17th Street Causeway Bridge

FT. LAUDERDALE

OWNER
Florida Department of Transportation

STRUCTURAL ENGINEER
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STEEL FABRICATOR:
PDM Bridge, Palatka, FL (AISC member)

STEEL DETAILER
Tensor Engineering Co., Indian Harbor Beach, FL (AISC member, NISD member)

APPROACH SPAN DESIGNER
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STRUCTURAL ENGINEERING SOFTWARE
GTStrudl

When a Florida Department of Transportation (FDOT) study recommended replacement of the 17th Street Causeway Bridge in Ft. Lauderdale with a new movable bridge, local residents called for a "signature bascule bridge" to provide a landmark gateway to the area's renowned beaches and waterways.

In response, the project team designed a one-of-a-kind, double-leaf bascule bridge to replace the existing drawbridge over the Atlantic Intracoastal Waterway. The solution was achieved through graceful form, reduced mass and an uncluttered appearance, without sacrificing structural efficiency and economy.

The bridge site is located just north of the ocean outlet at Port Everglades. Ft. Lauderdale is an international yachting center and Port Everglades is a major freight and passenger terminal. Right-of-way acquisition opportunities are limited at all four corners of the site by existing or planned development. Hotels occupy the NW, NE, and SE corners, and the SW corner is the site of a future hotel adjacent to the Ft. Lauderdale Convention Center.

The absence of a vehicle crossing at the port ocean outlet requires all north–south vehicular traffic traveling on SR A1A along the barrier islands to divert inland at this point. The 17th Street Causeway Bridge is the first bridge located north of the outlet and provides the primary-access crossing of the Intracoastal Waterway to Fort Lauderdale's beaches.

Given these conditions, the required horizontal and vertical clearance requirements for a fixed bridge were 125' and 135' respectively. The site could not accommodate a fixed span of sufficient height, since the approaches would dominate the landscape and adversely impact adjacent intersections and commercial properties.

Critical project objectives included:

- Construct a bascule bridge with a minimum horizontal clearance of 125' and a minimum vertical clearance of 55', with the movable span in the closed position (unlimited vertical clearance with the span raised)
- Provide a bascule span with a solid concrete riding surface
- Maintain four lanes of traffic and the navigational channel throughout construction
- Construct the new bridge parallel to, and centered about, the existing bridge alignment
- Give the new bridge FDOT's highest level of aesthetic consideration, Level III.

THE BRIDGE

The new 17th Street Causeway Bridge combines steel and concrete to span 1908' across the mouth of the Intracoastal Waterway. The dominant main span of the bridge is a steel double-leaf bascule span supported on concrete V-shaped piers. The bascule span features variable-depth steel box girders that span 210' between centers of trunnions. Smooth, variable-depth segmental-concrete box-girder spans form the approaches that complete the bridge. The bridge consists of approximately 958 tons of steel.

The bridge has two parallel carriageways. Each carries two 12' traffic lanes, an 8' inside shoulder, a 10' outside shoulder/bike lane and an 8' sidewalk. The out-to-out width of each carriageway superstructure is 53'-5½".

MAINTENANCE OF TRAFFIC

Construction phasing using a two-lane temporary detour bridge maintained traffic during construction, and proceeded as follows:

- Construct a two-lane temporary bascule bridge just south of the existing bridge.
- Divert eastbound traffic to the temporary bridge.
- Shift westbound traffic from the north half of the existing bridge to the south half.
- Demolish the north half of the existing bridge except for the bascule span (must be left in place as it is a two-girder system).
- Construct the north half of the new bridge, including construction of the bascule span above the existing bascule span.
- After completion of the north half of the new bridge, temporarily shift all traffic to the new bridge.
- Demolish the temporary bridge and the remainder of the existing bridge.
- Construct the south half of the new bridge.
- Shift traffic to final configuration.

The temporary bridge in itself was a challenging engineering solution. A single-leaf Dutch-style bascule with overhead counterweight was selected to meet the following criteria:

- Provide horizontal clearance of 100' and a minimum vertical clearance of 26.6' with the bridge closed.
- Provide two 11' lanes of one-way traffic and a 6' sidewalk
- Design for ease of construction with provision to relocate the bridge to another site
- Design for lowest cost, considering salvage value.

