Stretching over the Ohio River

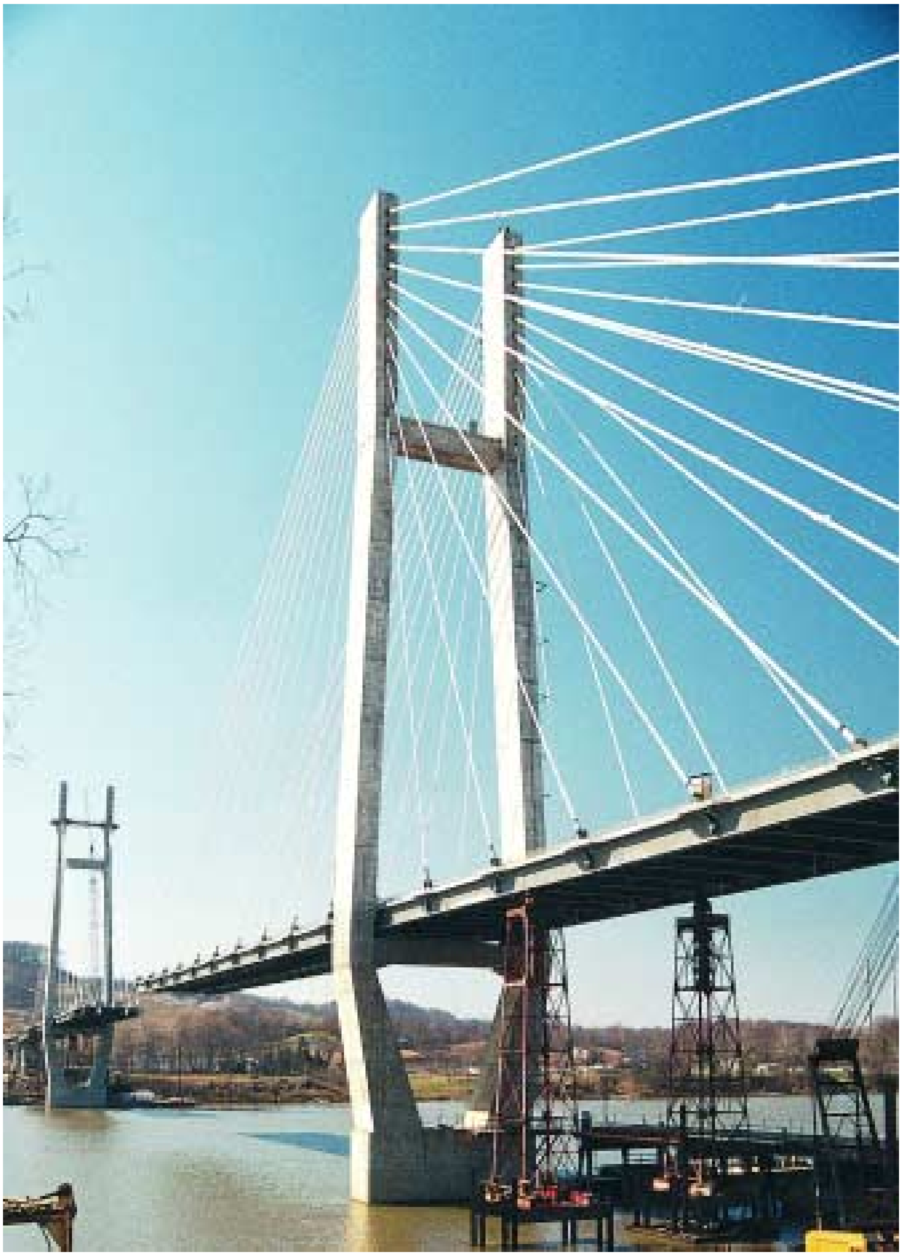
Cable-Stayed Bridge Uses New Post-Tensioning System

By William B. Caroland, PE, and Jorge M. Suarez, PE

Located approximately 2.8 miles downstream from the suspension bridge joining the towns of Maysville, KY and Aberdeen, OH, the Maysville Bridge is Kentucky's first cable stayed bridge. A new bridge had to be constructed because the existing suspension bridge could not safely handle large heavily loaded trucks due to its narrowness.

