Featuring asymmetry in two major planes, Michigan's first cable-stayed bridge was a challenge in both design and construction.

On a *Beautiful* Tilt

BY ROBERT B. ANDERSON, P.E., MIKE GUTER, P.E., AND VICTOR JUDNIC, P.E.

Peter Bugar, URS Corporation

The new Mexicantown Bagley Street Pedestrian Bridge in Detroit crosses I-75 and I-96 and is Michigan's first cable-stayed bridge.

DETROIT'S NEW MEXICANTOWN Bagely Street Pedestrian Bridge is the first cable-stayed bridge in the state and part of Michigan's \$230 million I-75 Gateway Project. The two-span, cable stayed structure crosses 10 ramps and roadways, including both I-75 and I-96, and provides a vital link between the east and west sides of Detroit's Mexicantown community.

The total bridge length is 417 ft, with a main span of 276 ft and a back span of 141 ft. The forestays are arranged in a fan configuration and are inclined in both the longitudinal and transverse directions. The bridge features a unique asymmetrical design, with a selected look of a single cable plane. A single 155-ft-tall inclined pylon provides the upper support for the cables, which form an eccentric plane and are anchored at the lower end to a tapered, trapezoidal, single-cell steel box girder.

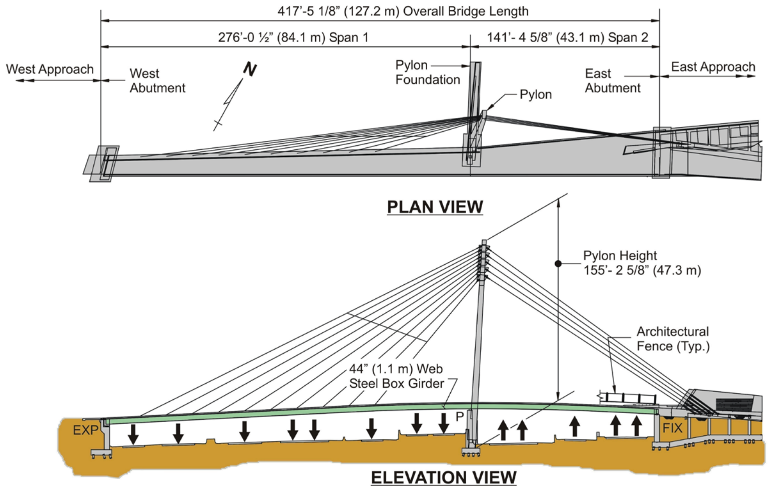
The back span balances the forces imposed by the forestays and anchors into a deadman/abutment. The welded steel, trapezoidal box girder carries the variable-width deck slab. The project incorporates five tuned mass dampers to control vibration of the bridge superstructure. Each portion of the project, including abutments, entry plazas, barriers, and fencing employs architectural finishes with three-dimensional variations, and is therefore highly stylized aesthetically.

The bridge lies on a tangent horizontal alignment. The western span expands from 15 ft, 3 in. to 21 ft, 6 in. while the shorter eastern span widens even more dramatically, from 21 ft, 6 in. to 34 ft. The pedestrian walkway entrance and exit grades of the vertical profile are at 5% grades and are connected by a 200-ft crest vertical curve whose midpoint is located near the pylon. The minimum vertical clearance to the closest underlying roadway is 16 ft, $10\frac{3}{8}$ in. at the eastern abutment.

The structural system—a single-cell box girder superstructure—is supported at the westerly forespan by stay cables anchored eccentrically to the girder shear center at the northern girder web. The eastern back span is self-supporting and also transmits compression forces introduced by the westerly forestays to the east abutment.

The eccentric cable loading on the single box girder system produces torsion and lateral thrust in the girder and this is resisted by upward, downward, and lateral bearings at the west abutment and tension linkages and vertical and lateral bearings at the pylon. This figure shows that both vertical and lateral bearings are used to resist torsion. The pylon linkage and bearing system also allows translation produced mostly by thermal affects along the longitudinal axis of the bridge.

The concrete and steel pylon is eccentric in two directions and also tapers in two directions from its base to its top. The foundation, at the base of the pylon, resists gravity loads primarily by a cluster of piles located at the line of action of the pylon. An extension of the foundation to the north helps to resist overturning loads created primarily by wind and live load effects.