AESTHETIC CHALLENGES

The bridge was to be a structure free of ornamentation or artificial color, with the use of natural material finishes. Segmental concrete boxes were chosen for the approach spans and steel box girders for the bascule span. Pedestrian overlooks were to be included at the bascule pier and bridge railings were to have open designs.

The most challenging design elements, which dominated all aesthetic discussion, were the bascule piers. Optimizing the structural efficiency of these critical elements was a means to a design that would contradict the expected mass of typical bascule piers.

Mass is typically provided in bascule pier design to enclose counterweights and machinery as well as for structural purposes. For a bridge of this size, a typical closed bascule pier would have a width of 55'-65'. With a vertical clearance of more than 55', the piers would be massive. This blocky structure would be disproportionate with the bridge superstructure and dominate the remainder of the bridge.

The design team developed a delta or "V"-shaped bascule pier, which fit with the loads and load path associated with support of the bascule leaf and approach spans. The front legs of the pier are positioned between the trunnions and live-load shoes that transfer loads from the bascule leaf to the pier. The rear legs are located under a rear diaphragm, which connects to the approach-span concrete box girder. By making the delta shape integral with concrete box girder approaches, the lower section of the pier could be slender, yet stiff enough to maintain the position of the movable spans. This bascule pier was coined the "Carina" pier, because its shape in the water evokes images of this Latin word for "keel".

Additional advantages of the Carina Pier include improved movable-span economy, pier openness, and additional working space within the piers. With the trunnion centerline offset towards the channel from the centerline of the Carina Pier foundation, the length of the bascule span between centerline of trunnions was reduced from 70 m to 64 m. This reduction translated to cost savings in the movable span, counterweights, and machinery.

Although in a typical bascule pier this height would present a problem of visual mass, in this case height was an advantage. Replacing the mass typical of the lower section with three "V"-shaped elements creates large open areas through the pier. This openness gives an impression of further reduction in mass so the bridge sits lightly on the water. The height and openness features the counterweight as a visual element rather than hiding it. Because the delta shape is wide at the top, it provides adequate space for machinery, electrical systems, and maintenance access. The configuration of the rear diaphragm allows the construction of a maintenance walkway around the perimeter of each counterweight.

The greatest advantage provided by the Carina Pier design is in the bridge proportions and visual continuity of the structure. The resulting bascule span length, measured between centers of the pier legs, is 241'-8". Measured from the center of the pier legs to the adjacent pier, the side spans are 207'-8". The result is an acceptable 0.85 ratio. The depth of the movable span varies from 7'-9" to 11'-2", similar to the depth of the approach structure.

Further, the Carina Pier legs are the same width as the approach pier columns. In most bascule bridges, the movable span, bascule pier and approach spans appear as three distinct elements, but this design provides structural and visual continuity. The main elements are of similar scale, shape and form, and are visually aligned to form a single element with the span closed.

Visual balance is maintained while the span is opened. The mass of the pier is focused at the pivot point of the bascule leaf, forming a focal point for leaf motion. As the leaf rotates above the channel, the counterweight is visible, rotating down between the legs of the Carina Pier.

BASCULE LEAF CONFIGURATION

The movable span consists of twin double-leaf trunnion bascule spans 210'-long center-to-center of trunnions (which are 177'-2" center-to-center of load shoes). Each leaf has an overall length of 144'–4" from tip to tail. The bridge spans a 125'-wide navigation channel skewed to the centerline of the bridge (77°28'05") and provides 55' of vertical clearance at the face of fenders with the span closed, and unlimited vertical clearance with the span raised to its maximum operating angle of 75°.

The 53'-5½"-wide spans are separated by a 13'-1½" open median. The bridge width could temporarily accommodate four 10' lanes and a 5' 7" sidewalk on one of the twin spans to permit phased construction. The bascule span has a closed deck with a 2% cross slope for drainage.

