DESIGN AND TESTING OF INNOVATIVE CRADLE SYSTEM FOR CABLE STAYS; MAUMEE RIVER BRIDGE, TOLEDO, OHIO

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ABSTRACT

A new stay cable cradle system allowed for flexibility in the pylon aesthetics of the New Maumee River Crossing, the system's initial application. The bridge will have a single 404' pylon; the top 196' faced in backlit glass. The cost-efficient cradle system saved the owner over $3 million and provides other advantages including improved fatigue resistance, continuity of main tension element, better load transfer to pylon and more complete inspection system with 2 reference strands per stay to verify the condition of the stays in the future.

Keywords: Cradle, Saddle, Cable Stay, Testing, Aesthetics, Pylon, Sheathing, Strand

INTRODUCTION

December 2001 brought the successful completion of all testing associated with the innovative new cradle system for stay cables designed by Figg Engineering Group (FIGG) for initial use on the Maumee River Crossing; I-280 (1.2 million square foot bridge deck) in Toledo, Ohio for the Ohio Department of Transportation (ODOT). The bridge will have a single 404' pylon; the top 196' faced in backlit glass (see Figure 1).

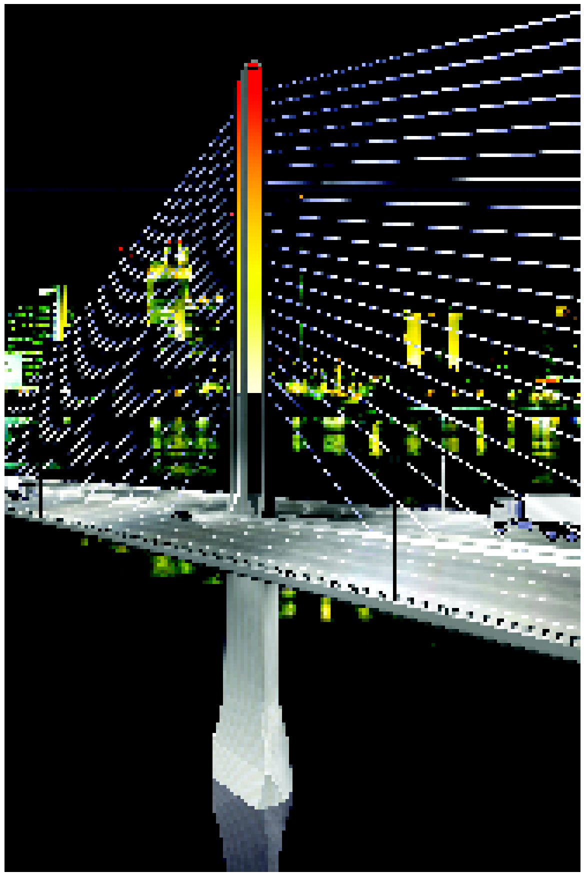

Fig. 1 Maumee River Bridge Night Time Rendering

The new cradle stay system provides a continuous cable stay from the bridge deck, through the cradle on the pylon and back down to the bridge deck. Each strand passes through its own individual stainless steel sleeve in the cradle assembly and is housed within stainless steel sheathing for its free length.

Previous cable stayed bridges have utilized either discontinuous cables with anchorages in the towers or continuous cables passing through curved saddle pipes where the strands bear one atop the other in the curved section of the cable. As stay cable size increases, the tensile forces in the tower of discontinuous cable systems (see Figure 2) become more difficult to manage.

