffolding collapsed in May 1990.¹²²

¹²⁰ "Giant Jig-Saw of 100-ton Pieces is Portland's Fremont Bridge," *Pacific Builder & Engineer*, 2 April 1971, 34-35.

¹²¹ Worley oral history (Appendices 17G in Field Records) 4.

¹²² "Worker Dies in Tumble," *The Oregonian*, 23 May 1970.

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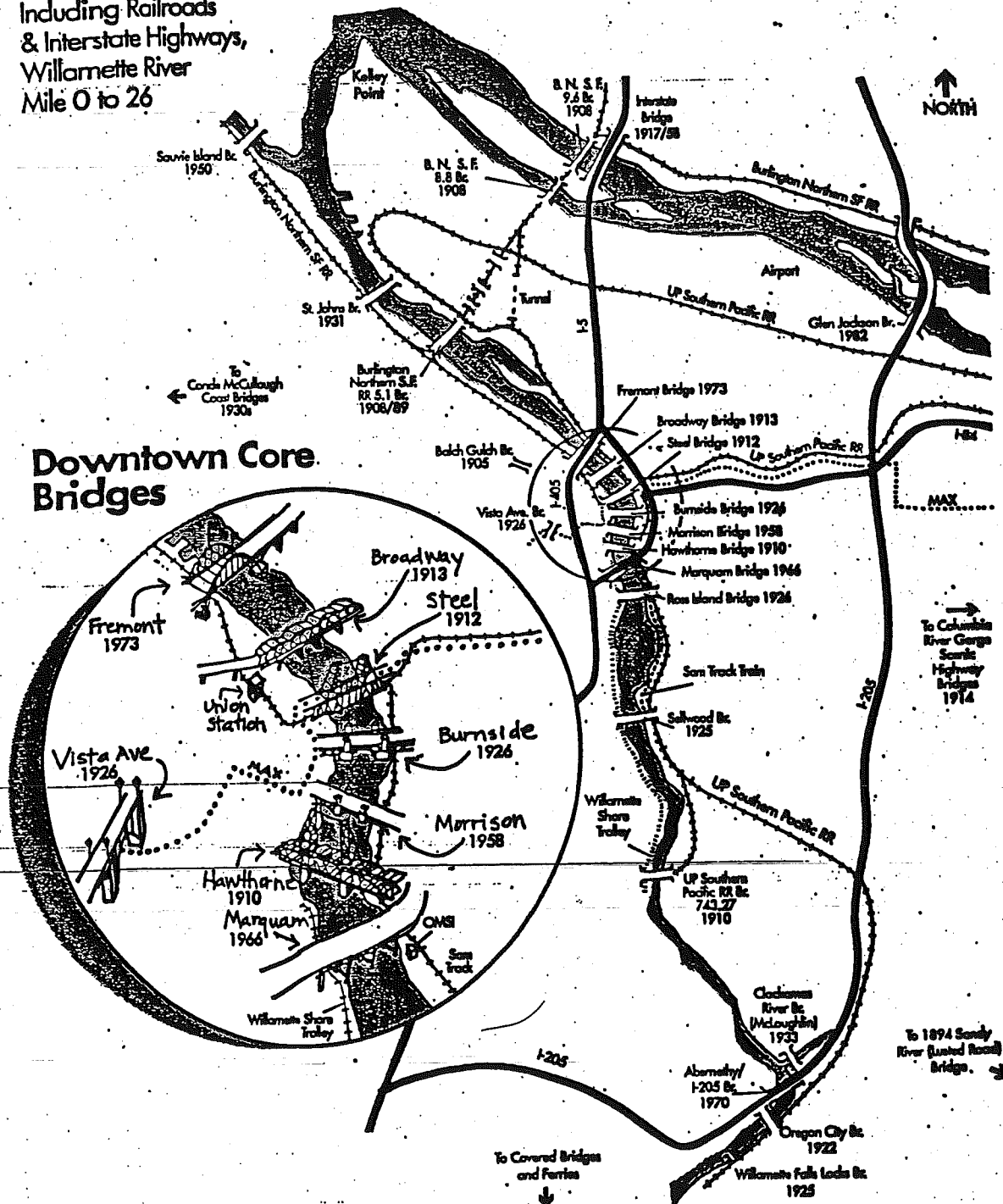
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Portland's Bridges

Including Railroads
& Interstate Highways,
Willamette River
Mile 0 to 26



Condensed Event Time Line: Fremont Bridge (1963-1997)¹

Notes: 1. Timeline begins with award of first engineering contract for Fremont Bridge. Prior planning studies are not included. 2. Unless noted otherwise, entries refer to the main three-span tied arch structure of the Fremont Bridge. Other entries refer explicitly to the East of West Approaches (also referred to in contracts and correspondence as "East and West Fremont Interchanges").