The Maysville Bridge had both a steel alternate and a concrete alternate for bidding, and American Consulting Engineer's (ACE) design group was awarded a design contract to design the steel alternate. In the conceptual stage, the Kentucky Transportation Cabinet (KyTC) and Federal Highway Administration (FHWA) asked ACE to consider several types of steel bridges. ACE studied a continuous parallel chord through steel truss, a continuous variable depth steel through truss, a cantilever suspended parallel chord through truss, a cantilever suspended variable depth through truss, and a steel cable stayed bridge. The FHWA directed that ACE not consider a tied arch due to some cracks and other problems found in other tied arch bridges over rivers in Kentucky. The channel span for the proposed bridge had been set by the Coast Guard to be a minimum of 1000' clear. After ACE made preliminary designs and studies, the cable stayed bridge, due to the long channel span, came out 13% less in cost than the next lowest cost steel alternate.

Two different span configurations were studied for the cable stayed bridge. The three span configuration had two end spans of 525' and a channel span of 1050'. The five span configuration had two anchor spans of 125', two flanking spans of 400' and a channel span of 1050'. Janssen & Spaans (J&S), one of ACE's subconsultants, used their BRUCO (Bridge Under Construction) computer program to analyze both configurations to determine which one was the best arrangement to pursue. The studies found the five span bridge to have the most advantages, and the preliminary plans were prepared.



Design Considerations

Stay spacing had been selected as 50 intervals. The stay pattern was a two-plane semi harped layout, chosen because a harp pattern has all the stays parallel, a taller tower, and causes more force on the stays. A fanned pattern was not chosen because it has the disadvantage of having all the stays come together at the top of the tower causing difficult anchoring or making the stays bunch over a saddle at the top of the tower.

Girder sections kept the wind exposure low but made the steel section deep enough to be stable and economical. After setting span lengths, girder section, stay pattern, and spacing, the tower dimensions were finalized. The height of the tower above the deck was set at 222.42', or 21% of the length of the channel span. The height of the towers from bottom of tremie to top of legs totaled 343'.

A decision was made to use force regulating units- liquid dampers (FRU) to allow both towers to be semi-fixed. Information from the recent California and Kobe earthquakes indicated that rather than fix one pier it was more desirable to provide as many as possible share the quake forces. Maysville had had a small yet surprising quake in 1979, since no one knew there was an active fault lying below. Taylor Devices Inc. of N. Tonawanda, NY, an AISC member, was contacted along with several other producers of similar devices. Taylor stated that by using proper valves and a special silicone oil, they could make an FRU that would allow slow movement from creep, shrinkage, and temperature movement but lock up when wind or earthquakes occurred, allowing both towers to share the forces equally.

Pictured above is a view of the bridge during construction. Looking west toward Kentucky, the photo show Tower 6 and temporary steel false work in place in flanking span.

Shown opposite is another view looking west, with Tower 6 half erected andTower 5 just started.

The construction photo above was taken during the positioning and leveling process of a girder on falsework, while the photo opposite shows work on the strands.

Rowan, Williams, Davies & Irvin (RWDI), the wind engineering subconsultant for the bridge, carried out their wind studies in five phases. First, a topographical model test and wind climate analysis determined the wind flow characteristic at the bridge site and design wind speeds for wind loading and aerodynamic stability. The second phase, a sectional model test, examined aerodynamic stability of the deck section. The static force and moment coefficients required for the theoretical estimation of wind loading were also measured at this time. The third phase of the test involved aeroelastic model tests to examine the stability and evaluate the response in strong turbulent winds for the completed bridge as well as for selected construction stages. The fourth phase of the study was based on the sectional model aeroelastic model wind tunnel results and theoretical buffeting analysis. The wind loads were evaluated for both the completed and construction configurations. The final phase of the study concerned examining the possibility of wind and wind/rain – induced vibrations for the stay cables.

The sectional model test indicated a stability problem with the proposed 3.5' tall solid concrete barrier rail. This led to the changing of the rail to a Texas Heavy Truck Rail, a 2.67' tall solid concrete barrier with a single steel rail on top. In addition, two baffle plates were attached at quarter points under the deck between and parallel to the girders. The aeroelastic tests showed that the baffle plates only needed to be placed in the middle two-thirds of the channel span. The cable vibration assessment resulted in recommending damping and secondary cross-cables.

