Construction of the Wichita Riverfront Cable-Stayed Pedestrian Bridges

JOHN P. BOSCHERT, Genesis Structures, Inc., Kansas City, MO
DAVID D. BYERS, Genesis Structures, Inc., Kansas City, MO
MATT INLOW, Dondlinger & Sons Construction Co., Wichita, KS

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ABSTRACT: Two unique cable-stayed pedestrian bridges were constructed in a culturally significant area of Wichita, Kansas. The bridges' tapered tower pylons and unique stay-cable configuration are symbolic of feather shapes and other Native American icons. Construction of the two bridges featured a complex erection sequence involving falsework construction in the river, post-tensioning of the precast concrete deck system and sequential cable tensioning.

INTRODUCTION

As part of Wichita's four-phase riverfront development program, two pedestrian bridges located at the confluence of the Arkansas and Little Arkansas Rivers were constructed. The bridges connect Exploration Place, a modern, interactive science museum, with the Mid-America All–Indian Center, surrounding lands that lie between the rivers and bicycle and hiking trails on the banks of both rivers. Figure 1 shows an aerial view of the bridge site during construction.

Fig. 1 – Bridge Construction Site

The city of Wichita, Kansas authorized a cable-stayed bridge design concept with asymmetrical tower locations. The main span cables reach out toward the "Keeper of the Plains," a 45-foot, raised statue that is one of the city's icons. (Figure 2)

Fig. 2 – Keeper of the Plains

The bridge's tapered tower pylons and unique stay-cable configuration are reminiscent of feather shapes and other patterns found in Native American headwear. Its curved tower shapes repeat the gracefully curved forms of the nearby Exploration Place, while providing a transition from this building's modern appearance to the more rustic statue and natural landscape of the Indian Center grounds.

The two bridges cross over the Arkansas River and Little Arkansas River with spans of 320 feet and 240 feet respectively and feature a complex erection sequence involving falsework construction in the river, post-tensioning of the precast concrete deck system and sequential cable tensioning that ultimately lifted the structure from the temporary supports creating the free-spanning cable-stayed spans. Construction was completed in January 2007.

Figures 3 and 4 show the Arkansas River and Little Arkansas River Bridges, respectively, and Figure 5 shows the completed bridges together from downstream.

Fig. 3 – Arkansas River Bridge

Fig. 4 – Little Arkansas River Bridge

Fig. 5 – Completed Bridges

BRIDGE CONSTRUCTION FEATURES

SAND ISLAND & COFFERDAMS – The hydraulic conditions existing at the peninsula bridge site allowed Dondlinger Construction the opportunity to partially block flow of both the Arkansas and Little Arkansas Rivers to construct temporary sand islands. The sand islands were constructed by simply dredging the adjacent areas of the river with native material and placing it at the desired location. The sand islands allowed construction access to nearly 80% of the length of both bridges. The sand islands are visible in Figure 1.

Each bridge's single tower pylon is supported by a pile footing and transitions through a geometrically unique concrete base. Cofferdam construction was utilized to allow access for driving the supporting piles and constructing the supporting footing structure. The cofferdams proved to be an economical way to provide a safe and water-tight working environment to allow construction of these components and setting the base of the steel tower.

A photo of one of the cofferdams is provided in Figure 6.

Fig. 6 – Typical Cofferdam

STEEL PYLONS – Each bridge is supported by a single steel pylon tower that is curved and inclined 8.5° with vertical and is approximately 125′ tall. Each steel tower pylon includes two legs with triangular sections, tapering from 60″ width to approximately 45″ width. The tower legs support the upper cable anchorage assembly which is a geometrically unique structural component which provides a transition for cable forces into the tower.

Erection of the tower structure was challenging because of the unique geometry of the steel segments and the angle of inclination. The individual tower leg segments weighed approximately 60 tons and were erected using a specially-designed lifting assembly and were rotated into position using two cranes. Figure 7 shows the erection operation of the tower legs.