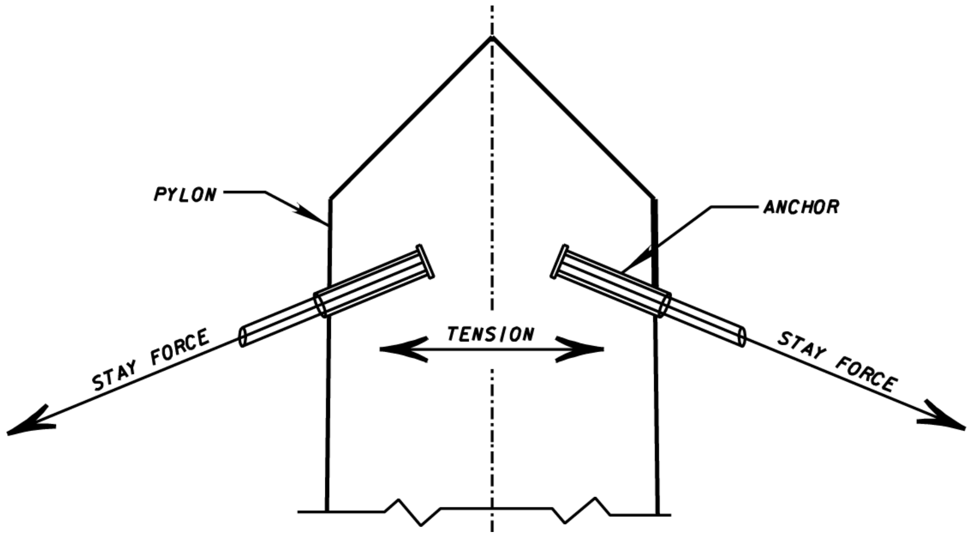

Fig. 2 Tension From Conventional Pylon Anchors

Similarly, as cable size increases, the contact forces between stay cable strands of systems utilizing conventional saddles becomes more of a concern. Since the stay cables of the New Maumee River Crossing are more than 170% the size of the previous largest American stay cable, a new approach was need.

MAUMEE RIVER CROSSING - AN INITIAL APPLICATION

For the New Maumee River Crossing, the main span cable-stayed unit consists of a single pylon with a single plane of stays and a 612’-6” span on each side of the pylon. During community design charettes led by Figg Bridge Engineers, the participants selected the theme of glass, based on the city’s rich heritage in the glass industry. The decision to incorporate glass into the bridge design was manifested by facing four sides of the top 196’ of the pylon with glass.

Without the new cradle system, this aesthetic treatment of the pylon would have been impossible, as would the slender design of the pylon itself. Utilization of traditional anchor systems would have required the pylon to be at least an additional ten feet in width. The series of 20 stay cables, each inside stainless steel sheathing for their free length, will run continuously through the cradle within the pylon to support the bridge deck. Stay sizes vary from 82 to 156 strands. The 156 strand cable will be the largest ever used on a cable-stayed bridge. This stay cable size and load capacity is also a significant increase over the largest US stay cables in existence. Additionally, the Maumee River Crossing includes the use of stainless steel material in lieu of HDPE or carbon steel for the sheathing and incorporates epoxy-coated strands.

BENEFITS AND FEATURES OF THE CRADLE SYSTEM

One of the primary benefits of the new stay cable cradle system is to allow engineers to design pylons that will be slender and aesthetically-pleasing by eliminating the anchors previously used in many previous pylon designs.

The cradle is a proven cost effective system. Prices for the cable stay system verify that each "Cradle System" is less expensive than the two anchors in the pylon that it replaces. Additional cost savings occur because of the reduced materials in the pylon resulting from the possible size reductions and elimination of direct tension between conventional pylon anchorages (see Figure 2). Instead, the cradle applies the stay cable forces to the pylon in a more natural compressive manner (see Figure 3).