Traffic rides on an Exodermic bridge deck that spans longitudinally across floorbeams, typically spaced at 14'-5" on center. The floorbeams and cantilevered brackets frame into twin-box main girders spaced at 29'-6" on center. The webs of the box girder are spaced 4'-11" on center. The counterweight consists of a steel box shaped to match the Carina Pier and filled with concrete and steel ballast.

Each main girder is supported on simple trunnions that pass through both webs of the box main girders. Live-load shoes are located at the front wall of the pier. Span locks are located inside the box girders at the tip of the main girders. The span is raised via an electro-mechanical drive system with racks secured to the bottom flange of the main girders.

BASCULE LEAF INNOVATIONS

The bridge's innovative bascule-span superstructure displays structural efficiency, economy, and reduced maintenance requirements. Its configuration incorporates the use of steel-box main girders, floorbeams with moment-resisting connections and a lightweight Exodermic bridge deck made composite with the floorbeams and main girders.

Steel box girders initially were proposed for this project because of improved aesthetics. The y eliminate the bottom-flange overhangs and external web stiffeners. The lateral and torsional stiffness of the box girders also eliminate the span lateral bracing that typically clutters the span underside. The box girders reduce maintenance requirements by eliminating external horizontal surfaces where moisture-retaining debris collects. Also, the torsional rigidity of the box girders permit the use of moment-resisting floorbeam connections for efficient load distribution.

Weight savings in the bascule-leaf structural steel and deck translates to savings throughout the structure. To minimize the weight of the bascule leaf, weight-saving details were incorporated into the main girders. Forward of the live-load shoes, the main girders consist of light, open-tub box girders. A combination of transverse and longitudinal web stiffeners minimize the box-girder web thickness. A continuous longitudinal bottom-flange stiffener similarly reduces the thickness of the bottom flange. This weight savings offsets the additional labor cost of the stiffeners. Behind the live-load shoes, where weight is not as serious, the open-tub box girders transition to a closed-box configuration. The closed-box provides a torsionally rigid element near the trunnions, where it is imperative to maintain alignment of the main girders, especially prior to deck construction.

Longitudinal stiffeners are required on one side of the web only, and are placed within the box girders. Although fatigue is typically a concern with web and flange stiffeners, here the longitudinal stiffeners were located either within the compression zone or near the composite-section neutral axis where the stress level is low.

Continuity at the welded connection between the floorbeams and main girders, and the torsional resistance of the main girders provided efficient load distribution. Reduction in distribution of live loads to the main girders ranges from 5% to 12% when compared with simple distribution. The continuity and torsional resistance provides additional structural efficiency by redistributing loads from one main girder to the opposite girder (load sharing). Comparison of main-girder bending moments with and without this redistribution revealed reduction in live-load bending moments in the main girders from 30% to 50%.

EXODERMIC DECK SYSTEM

A concrete-deck system provides rideability, skid resistance and minimal traffic-induced noise. An Exodermic deck with sand-lightweight concrete was selected for its structural efficiency. The Exodermic deck mounts a thin reinforced-concrete slab on top of a fabricated steel grid. The Exodermic deck spans longitudinally 14'-5" floorbeam-to-floorbeam, permitting elimination of steel stringers that typically support the deck between floorbeams. This uncluttered design eliminates details (e.g., stringer end connections) typically susceptible to corrosion and fatigue.

The Exodermic deck system consists of a 4½"-thick reinforced structural sand-lightweight concrete slab composite with a 5¼" manufactured steel grid. The lightweight concrete specified has a unit weight of 115 pcf, using expanded-shale lightweight aggregate. Sand is used for the fine aggregate to provide improved wear and skid resistance. Composite action between the concrete slab and the steel grid is achieved through tertiary bars and a grid of studs that extend into the slab. The Exodermic deck is made composite with the floorbeams and main girders for additional structural efficiency. This is the first bascule bridge to make the Exodermic deck composite with the main longitudinal-load carrying members.

Since the Exodermic deck serves as a large diaphragm to resist lateral loads, and the main girder boxes provide large torsional and lateral resistance, permanent lateral bracing for the leaf is not required.