Timeline

Oregon State Highway Department (OSHD awards original contract for preliminary design studies for Fremont Bridge to Parsons, Brinckerhoff, Quade & Douglas, NYC	10 October 1963
Storch. C.B.A. team submits proposal for three-span tied arch alternate	October 1964
OSHD signs agreement with Parsons for final design of three-span the arch bridge including substructure	21 September
OSHD awards contract for design of East and West Approaches to Howard, Needles, Tammen & Bergendoff (HNTB), Kansas City, Missouri	15 March 1967
OSHD awards contract to Peter Kiewit Sons' for construction of piers for tied arch structure and street relocation.	27 February
OSHD awards contract for construction of West Fremont Interchange Unit 1 to Anderson-Hannan (joint venture) of Portland	29 April 1969
OSHD awards contract for construction of Fremont tied arch superstructure to Murphy Pacific Enterprises, Emeryville, California	3 July 1969
OSHD awards contract for building work at East Fremont Interchange to E. Carl Schiewe Co. of Portland	9 September

¹ See Historic American Engineering Record (HAER), National Park Service, U.S. Department of the Interior, "Fremont Bridge," HAER No. OR-104.

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ODHD awards contract for construction of East Fremont Interchange Units A, B and C to Willamette River Contractors (joint venture of Willamette Western and Drake Construction)	11 September 1969
Murphy Pacific subcontract with adhesive Engineering to install epoxy asphalt on Fremont's upper deck	20 November 1969
First structural steel erected on Fremont project: West Approach ring girder set by steel erector Willamette-Western	21 July 1970
OSHD awards contract for construction of West Fremont Interchange Unit 2 to Drake-Willamette (joint venture)	26 August 1971
Tie girder cracks in west side span during erection	28 October 1971
OSHD awards contract to HNTB for study of side span erection procedures and the tie girder crack.	9 November 1971
OSHD engineers and consultant hold "slide rule session" at State's Metro office to determine cause of tie girder fracture; outcome; caused by locked-in stresses.	28 February 1972
Statement by Tom Edwards, State Highway Engineer, concerning cracked girder in Fremont.	21 March 1972
HNTB submits report on Center Span Erection	7 April 1972
Murphy Pacific ironworkers placed final piece of arch steel in center span at Swan Island	1 May 1972
OSHD announces that FHWA will pay 92% of \$5.5 million cost of repairing tie girder crack	27 December 1972
Murphy Pacific completes center span lift	16 March 1973
People's Day on bridge	11 November 1973
Bridge opens to traffic	15 November 1973
Fremont wins annual Long Span Bridge Award from the	

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American Institute of Steel Construction 1974

Public event to celebrate U.S. and Oregon Bicentennial flags installation (by helicopter) on top of bridge. Poles, flags and installation cost \$10,000. 17 May 1976

OSHD completes two-year program of wear test measurements on Fremont's upper deck wearing surface March 1977

Asphalt Engineering (Construction Polymar Technology) completes application asphalt concrete overlay to top deck 29 August 1978

OSHD contracts with Wiss, Janney, Elstner (WJE) of Chicago for post-construction study to assess long-range performance of Fremont's main supporting members 6 January 1979

Ice Detector system for upper deck and approach spans installed by OSHD, and approved by FHWA; \$122,000 approximate cost 21 August 1980

OSHD inspects suspender cable spacers (vertical cable wind stabilizers). 14 December 1981

WJE submits a report on "Post-Construction Evaluation Study, Fremont Bridge" 30 December 1981

OSHD issues status report on "Fremont Bridge Post-Construction Study" by HNTB. Report notes that HNTB's study included a review of the Fremont design by Ammann & Whitney of New York 17 March 1982

Oregon Transportation Commission meeting request for access lighting and minor structural modifications; Phase I cost \$100,000 1983

OSHD awards contract to Warren Pacific for structural modifications including work at the Panel Point 14 and 34 arch-tie girder intersections over the river 1984

John Howard, OSHD Project Manager, issues Narrative Report on Fremont Bridge Modification Project as executed by Warren Pacific. Project work began in 1984 and finished in February

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1987

18 March 1987

Nozwar Ardalan, OSHD engineer, writes memo to file reporting on "limited multi-year (5-year frequency) inspection" of Fremont Bridge by an ODOT team in Oregon 1991

4 February 1992

ODOT awards contract to WJE for In-Depth Inspection

9 September 1996

ODOT Maintenance orders inlay paving for top deck of Fremont

14 January 1997