Post-Tension System

The stay cable to edge girder connection is one of the bridge's unique innovations. ACE's structural engineers wanted to develop a stay to girder web connection that would avoid piercing the top flanges causing fatigue problems. ACE considered a post-tensioned connection arrangement to further eliminate fatigue from varying stay forces. A concept and description was sent to Michael Baker Jr., Inc. (MBJ) structural engineers, ACE's superstructure sub-consultant, and they developed the connection using a complex three dimensional finite element program. MBJ engineers proportioned the members of the connections in accordance with stresses, a subject that became a paper given at the 1995 International Bridge Conference. The final design of the connection used eight high strength ASTM A 354 BD rods, four on each side of the top flange, post-tensioned against two unsymmetrical built up welded H sections with four-inch thick end plates. The rods were either 1.75" in diameter or 2.5" in diameter depending on the stay cable force. Two sizes of the rods were used for simplicity. The FHWA had insisted that ACE prove this approach was better than an all welded stiffened plate connection. MBJ engineers analyzed both these connections. The connection with the high strength rods proved to be far more resistant to fatigue. Structural engineers from ACE and MBJ made a trip to Lehigh University in Pennsylvania and discussed the connections with expert Dr. John Fisher, the Joseph T. Stuart Professor of Civil Engineering and Director of the Center for Advanced Technology for Large Structural Systems. In his report on his review of the two connections, Dr. Fisher stated that the connection with the post-tensioned high strength rods was far more fatigue resistant than the single welded stiffened plate connection with category E' welds.

J&S, using their BRUCO program, determined that the channel span would permanently deflect about 2' over a period of 10,000 days due to creep, shrinkage and long term prestressing losses. As a result, ACE designed the structure to pull back the tops of the towers at erection so that the channel span would be about 2' high at closure and come to the approximate roadway profile in 10,000 days. This would prevent having a sag in the deck at 10,000 days. Pulling back the tops of the towers at erection had an added bonus in that it reduced the moments in the tower legs and required less reinforcing steel.

After approvals of the 60% plans by the KyTC and the FHWA, MBJ proceeded to set up the final model in a computer program and design the girders, stays and precast deck sections. Longitudinal deck post-tensioning offset certain live load positions on the bridge, which produced tension in the deck. Baker designed the wind shear locks, bearings, and hold-downs. They also designed temporary brackets to keep the superstructure in place at the towers until the span was closed and FRU's in place.

Fuller, Mossbarger, Scott and May (FMS&M), the geotechnical sub-consultant, had taken soil and rock borings and determined the possible types of foundations to fit the geotechnical conditions at the bridge site. ACE proceeded to design the substructure including the towers and the approach bridge. ACE gave FMS&M the loads on the substructure and indicated their preference to use drilled shafts on piers 3, 4, towers 5, 6, and pier 7. They decided steel H bearing piles were best for End Bent 1 & 2 and Piers 1 & 2. FMS&M determined the settlement at the end bents and the socket length for the drilled shafts to support the loads. They also checked for fence posting of the drilled shafts. Using this information, ACE proceeded to finalize the piers, endbents, and tower designs.

ACE had decided early in the preliminary design stages that the main pier towers would have a goal post "H" shaped configuration. The base remained as small as was prudent to reduce the size of the cofferdam,

tremie seal and footing. The footing was cast on a tremie seal and supported by sixteen 72-inch diameter drilled shafts socketed 10' into solid limestone in the river bottom. Permanent steel shells cast the concrete in the drilled shafts. The footing and stem of the towers are solid reinforced concrete sections up to the lower strut, just below the superstructure girders and deck. From the lower strut that connects the two tower legs, the legs are hollow reinforced concrete box sections to the top of the tower to accommodate the anchorages for the stays. The upper strut lies just below where the stay anchorages start. Both struts are post-tensioned to the tower legs with multistrand prestressing tendons. The upper tower legs, where the stays are anchored, are also post-tensioned in both directions with straight strand tendons.