STEEL COUNTERWEIGHT BOX

A steel counterweight box balances the movable-span weight while providing an aesthetic complimentary to the steel box girders and bascule pier. The counterweight box and main girders behind the trunnions are filled with steel ballast and concrete. The bottom soffit of the counterweight box is curved to match the bottom soffit of the bascule pier with the span in the closed position. The front face of the counterweight box

is curved to tuck below the cantilevered machinery floor with the bridge in the open position. Curved internal diaphragms transfer loads to the transverse diaphragms, which carry weight to the main girders. The box also eliminates the need for substantial falsework over the water, since its design supports the weight of the steel ballast and concrete.

The bridge design yields a low unit weight of structural steel equal to 80 psf. The Exodermic deck adds a unit weight of 75 psf, for a total bascule-leaf unit weight of 155 psf. The total weight of each leaf is 1,169 tons. The counterweight, including steel box and concrete ballast, weighs 696 tons.

OPERATING MACHINERY

The FDOT stressed maintaining bridge operation. Criteria were imposed to eliminate single-point failure elements and to implement redundancy.

The structural configuration provides for redundant trunnion bearings. Each leaf rotates about a pair of trunnion assemblies. Each assembly consists of a trunnion shaft that passes through both webs of the box girder and is secured to the webs via hub assemblies. The trunnion shafts are supported on spherical roller bearings. The span can remain operational with either of the inboard bearings removed for repairs, reconditioning or replacement. If an outboard bearing requires work, an inboard bearing can be moved temporarily to the outboard location. The bearings are sized to accommodate the larger reactions introduced with the removal of one of the bearings. The torsional rigidity of the main girder boxes and the rigid frame connections between the main girder, floorbeams and counterweight box is adequate to temporarily resist the inboard end of the trunnion in an overhung trunnion arrangement. The spherical roller bearings contain sufficient rotational capacity to accommodate the structure deformation.

Fully redundant operating drives also are provided. Each independent drive train consists of a 93.25kW, 150rpm, four-quadrant DC motor that drives a pinion through a pair of gear reducers. The pinion engages a rack mounted in a frame secured to the underside of the main girder box. Each independent drive train has the capability of driving the bridge on its own at full speed under maximum design conditions, although the drives work together under normal operation.

A SIGNATURE BRIDGE

The 17th Street Causeway Bridge blends with the natural landscape of the area and enhances the surrounding community. The one-of-a-kind bascule span provides a spectacular view. Pedestrian overlooks were provided on the Carina piers. Soft, energy-efficient lighting was incorporated into the railings. The bridge design includes public plazas in the open areas beneath the new bridge, with public parking and views of the Intracoastal waterway and Fort Lauderdale. The plazas include a circular stairway and walkways to nearby resort hotels.

Of three bascule bridges constructed in FDOT District Four between 1998 and 2002, all with the same span requirements, the 17th Street Causeway Bridge had the lowest bascule-span cost per square meter of deck area. The bridge is also the tallest and longest movable span of the three. ★

NATIONAL AWARD

LONG SPAN

The Leonard P. Zakim Bunker Hill Bridge is the focal point of Boston's multi-billion-dollar Central Artery/Tunnel Project. The new "Gateway to Boston" epitomizes the philosophy of form following function; a signature structural form was borne out of a multitude of functional requirements and stringent site constraints.

The bridge's first four lanes opened to northbound traffic in March 2003. Six more will open and ease the gridlock that has plagued Boston's downtown elevated highway system for decades. The bridge's two-lane cantilevered roadway carries northbound traffic from the Sumner Tunnel and North End. A series of parks and recreation areas, encompassing 44 acres, are planned for the riverbanks at the bridge base.

INNOVATION IN STEEL DESIGN

A light steel-composite main span stretches 745' over Boston's Charles River. It is arranged in a hybrid structural configuration with heavy concrete back spans, and produced the optimal layout for the bridge's site-constrained urban location. The hybrid configuration is a first-time application in the United States.