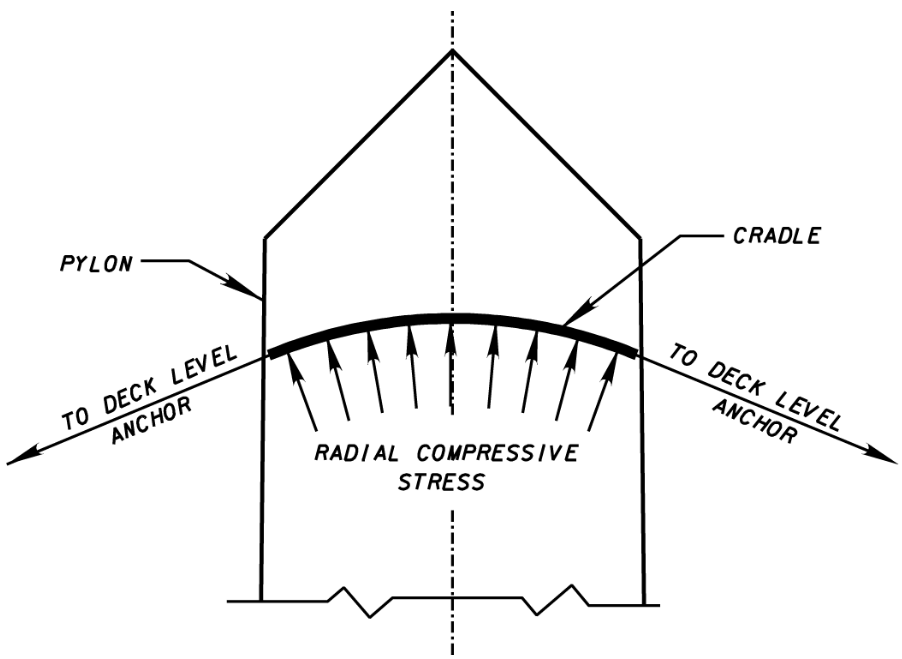

Fig. 3 Application Of Loads From Cradle System

The cradle system allows for long-term verification of the condition of the stay cable system, in the future, in ways not previously possible. Reference strands can be incorporated for purpose of future inspection. A "reference strand" is a cable strand that can be removed as a single piece from deck anchor to deck anchor, visually inspected and later subject to independent laboratory tests if desire. Any strand within the cable can be selected as a reference strand. It is not necessary to pre-designated which strands are to be "reference strands", only how many have been included per cable. Reference strands do not have to be replaced if and when removed. For the New Maumee River Crossing, a total of 40 reference strands were included in the design. These may be removed and inspected at 25 years, 80 years, etc. to verify the condition of the stays, without compromising the designs integrity.

DETAILS OF THE CRADLE SYSTEM

The new cradle stay system utilizes continuous cable stay strands from the bridge deck, through the cradle on the pylon and back down to the bridge deck (see Figure 4).

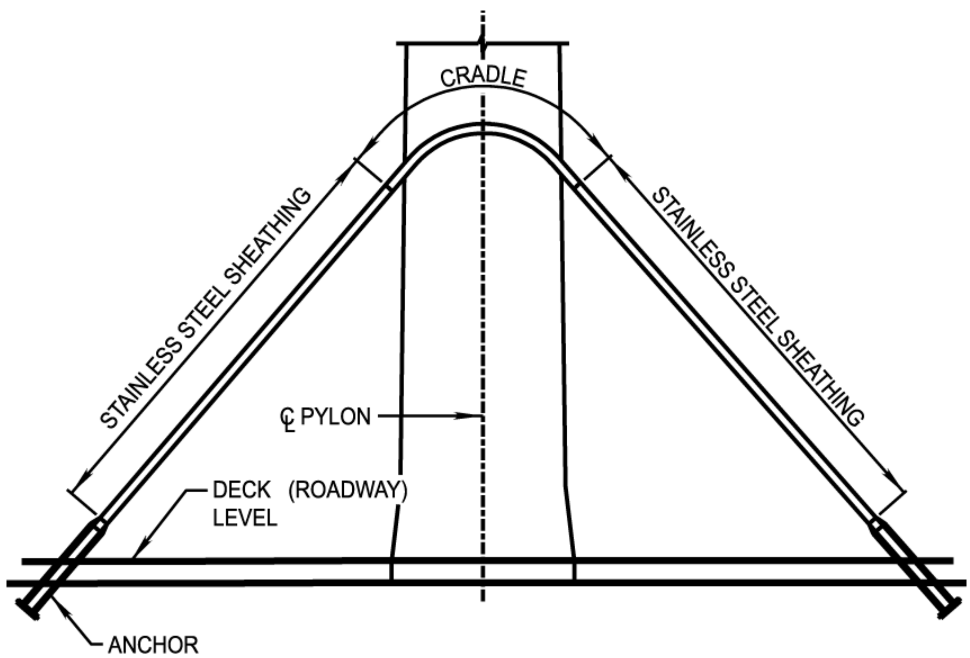

Fig. 4 General Cable Layout

Each strand passes through its own individual stainless steel sleeve in the cradle assembly (see Figures 5 & 6) and is housed within stainless steel sheathing along its free length.