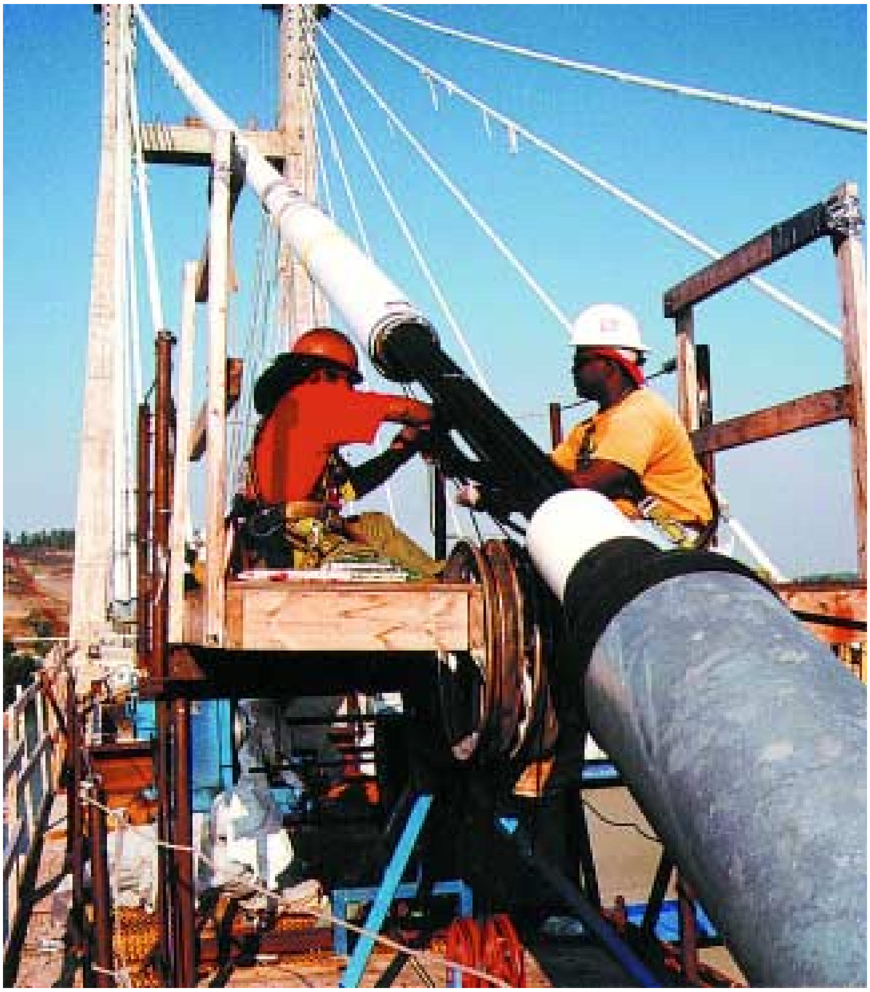
Other Considerations

The Maysville Bridge has state of the art details to resist wind-rain stay vibration and galloping. The HDPE pipe, a co-extruded pipe that encases the stays, has a thick, black inner layer that protects from ultraviolet rays. A thin white outer layer reflects the sun and helps keep the stay pipe cool. A 1/8" round bead of HDPE is welded in a spiral configuration around the length of the pipe to break up the airflow which causes galloping and vibration. Stay damping cables, attached between stays at as near normal to each stay as possible, fasten to the stay pipe with a soft 1 and ½ inch thick neoprene collar clamped around the stay pipe with a steel collar. The soft neoprene collar protects the stay pipe from bending fatigue at the clamping point and also helps to dampen the vibrations and galloping.

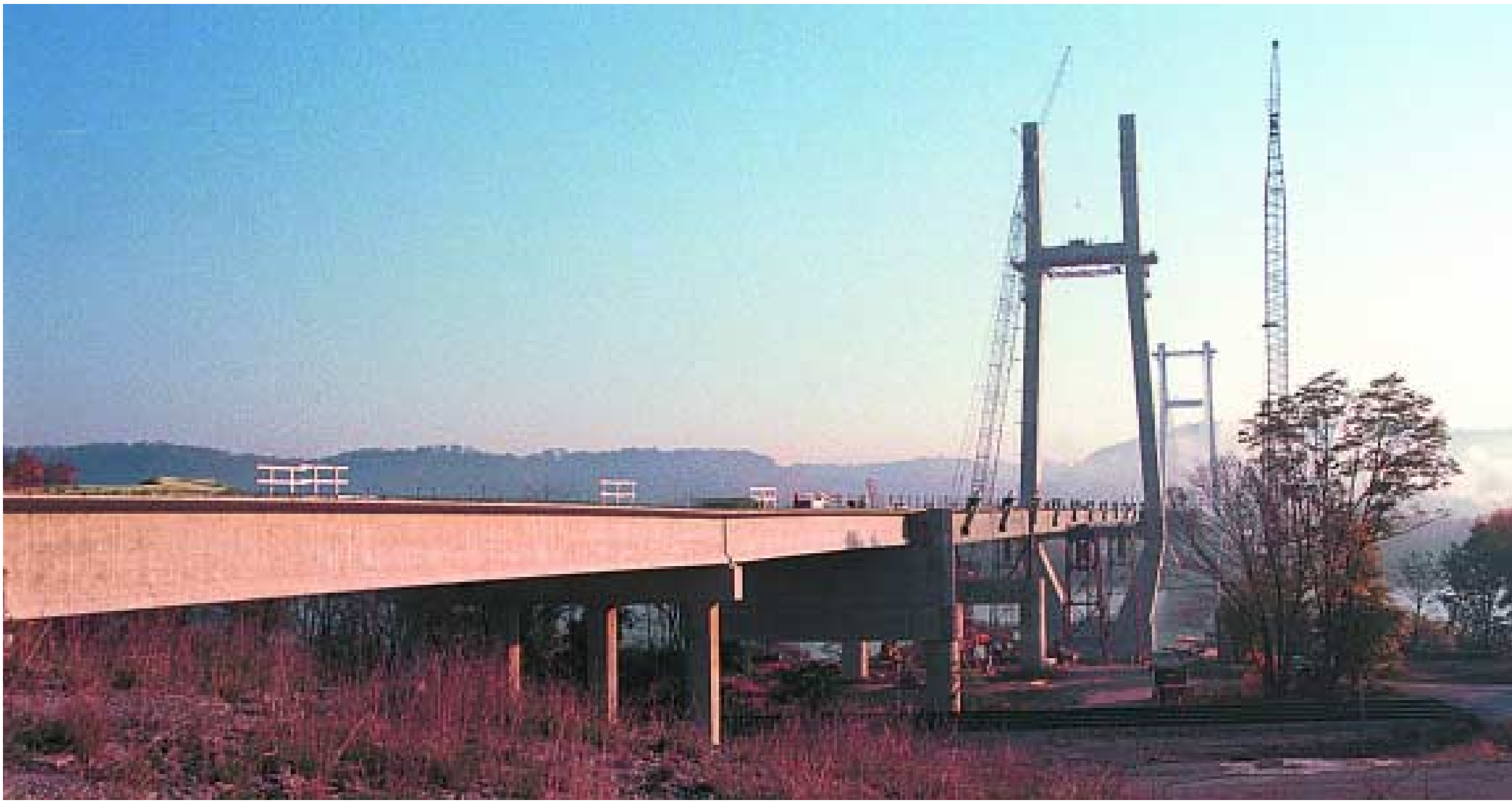
The expansion dam was unlike devices on other types of bridges. A cable stayed bridge has requirements for thermal expansion and contraction and allows for elastic shortening and creep over a long period of time. The fingers of the dam were set at closure with enough end clearance to provide immediate thermal expansion and long enough to take care of maximum thermal contraction, elastic shortening and creep over 10,000 days. The drainage trough under the finger expansion dam also posed a particular problem. The creep movement would move the trough several inches and the metal box used to catch the discharge had to be large enough in the longitudinal direction to intercept the drainage at the extremes of movement.