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Photo © Andy Ryan

The main span's steel framing consists of two longitudinal box edge girders of trapezoidal cross-section and transverse floor beams at 20' centers. The supporting cables attach to the outer fascia web of the box edge girders between the floor beams, allowing the floor beams to cantilever 45' to the east side of the bridge.

A longitudinal fascia girder frames into the outer ends of the cantilever floor-beam extensions. Precast concrete panels, made composite with superstructure steel framing through cast-in-place closure strips, form the deck.

STEEL COMPOSITE TOWER

The eccentrically placed dead and live loads, due to the cantilevered roadway, resulted in tensions on the eastern cables that were considerably larger than on the corresponding western cables. This difference in cable tensions under dead load created a considerable amount of torsion and lateral bending in the tower spire. It also led to complexities in bridge-erection analysis; the net transverse cable forces acting on the deck during cantilever construction were carefully considered. Use of a composite tower design with a grade 70 high-performance-steel core, which doubled as a cable anchor box, was key. This also was a first-time application.

Use of lightweight concrete for the cantilevered lanes minimized the tower-spire torsion and lateral bending. This reduced the difference in forces in the eastern and western cables to about 60 percent. Compact cable-anchorage details were used to minimize the transverse cable spacing, reducing the torsion lever arm.

Residual torsion was eliminated through a counteracting moment produced by placing the main-span cable pairs eccentric from the tower centerline. The two-stage minimization procedure reduced the required eccentric offset to just 3" with respect to the tower centerline with no significant visual effects.

COMPACT DETAILS AND CONTROLLING GEOMETRY

The bridge's cable arrangement, inverted Y-towers, and wide roadway section produce a structure with a high degree of three-dimensionality. This increases the complexity of framing and detailing of bridge elements. In particular the cable geometry required considerable engineering to enable the proper anchoring.

The slender towers and the compact tower-leg sections optimized the use of composite tower design with a steel inner core. The core controlled the complex geometry of the cables using the shop-fabricated steel box; it eliminated the need for post-tensioning in the tower walls to resist tensile forces due to cables; and it served as reinforcing steel for the tower in the vertical direction. The composite tower design also enabled a reduction in the cross-sectional dimensions of the tower spire section, improving visual quality.

GIRDER-TO-CABLE ANCHORAGE DETAIL

A similar compact detail designed with 70 HPS steel was used for the cable anchorage at the girder. This allowed an effective load-transfer mechanism between the cable and the girder, placed bolts and welds in preferred action modes (shear vs. direct tension), and provided a high degree of accessibility for inspection and maintenance. It also improved fabrication and constructability due to the single weldment. Grade 70 HPS was used for the cable anchorages and steel-composite tower spires, providing increased strength and high ductility. The steel improved fabrication of the cable-anchor pipes, reducing plate thickness by nearly one-third. It also reduced the anchor-box weight by the same percentage, minimizing the number of splices needed for construction considering the lift weights. This was a first-time application.

STEEL ISOLATION CASINGS PREVENT IMPACT TO EXISTING TUNNEL

The Massachusetts Bay Transportation Authority's (MBTA) Orange Line subway tunnel is located in the immediate vicinity of the south tower foundation and passes directly under the north tower. A tunnel ventilation building is within 2' of the south tower and a 36" critical water main is located within the south tower foundations. The transmission of lateral bridge loads to these existing underground facilities through surrounding soil was determined to be unacceptable. This required isolation of the drilled shafts nearest to these facilities from the surrounding soil by encasing them within an outer structural steel shell. This was a first-time application.

BRIDGE LAYOUT AND AESTHETICS

Site constraints included the existing subway tunnel near the bridge foundations, the existing double-decked bridge (that had to remain until the new bridge was complete), the Charles River locks and dams, and the underground water main. The 745' main steel span placed the two tower foundations on land, providing a channel free of piers in the water immediately upstream of the Charles River locks and dam. Site constraints meant the tower width at the deck level could accommodate only eight of the bridge's 10 lanes. The two remaining lanes were cantilevered to the outside of the eastern cable plane (within the main span).