Fig. 7 – Tower Leg Crane Pick

Erection of the upper tower segments and upper cable anchorage assemblies was done in a single operation. Again, the complex geometry made the erection sequence challenging. Picking the 30 ton upper tower segment was done using a single crane and a second line which was used to rotate the piece back for the inclination angle. Figures 8 and 9 show the crane pick for the upper tower segment.

Fig. 8 – Upper Cable Anchorage

Fig. 9 – Upper Tower Crane Pick

Connecting the upper tower segment to the supporting tower legs required a significant partial penetration field weld. Timely completion of this weld was critical as continuous crane support was required until the positive connection was made.

Figure 10 shows one of the completed towers prior to cable installation.

Fig. 10 – Completed Tower

The steel towers were fabricated by PDM Bridge.

CONCRETE DECK SEGMENTS – Precast and post-tensioned deck segments make up the bridge superstructure and provide the walking surface for pedestrian traffic. The deck segments are hollow two-cell trapezoidal sections, typically 12′ - 4″ wide x 4′ – 0″ deep x 32′ long, and weigh approximately 55 tons each. Bridge 1 includes 11 segments, while Bridge 2 includes 9 segments. The concrete deck segments were match-cast in the precast yard to insure proper final geometry in the field.

The concrete deck segments were fabricated by CoreSlab Structures, Oklahoma City. Figure 11 shows one of the deck segments in the precast yard.

Fig. 11 – Precast Deck Segment

Falsework – Temporary support structures were constructed in the river (sand island) to support the individual precast deck segments prior to post-tensioning and cable installation. The falsework structures were designed and fabricated not only to vertically support the weight of the precast deck segments, but also to allow for longitudinal movement of the segments. Each segment was lifted vertically into place, then rolled back into the adjacent segment for proper fit-up. Additionally, the falsework structures were required to accommodate the axial shortening due to post-tensioning operations without participating in the final structural stiffness. Specially-designed deck saddles on steel rollers were incorporated into the falsework details to allow longitudinal movements. Figure 12 shows a precast deck segment being lifted onto a typical falsework bent structure.

Fig. 12 – Deck Segment & Falsework Structures

Post-Tensioning – Two types of longitudinal post-tensioning were utilized on the project. The individual segments were initially post-tensioned together using (4) 1″ Diameter Grade 150 bars tensioned to 77 kips per bar. This operation was done as the segments were erected to incrementally connect them together. Following the erection of all the deck segments, the continuous line of segments was post-tensioned to a much higher force using high-strength post-tensioning tendons. Four post-tensioning tendons, comprised of (19) 0.6″ diameter strands, were positioned in a smooth parabolic curve using internal ducts and were tensioned to 835 kips each to control stresses for the final design.

Tuned Mass Dampers – Two tuned mass dampers (TMDs) were installed in each bridge to control pedestrian-induced vibrations. The TMDs were mounted on the center web wall of the deck segments. These TMDs were intended to mitigate bridge motion for several specific modal frequencies which were determined to be potentially problematic in the original design.

The as-built structures were dynamically tested and the modal frequencies of concern were confirmed. The TMDs were tuned for the specific dynamic properties of the as-built bridge, based on the data obtained in the field test.

Figure 13 shows a schematic images of one of the tuned mass dampers.

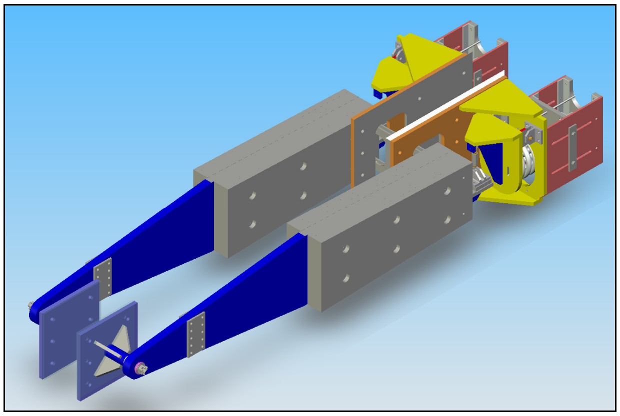

Fig. 13 – Tuned Mass Damper (Schematic)

Motioneering, Inc. performed the dynamic testing and manufactured the tuned mass dampers.