The Maysville Bridge was bid on December 13, 1996 with both steel and concrete superstructure alternates. Traylor Brothers, Inc. (TBI) was the low bidder at $36.4 million for the ACE steel alternate, approximately $1.9 million less than the second place bidder, which bid the concrete alternate. TBI was awarded the contract to build the bridge.

The New Maysville Cable Stayed Bridge will be on US Route 62/68 and will connect the AA Highway (which parallels the Ohio River, runs from Alexandria, KY to Ashland, KY and links up with I-64 at Grayson, KY) with US Routes 52, 62, and 68 on the Ohio side of the Ohio River. The new bridge has two 12' wide traffic lanes and two 12' wide shoulders for a curb to curb width of 48'. Center to center of stay planes is 55' and the out to out of deck width is 58.5'. The depth of the welded plate girders is 84" in the first 201.67' at each end of the bridge and 60" deep on the remainder of the bridge. Floor beams are spaced at 16.67' and a single stringer runs down the middle centered between the two edge girders. The top flanges of the floor beams and the stringer were sized wider than stresses necessitate in order to be used as a form for the cast-in-place splices for the precast deck slab sections. Precast deck slab sections were 15.42" wide, measured along centerline of deck, and 26.42' long, measured across the deck. The remaining 1.25' of clear space between the edges of the precast sections is used to couple the longitudinal post-tensioning bars, tie reinforcing steel, and provide a cast-in-place concrete infill splice. A concrete strength of 7,000 psi was required for the precast sections at 90 days, and at least 180 days old before placement on the bridge. Concrete strength for the infill splices shall reach 7,000 psi in three days to expedite construction and deck longitudinal post-tensioning. The precast slab sections are 9.75" thick with a wearing surface comprised of 1.5" of latex modified concrete overlay, placed after closure of the spans.



Shown above is the process of pulling strand into the HDPE stay pipe.



AISC-members Vincennes Steel Corp. of Vincennes, IN and Tensor Engineering Co. of Indian Harbor Beach, FL served as the fabricator and the detailer on the project, respectively.

At the present time all the substructure units are in place, with the approach bridge spans also complete. The Tower 6 half of the cable stayed bridge is completely erected, and the Tower 5 half of the cable stayed is well under way. Closure of the channel span will occur in April or May of 2000 with final completion and opened to traffic in the fall 2000. Kentucky will be the featured state at the International Bridge conference June 12 to 14 with this bridge featured in Kentucky's presentation. The cities of Maysville and Aberdeen are already very proud of the new bridge and look forward to the grand opening.

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