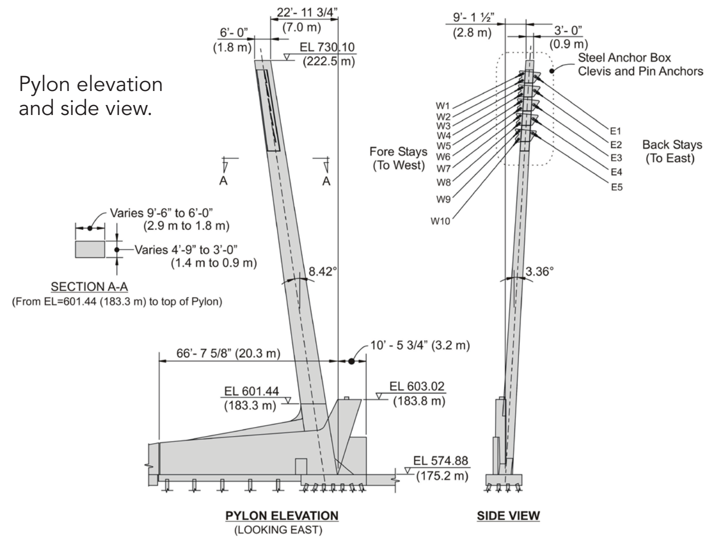
The plan and elevation view show the bridge's general layout, including the pylon's eccentricity in two directions.

Construction Activities and Scheduling

This bridge required a detailed erection manual and geometric control plan prepared by a specialty erection engineer. The erection manual outlined 62 individual stages for completing the bridge and closely followed the proposed erection plan conceptualized by the design engineer and included in the contract documents.

To ensure that survey discrepancies would be minimized and resolved quickly, the project team agreed to coordinate all surveys. The erection engineer, as part of the erection manual and ongoing computations, provided target coordinates and elevations for key points and elevations, including at the pylon stay housing, at temporary shoring, at box girder splices, along the box girder deck and at all stay cable connection points.

The contractor and the owner/engineer closely monitored the geometry throughout construction. In one instance, the temporary guys were adjusted to correct the location of the pylon stem; however giving credit to the accuracy of the erection engineer's analysis, the geometry largely agreed with the predictions.



Pylon elevation and side view.

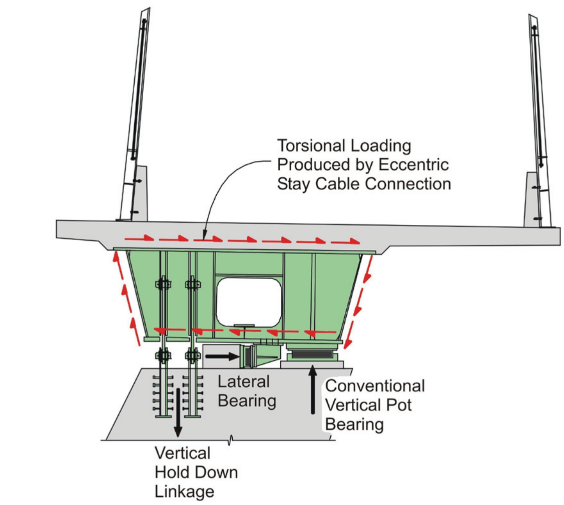
The steel box girder erection scheme required three falsework towers to support the west span before the stay cables were installed. The contract documents included camber values to account for these three temporary supports. Two additional falsework towers were provided at each side of the pylon to support the girder prior to the deck pour engaging the vertical and lateral bearings and link plates at that location. The contractor opted to complete the top of the pylon strut after placement of the steel box girder to mitigate tolerance and fit-up requirements of the girder itself and the many support elements.

The first major step in the bridge's construction was to build the abutments and the pylon. To help maintain alignment and provide support during construction and prior to installation of the stay cables and pylon post-tensioning, the pylon was temporarily guyed with four guys at two vertical levels. At each level, guys extended transverse and longitudinal to the bridge axis to maintain pylon stability and provide support in all directions.