CABLES – Stay cables are ASTM A586 Galvanized Structural Strand material, with 2″ diameter typically and 3 3/8″ diameter at the end cables. The fixed-length cables connect to the upper cable anchorage with open strand sockets at the top anchorage points and Type 7, adjustable bridge sockets at the bottom cable anchorage points. The lower cable anchorage mechanism consists of steel pipe assemblies cast into the deck segment concrete

Figure 14 shows the lower cable anchorage assembly schematically, including the supporting pipe and anchorage hardware along with the longitudinal post-tensioning tendons.

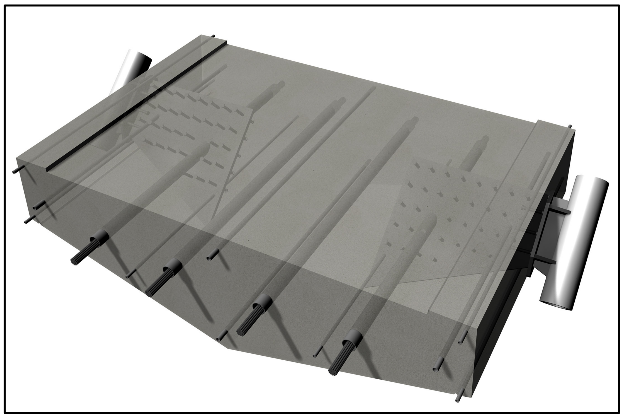

Fig. 14 – Typical Lower Cable Anchorage
(Image courtesy of HNTB Corporation)

Cable Tensioning – Cable installation and tensioning was accomplished in two phases. The initial phase was the installation of each cable tensioning to a very small force. The Type 7 sockets were lowered through the supporting pipe and anchored with heavy-duty bearing ring plates and spanner nuts. The fixed-length cables had to be just long enough to reach the anchorage point for the installation stage. The initial tensioning value was applied to remove most of the cable sag. The second and final tensioning sequence was performed to lift the bridge off the falsework supports by tensioning the cables to the final tension force. The tensioning sequence was precisely planned and monitored, as tensioning a specific cable would unload the adjacent cables.

Figure 15 shows the installation of a typical cable into the lower anchorage pipe.

Fig. 15 – Typical Cable Installation

Cable tensioning to specified tension values was accomplished using hollow-cylinder jacks calibrated for hydraulic pressure vs. load. After each cable installation or tensioning sequence, all cable tensions were checked using an instrument which relates the cable vibration to the cable tension. This instrument was ultimately used to check that the final cable tension values were within the specified allowable range of acceptability.

CBSI, Inc. and WRCA supplied the cable materials and the cable installation equipment.

ERECTION ANALYSIS

Staged Construction Modeling - Project specifications required that the contractor submit independent calculations illustrating the structural effects of the proposed bridge erection sequence to verify that the structural integrity would not be compromised. Additionally, a time-domain analysis, accounting for concrete creep and shrinkage, was required because of the high axial and bending stress in the post-tensioned, cable-stayed deck segments. The deck segments were match-cast such that the bridge would settle into the target geometry after 10 years of service. To accomplish this, the time-dependent effects of creep and shrinkage in the post-tensioned concrete segments had to be evaluated.

Genesis Structures utilized LUSAS Bridge Analysis finite element software to model the staged construction, including the effects of temporary falsework supports, post-tensioning, sequential cable installation and stressing, creep, and shrinkage. Figure 16 shows the LUSAS model for Bridge 1.