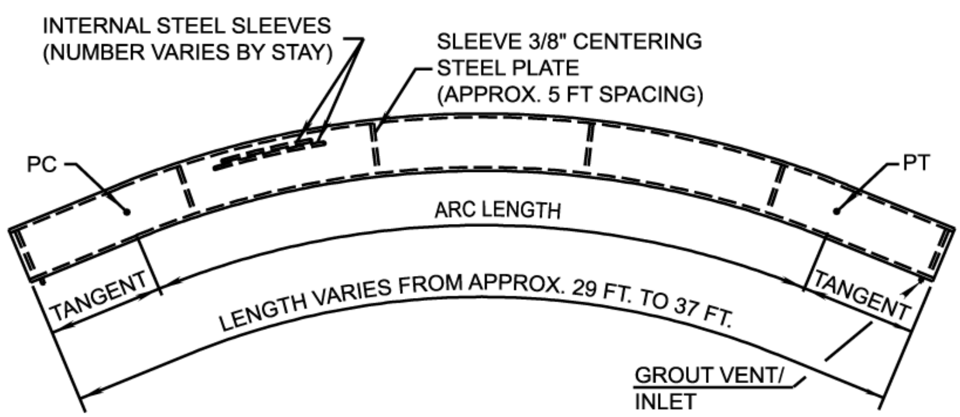

Fig. 5 Cradle Detail (Elevation)

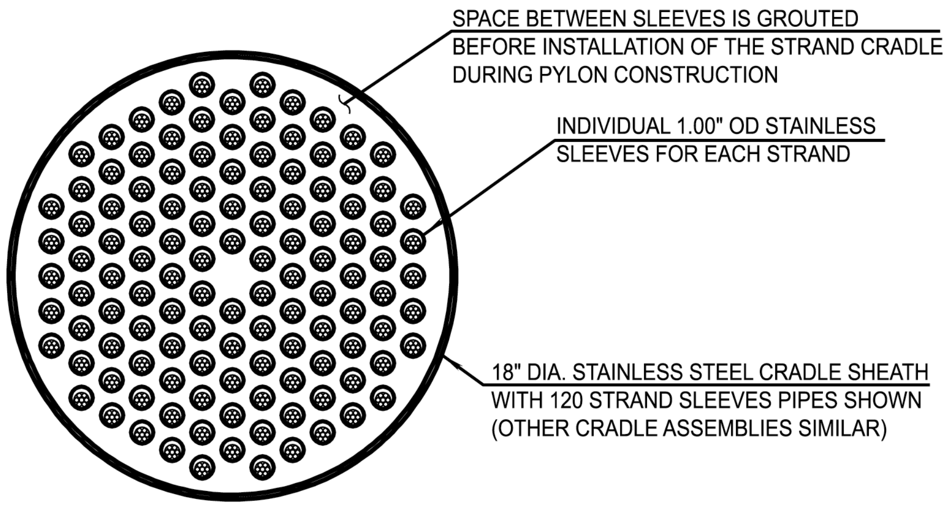

Fig. 6 Cradle Detail (Cross-Section)

The ends of the internal sleeve pipes are flared (see Figure 7) to protect the epoxy-coated strands from potential damage by scraping.