Robert B. Anderson, P.E., is a senior structural engineer for URS Corporation, Tampa, Fla., and has been involved in the planning, design and construction of bridges for more than 21 years. Bob's experience includes the design of five major cable-stayed bridges, several major freeway-to-freeway interchanges, as well as numerous water crossing structures. Mike Guter, P.E., is a project manager for URS Corporation in Grand Rapids, Mich. He has worked on a variety of transportation projects since beginning his career in 1993, including roles in both construction and design. Victor Judnic, P.E., is a senior construction engineer for the Michigan Department of Transportation. His experience includes the design and construction of harbors, roads and bridges over the past 21 years.

Construction started at the east abutment, which serves as the bridge abutment; an earth anchor wall for five stay cables anchoring the front span of the bridge; and an architectural plaza that transitions from the pedestrian bridge to a much larger non-structural plaza area. This abutment also was used as the temporary anchor point for the east temporary pylon guys.

Additionally the east abutment provided the fixity for the steel tub girder, with a diaphragm cast integrally with the girder. The eastern end of the girder was temporarily supported on bearings to allow for beam rotation during the deck pour. The temporary bearings ultimately were encapsulated in concrete and the integral abutment connection was made complete.



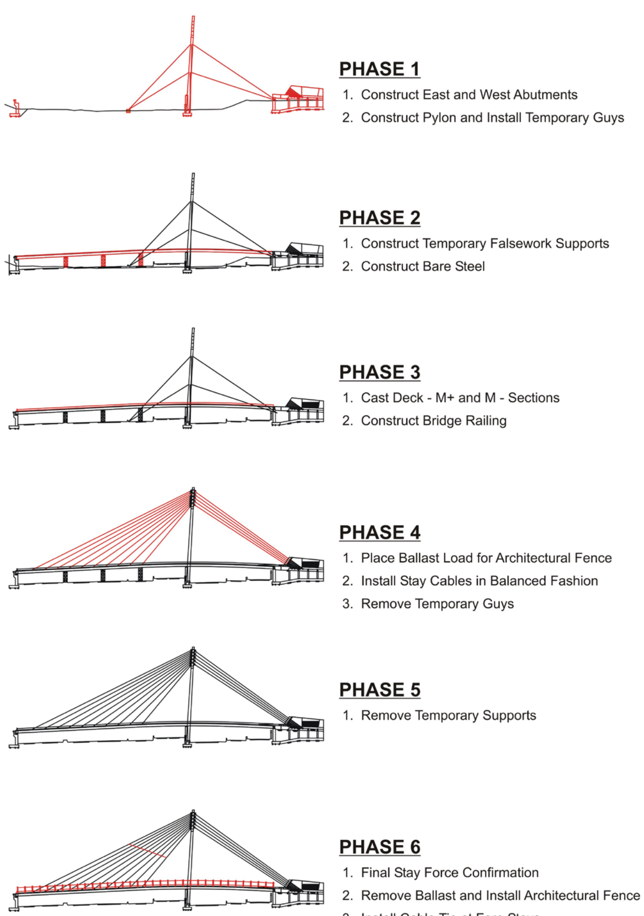
Layout of the pylon linkage and bearing system, showing hold down linkage as well as vertical and lateral bearing areas.

The back span is fully supported by the east abutment and the pylon strut. The east abutment earth anchor wall is constructed on a 6-ft by 6-ft, 11-in. concrete grade beam that was integrally tied to the remainder of the abutment with steel reinforcement. The stay cables are anchored with steel forgings connected to post-tensioned anchor rods that include an end plate poured into the grade beam. A structural and architectural wall extends up from the grade beam, supporting, hiding and protecting the anchor rods. This wall has aesthetic treatments including bush-hammered and board-formed surfaces.

Accommodating Foot Traffic

Some pedestrian bridges have shown sensitivity to the dynamic affects of foot traffic. The design engineer worked in conjunction with a specialty dynamics consultant who specified and detailed a five-component tuned mass damper system that was included as part of the contract documents. The installation of the tuned mass damper system was undertaken after girder erection and prior to the deck placement. Four of the dampers resolve vertical movement and a single damper resolves lateral movement. When the bridge was nearly complete, the damper system designer conducted a series of dynamic tests to establish the spring fabrication parameters. After spring fabrication and installation, the damper system characteristics were fine tuned to correspond with the measured dynamic response of the bridge and to ensure their effectiveness.