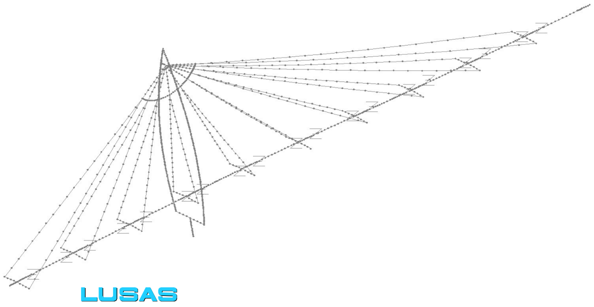

Fig. 16 – Bridge 1 Staged Erection Model

The results of the staged erection finite element analysis provided falsework reactions for design, deck segment target geometry for match-casting camber, deck segment stresses due to gravity and post-tensioning, expected tower displacements during construction, and cable tension time-history plots. Excellent correlation was obtained with the actual field-observed data. Of special interest was the cable tensioning time-histories, as the cables are the critical elements in the bridge. Figure 17 shows the cable tensioning time-history of a typical cable and illustrates the comparison between the predicted and observed tension values.

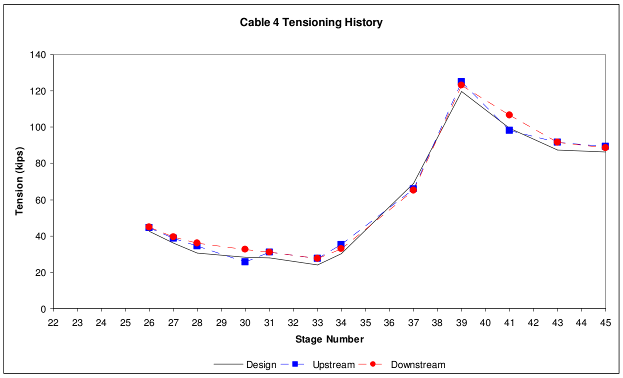

Fig. 17 – Cable Tension vs. Construction Stage (Predicted & Observed)

3D Solid Deck Segment Analysis – Fabrication and placement of the tuned mass dampers required that the planned openings in the concrete deck segments be enlarged and modified. To verify that the concrete deck segments would not be overstressed as a result, three-dimensional solid modeling of the deck segments was accomplished using LUSAS to simulate the stress effects due to the lifting and post-tensioning with the modified openings. These models revealed that the enlarged openings would not overstress the segments. Figure 18 shows the 3D solid model of a single deck segment.

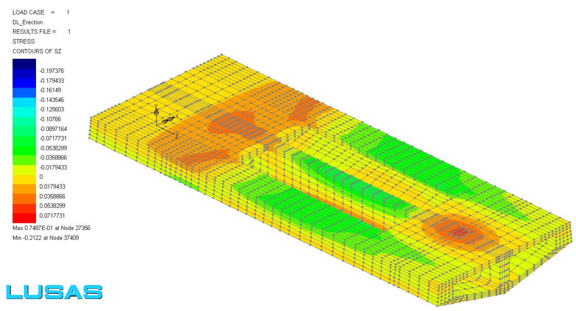

Fig. 18 – Deck Segment 3D Solid Model

<u>3D Tower Analysis</u> – The results of the staged construction model indicated that high stresses occur in top of the tower pylon in the area near the upper cable anchorage. These high stresses warranted a more in-depth analysis of this area, so a 3D finite element model using planar surface elements to represent the steel pieces was created to study this area more intensely. The results of this effort and further investigation by the designer resulted in an increased weld size at the tower. Figure 19 shows the 3D tower analysis model.

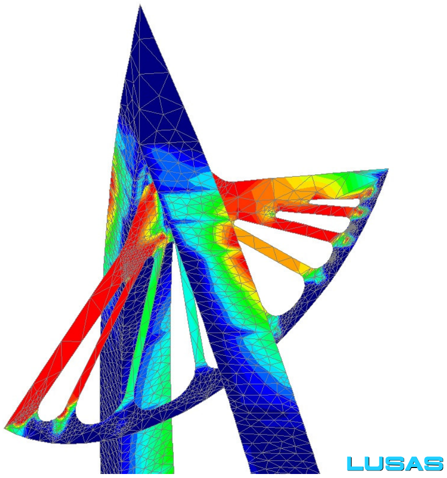

Fig. 19 – Detailed 3D Tower Model

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