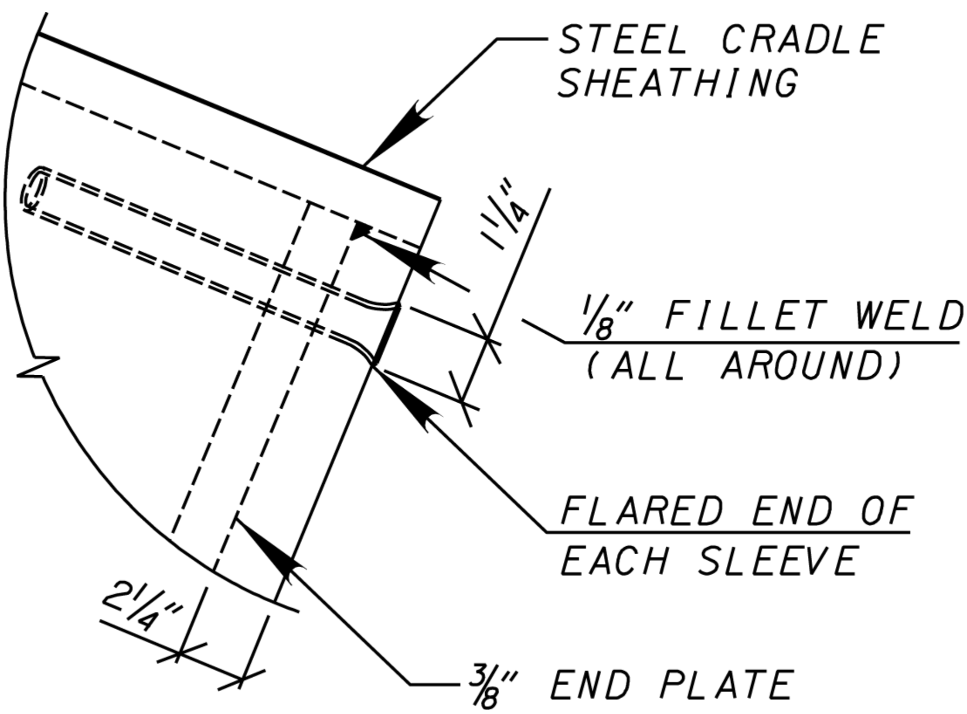

Fig. 7 Cradle End Detail

STAY CABLE SYSTEM PRE-PURCHASE & TESTING

Given the significance of the new system, along with additional innovations on the Maumee River Crossing, the Ohio Department of Transportation (ODOT) and the Federal Highway Administration required a comprehensive testing program before approval to proceed.

As recommend by FIGG, ODOT pre-purchased the stay cable system (from DYWIDAG-Systems, International, USA, INC (DSI)), including all strands, anchors, sheathing and miscellaneous components for the testing and production phases. (This pre-purchase of the entire stay system is a first for America and will become a FIGG standard on future cable stayed bridge to save money and time.)

The complete stay cable system will be provided to the successful Contractor (FruCon). Under this delivery system, the Contractor is not responsible for the stay-cable testing program. Testing of the stay cable system, including the new cradle portions, involved material acquisition, production and acceptance testing for the components of the stay cables, along with fatigue and strength testing of full-scale cable assemblies.

Testing was conducted by CTL (Construction Testing Laboratories, Inc.) under contract to ODOT. All tests were conducted in accordance with the PTI recommendations and reviewed in advance by the FHWA.

OVERALL TESTING PROGRAM

Acceptance testing was performed in accordance with the 1993 PTI Recommendations for Stay Cable Design, Testing and Installation (and included the leak test which was adopted from the 2000 edition). All testing was completed successfully in early December 2001.

The acceptance testing program consisted of the following tests:

- Axial fatigue and ultimate static test of an 82-strand specimen that is fully representative of all materials, details, fabrication and assembly procedures proposed for production anchorages. Each specimen consisted of two anchorages with a clear space of approximately 180 inches between anchor faces.

- Axial fatigue and leak test of a 119-strand specimen. In addition to the fatigue testing of the specimen and, as part of the corrosion protection qualification of the anchorage assembly, the stay cable anchorage specimen, complete with transition zone, a minimum of one meter of free length, and all seals, coatings and coverings that will be installed in the actual application were subjected to a leak test.