The west abutment was the next substructure element to be constructed. A more conventional abutment, it includes three pot bearings supporting the steel box girder vertically (both upward and downward to prevent torsional rotation) and transversely.



Major construction phases of the Bagley Street Bridge.

On to the Superstructure

The east abutment earth anchor wall plate, pylon stay cable housing, and steel box girders are shop fabricated steel components. The earth anchor plate forms a base for the five east stay cable anchor blocks. This assembly was cast into the concrete earth anchor wall. Post-tensioned bars extend from the face of this plate into a concrete beam that sits underneath the earth anchor wall.

The pylon stay cable housing is 30 ft, 6 in. in height and forms the northern half of the top pylon stem. The stay housing includes five 2½-in.-thick plates with two pinholes on the west side and one pinhole on the south side for connection to the clevis-type stay cable anchorages. The placement of the stay housing was controlled by levelling nuts on 18, 1½-in. anchor bolts poured into the pylon stem.

The box girder remains a constant width from the west abutment to just west of the pylon, at which point it begins to widen to its largest width at the east abutment. The top flange of the box girder also varies from being solid across the top, in areas of high torsion, to being split into two flanges on top of each web. In areas where the top flange spanned from web to web, plates were added to provide bending strength to support the concrete deck placement. In addition, tuned mass dampers (see sidebar) installed between the west abutment and the pylon required top flange openings to be covered with plates after installation.

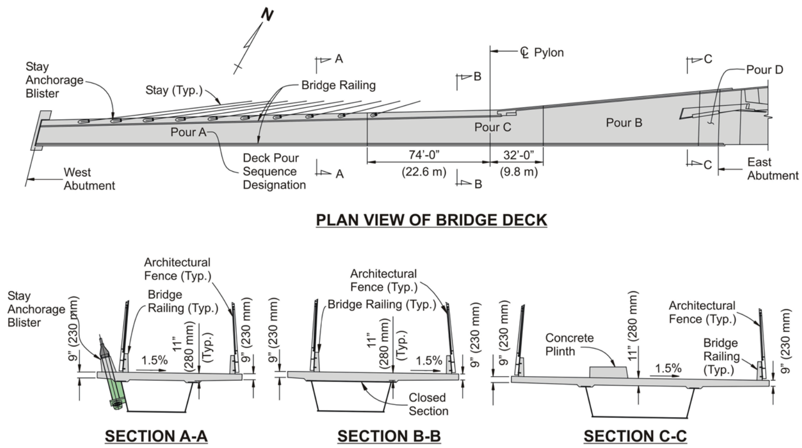
Phase 2 (see construction phase diagram) shows the next major construction step involving the assembly of the steel box girder on both falsework and permanent supports. Temporary support elevations were determined as part of the erection manual. Top of beam elevations were determined and checked against the anticipated elevations (which included the girder camber accounting for later deflections), and then screed rail elevations were established and the deck slab was cast in typical fashion. Because fencing fabrication and installation took longer than expected, the contractor elected to temporarily ballast the bridge with a uniform load consisting of wide-flange steel beams from their stockpile.

The most complex part of the deck slab construction was developing a unique deck forming system to construct the large overhangs (see diagram, Phase 3). The contractor devised a formwork system suspended beneath the bridge and hung from the box girder flanges. HP12×53 sections were the primary members spanning from flange to flange and overhanging each side from which forms were supported. The hangers counteracted torsional forces of the asymmetrical deck overhang by using steel plates as beams extending across the top of the box girder. Uplift forces were counteracted at the center of the beam with a welded tie-down at the solid top flange and cable tie-down at the open flange sections of the box girder. The overhang forming was set approximately ½-in. high to account for the anticipated deflections of the overhang during the deck pour. To maintain the freeway opening date of July 4, 2009, the deck slab was poured during February 2009, an unusual occurrence this far north.

Phase 4 involved the installation and stressing of stays in a balanced fashion at both the west and east sides of the pylon. Each of the 15 stay ends (10 in the forespan connected to girder and five connected to the east abutment back stay) had a targeted force. Some of the stays required only a single jacking operation within the erection manual sequence, while others required two jacking operations at different stages within the erection manual sequence. During the jacking operations and upon completion, the geometry of the system was verified. As the installation of the permanent stays progressed, the temporary guys were removed. Also, the stressing of the stays caused a decrease and eventual lift-off at the temporary falsework supports. At Stages 47, 53, 54, and 60 of the erection engineer's detailed construction sequence, the vertical pylon post-tensioning was installed and stressed in stages.

Working with the Stays

The stay cables consist of galvanized steel wire rope comprising structural wire (ASTM 586) with a hot-dipped galvanized Class A coating for the inner wires and Class C coating for the outer wires. One end of the cable at the pylon used a pin and clevis anchorage system. The forestays used a threaded spanner nut anchorage system at the girders. The back stays were anchored at the east abutment with a steel anchor block casting and shims that were tensioned with four anchor rods each embedded into the abutment mass. The clevises and other hardware were manufactured in a lost sand casting process (ASTM 148). The stay cable socket-to-strand connection was accomplished by splaying the wire rope and pouring molten zinc into a conical shaped space. The sockets are designed and attached to develop 110% of the breaking strength of the



Deck plan and cross sections. Note the variation in relative location and size of the steel box girder.

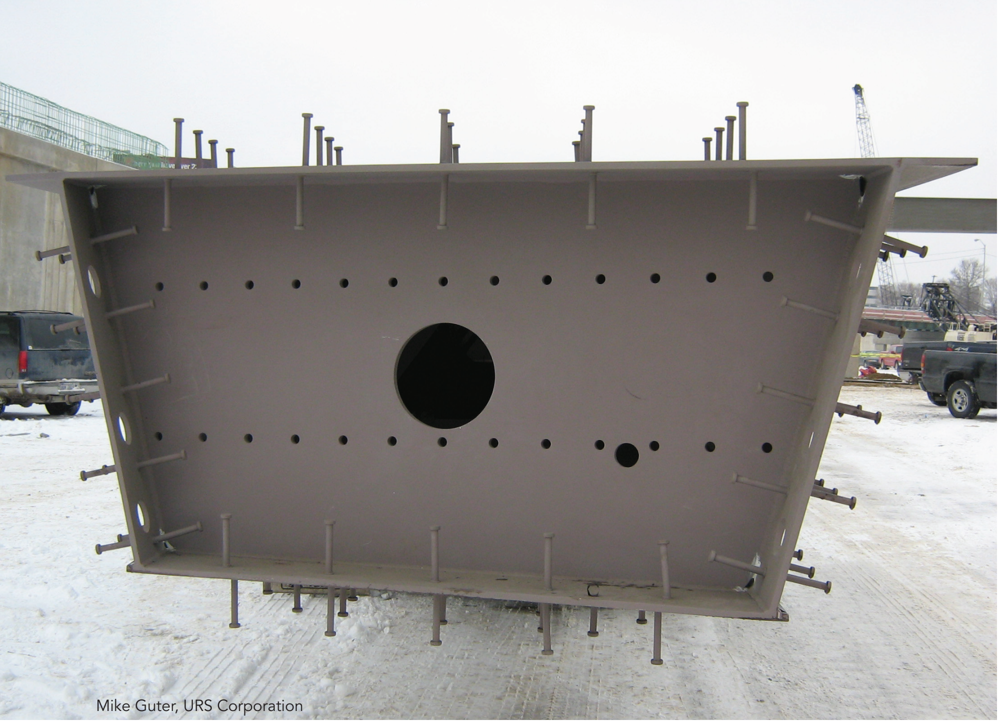
Bob Anderson, URS Corporation

The pylon stay cable housing in place with the lower two back stays attached.

The 30-ft, 6-in.-high steel pylon stay cable housing forms the northern half of the top pylon stem, shown here prior to placement with concrete formwork panels attached. Five 2½-in.-thick plates have two pinholes on one side and one pinhole on the other for connecting the clevis-type stay cable anchorages.

The west abutment prior to setting the tub girder. Note the non-symmetrical support system, with hold down anchorage on the left and bearing on the right.

Mike Guter, URS Corporation



Mike Guter, URS Corporation

The end of the tub girder with welded studs attached, ready for placement on the west abutment.

cable. All sockets were proof tested to 55% of the breaking strength of the cables. The lengths of the cables were determined by survey following completion of the pylon and erection of the girder. Tolerance was provided in the threaded socket length to account for construction tolerance and temperature compensation.