- Axial fatigue and ultimate static test of a 156-strand specimen (a world record for stay size) that is fully representative of all materials, details, fabrication and assembly procedures proposed for production anchorages. Each specimen consisted of two anchorages with a clear space of approximately 180 inches between anchor faces.

- Single strand cradle testing. Prior to conducting a test of the full size cradle specimen for the combined axial/flexural fatigue test, three similar tests (each with a different radius) were conducted on one-strand specimens. The purpose of these single strand tests was twofold. First, it provided a value for the friction coefficient between the epoxy-coated stay cable strand and the stainless steel sleeve inside the cradle. Second, it provided an initial indication of the fatigue behavior of the epoxy-coated stay cable strand interaction with the stainless steel sleeve.

- Axial/flexural (Cradle Test) test of a 119-strand specimen. The specimen for the test was fully representative of all materials, details, fabrication and assembly procedures proposed for the production anchorages and stay cable cradles. The specimen consisted of two anchorages and one complete stay cable cradle assembly (see Figure 8).

Fig. 8 Axial/Flexural (Cradle Test)

FABRICATION OF THE TEST CRADLE

The cradle consists primarily of a large diameter curved exterior sheathing, internal centering "cheese plates" and curved individual strand sleeves. Each of these components is stainless steel.

Fabrication began with installation of the centering plates into the exterior sheathing and installation of the individual sleeve pipes (see Figures 9 & 10).

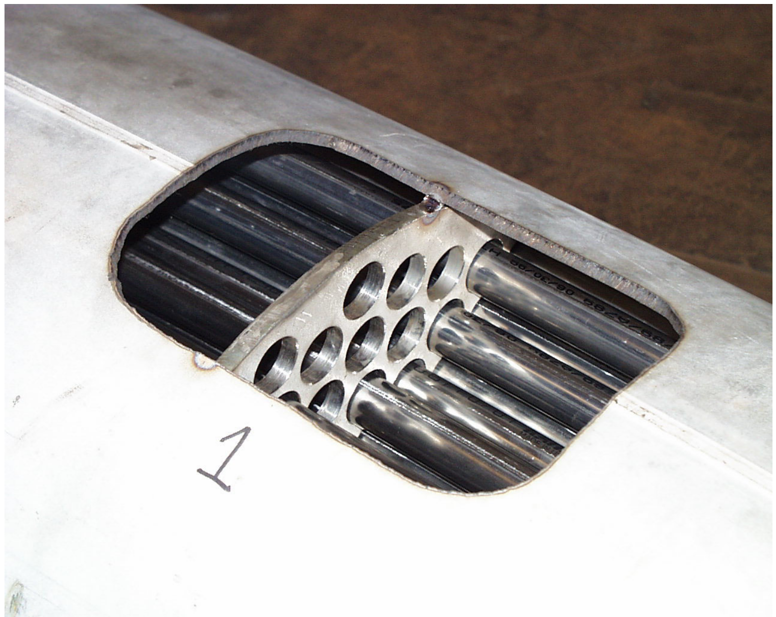

Fig. 9 Installation of Centering Plates

Fig. 10 Installation Of Individual Strand Sleeves

Once fabrication of the cradle components was completed, the interior of the system (between the individual strand sleeves) was grouted (see Figure 11)

Fig. 11 Grouting of Cradle

Once completed, the fully grouted cradle pipe assembly was installed into the concrete test block (see Figures 12 & 13).

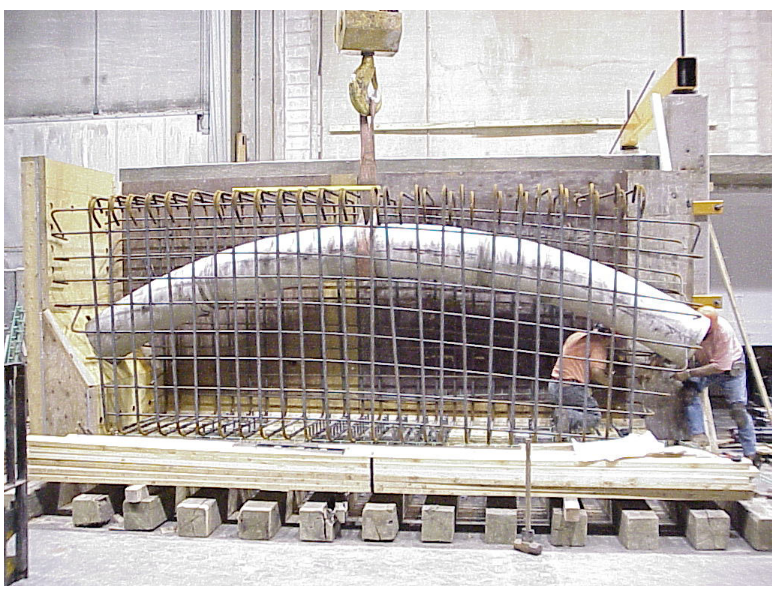

Fig. 12 Cradle Test Block Fabrication

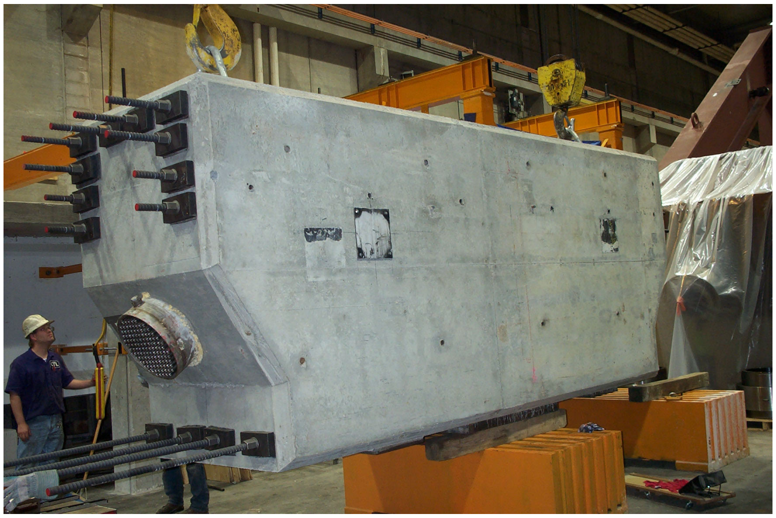

Fig. 13 Completed Cradle Test Block

The completed test block was then placed into the test frame, the epoxy coated stay cable strands installed and stressed to their initial load (see Figure 14).

Fig. 14 Epoxy Coated Strands Exiting From Test Cradle

CRADLE TEST RESULTS

The cradle test was cycled through more than 2 million cycles of combined axial and flexural fatigue loading without any wire fractures. The cyclic load values were highly elevated values compared to the actual anticipated fatigue range of the actual bridge. It is estimated that the total accumulated fatigue damage during the test was more than 3500 times that which will accumulate in any bridge cable during 100 years of service.

OUTCOME

The successful completion of the testing phase validated the FIGG-designed cradle system and allowed the Maumee River Crossing to move forward to bid on January 17, 2002. It also offers ODOT and future clients many benefits:

- Cost-effectiveness: The cradle system saved over $3 million on the Maumee River Crossing Bridge. When cable stay anchors are used in pylons, the pylons need to be large enough to permit internal access during construction for stressing operations of the stays and for inspection of the anchors after construction. Also, significant additional reinforcing is needed to overcome the large splitting stresses in the concrete pylon. By using the cradle, internal to the pylon, access requirements are eliminated allowing the use of a smaller pylon cross section. This saves not only concrete and steel, but also construction time. Additionally, the unit cost of a cradle is less than that of the two pylon anchors it replaces.

- Improved Fatigue Resistance: Perceived concerns generated by strand-to-strand interaction in the curved portion of the cable saddles is eliminated by the use of individual sleeves inside the cradle for each strand. All strands run parallel from anchor at deck level to cradle to anchor at deck level.