Because galvanized wire rope is able to wick moisture within the cables, painting of the stay cables was included in the contract to prevent the ingress of water and corrosive elements. However painting subsequently was eliminated due to concerns about the long-term effects of locked moisture and oils on the coating system. Serrated nuts were added at the low cable anchorage at the west girder and weep holes to the anchor WT's attached to the girder webs to facilitate the draining of water from the cable bottoms.

The first step in field installation is to unwind the cables from wooden shipping spools. Because of their length weight, this can be an awkward operation and requires special attention to avoid unwinding the spools too fast. To protect the galvanized coating on the cables, they are laid out on a protected surface. The cables are then lifted by two cranes and attached at the pylon stay cable housing, then attached at the girder or abutment.

For the Bagley Street Bridge's western forestays, workers installed a threaded stressing rod into the anchor socket, along with a temporary extension rod, which allowed stressing by a single center-hole jack. Once the proper tension was achieved, a ring nut was spun tight.

At the east abutment, a stay cable anchorage block was positioned through four threaded anchor rods. These rods were stressed to a prescribed tension by four center-hole jacks bearing against nuts on the rods and the anchorage block. Once the tension was achieved, shims were installed between the stay cable anchorage block and the base of the abutment earth anchor wall. Final tensioning of the anchor rods, with the shims in place and preventing the cables from being further loaded, was done to a high load level to ensure the shims remain in compression.

Calibrated jacks were used to stress the cables. However, the stay cable supplier used a secondary "tensionometer" to monitor the stay cable tension in all the cables after each was stressed. This device accepts inputs of cable density and length and has an accelerometer sensor that is able to measure the primary frequency of a cable. The cable is forced to vibrate by field personnel. With these vibration inputs, the tensionometer outputs a measured force obtained by classical equations that are programmed into the equipment.

Finishing Up

The bridge finishing works shown in Phase 6 include the final steps involved in the construction of the bridge. These included verification of cable forces and girder and pylon geometry; installation of the architectural fence; installation of a cable tie at the forestays to reduce stay cable vibrations; and final tuning of the tuned mass dampers.

Other tasks included in the bridge finishing works were:

- Removal of steel ballasting and construction of concrete barrier rail
- Sandblast finishing of the pylon, deck overhangs, and barrier rail
- Installation of modular expansion joint at the west abutment
- Concrete benches at the pylon and east abutment and decorative concrete treatments
- Completion of lightning grounding system
- Installation and aiming of decorative lighting
- Grouting of east abutment post-tensioned stay cable anchor rods
- Installation of architectural edge plates and fence mesh covering at east abutment

The Mexicantown Bagely Street Pedestrian Bridge opened May 5, 2010. It was part of a Cinco de Mayo festival organized by the Southwest Detroit Business Association and the Detroit Consulate of Mexico in salute of 200 years of Mexican independence.

Bob Anderson, URS Corporation

The completed west abutment.

The complex erection sequence required the use of three falsework towers, which supported the west span until the cable stays were attached.

A project of this magnitude relies on contributions from many individuals; therefore, the authors also wish to acknowledge and give their sincere appreciation to Bob Jones and Josh Goldsworthy (Walter Toebe Construction), Dave Rogowski (Genesis Structures), Eric Morris and Ken Price (HNTB), Jerry Clodfelter (CBSI), Jorge Suarez (Michael Baker Corp.) and Peter Bugar (URS). MSC

Owner
Michigan Department of Transportation

Architect
Van Tine/Guthrie Studio of Architecture, Northville, Mich.

Design Engineer
HNTB Corporation, Chicago
(AISC Member)

Construction Inspection Engineer
URS Corporation, Grand Rapids, Mich., and Tampa, Fla.

Specialty Construction Inspection
Michael Baker Corporation, Pittsburgh

Steel Detailer
Tensor Engineering, Indian Harbour Beach, Fla. (AISC and NISD Member)

Steel Fabricator
Industrial Steel Construction, Gary, Ind. (AISC and NSBA Member)

Erection Engineering
Genesis Structures, Kansas City, Mo. (AISC Member)

General Contractor
Walter Toebe Construction, Wixom, Mich.

Structural Software
Lusas Bridge

Stay Cable System Suppler
CBSI, Houston