- Continuity Of Main Tension Element: Allows use of a continuous primary tensile element from deck level anchor to deck level anchor.

- Better Load Transfer To Pylon: The load transfer to the concrete pylon occurs in a natural compressive contact stress applied vertically to the pylon. Not only is this a more desirable structural condition, but it also saves time and money since no additional reinforcing is required in the pylon to control the high splitting forces that would be introduced if anchors were used in the pylon.

- More Complete Inspection: Provides the flexibility of "reference" strands that can be removed in their entirety at desired time intervals for inspection...15 years, 50 years, etc. so that ODOT will always know the condition of the stays. This is the only cable stay system with this “foolproof” continuous end-to-end stay inspection system.

CONCLUSION

The innovative cable stay cradle system designed by Figg Engineering Group, initially for the Maumee River Crossing, and for use on future cable stay bridges, will revolutionize cable stay bridge design. It will allow this type of bridge to be even more economical, thus attractive for many major spans around the world. It also allows for easy inspection of the stays at 20 years, 75 years, etc. in the future.

The elimination of pylon anchors allows the designing engineer to utilize a wide variety of shapes and aesthetics in designing the pylons of cable-stayed bridges. This greater freedom will encourage engineers to design bridges as art (see Figure 15).

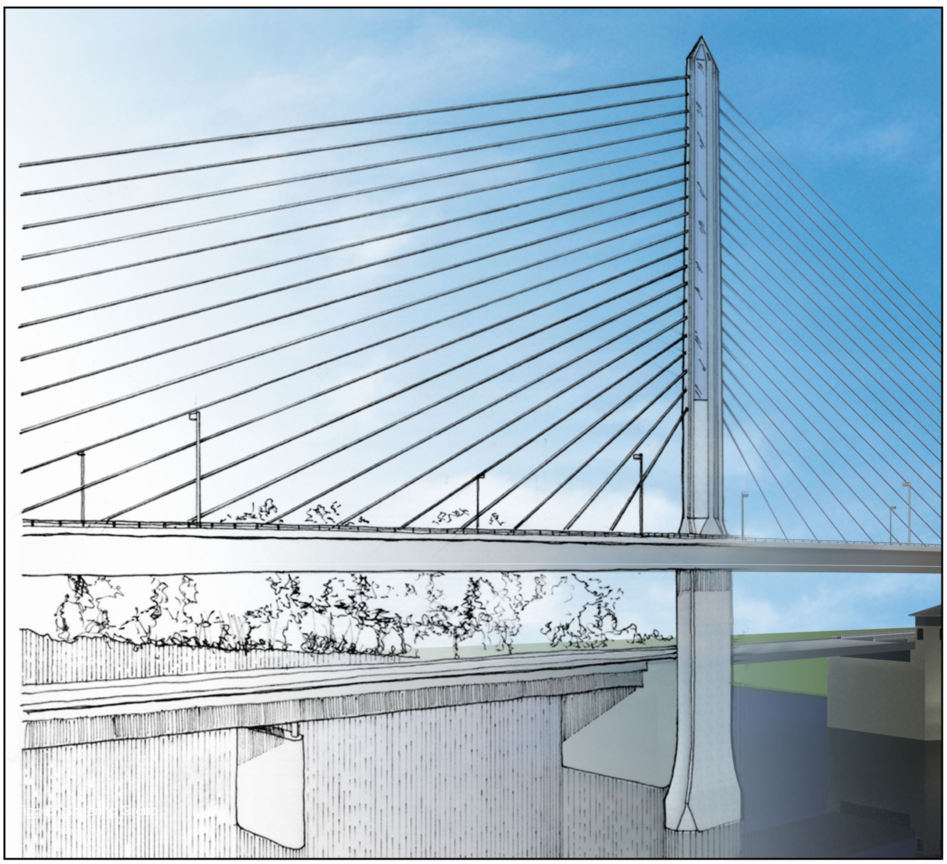

Fig. 15 The New Maumee River Bridge (foreground)
With The Existing I-280 Bridge (background)