The CA/T Project involved depressing the I-93 arterial roadway below ground as it cut through downtown Boston. The need to tie in to the I-93 tunnel as it emerged required a ground-hugging profile at the south end of the bridge. The bridge soffit was barely 20' above the finished ground as it reached the south bank of the river at a relatively steep 5-percent grade. Geometric limitations at this end resulted in a relatively short south back span with a span ratio of just 0.31.

The overlap of the existing bridge and new bridge at the end of the south back span made anchorage of cables along the median of the roadway the only viable solution for the back spans. The main span is supported with two cable planes along the longitudinal edge girders.

This cable geometry necessitated the inverted Y-towers. The towers were widest at the roadway level and bent back below the deck, forming a diamond shape. The cables positioned along the median and the extremely short south back-span length made the marrying of the light steel-composite main span with the torsionally rigid and heavy concrete box-girder back spans optimal.

DESIGN CHALLENGES

Some other factors that contributed to the complexity of design:

Exceptional deck width: At 10 lanes and 183', the structure is the widest cable-stayed bridge in the world. Because of limits on the maximum tower width, two lanes had to be positioned outside of the eight-lane roadway carried within the tower legs, cantilevered to the outside of the east cable plane.

Shadow effect: As an environmental commitment, the shadow effect of the bridge's wide deck on the river needed mitigation. Bridge deck openings in the median and in the space between the eight-lane main roadway and two-lane ramp were provided to mitigate shadow effects. The force effects around these openings were carefully analyzed.

Tower strut: The change in direction of the tower legs at the roadway produced a diamond shape and required a horizontal tie member at the roadway to connect the hip points of the tower diamond. The deviation of the large gravity loads carried by the towers due to the directional change produced enormous tensile forces in this

Photo Courtesy Phil DeJoseph

tie member, or tower strut. In addition, the interaction of the tower strut with the back spans produced torsion, bi-directional bending and shear.

Geotechnical conditions: The over-burden fill material involved potential environmental contaminants. The foundations located in highly variable and relatively weak rock conditions required special design and construction considerations.

Seismic considerations: Design criteria required elastic structural response under 0.17g rock acceleration. This, combined with the presence of potentially liquefiable soil lenses in the north back-span area, posed project challenges.

Asymmetric and hybrid structural layout: The bridge is the first major asymmetric and hybrid cable-stayed bridge in the United States. Its back-span layout and two cantilevered lanes make the bridge asymmetric in both longitudinal and transverse directions. The hybrid bridge consists of a steel-composite main span over the Charles River, steel-composite towers and concrete box-girder back spans joined to the main span at the tower strut. The hybrid layout accommodated the bridge's relatively short back spans.

Cantilevered ramp: The cantilevered ramp produces a global eccentric loading on the bridge structure under both permanent dead load (DL) and transient loading. The DL eccentricity produces an imbalance of cable forces between the western and eastern cables that, in turn, produces torsional and transverse bending moments in the tower spire.

Interface of bridge construction with surrounding contracts: Numerous ramps phasing in and out under the north back span left little room for falsework for the cast-in-place box girder construction. As a result, the north back span was designed to provide the contractor with the option for incremental launching, starting from the tower. The congested site provided minimal space for contractor laydown.

ENGINEERING SOLUTIONS

Innovative design solutions were developed to address the multiple project complexities.

Geometric refinements: Stay-cable geometric refinements eliminated the tower-spire torsion and minimized lateral bending caused by the two-lane cantilevered ramp. They also eliminated the need for external cable anchorages at the tower. The bridge marked the first such application of the process.

Analysis refinements: Included were significant three-dimensionality and the cantilevered ramp's impact on static, dynamic and stage-by-stage construction. The difference in DL cable forces on the bridge's eastern and western cables produced a net transverse force that tended to steer the bridge superstructure to one side during cantilever construction; this situation required refined construction staging. In addition, the hybrid span layout required careful consideration of force transfer between the main-span and the back-span structural systems.

Use of optimal materials: High-performance steel was used for the cable anchorages and steel-composite tower spires, providing increased strength and high ductility in these critical components. The main span used painted, grade 50 structural-steel framing. The bridge marks the first use of such diverse materials on a single structure. Heavyweight concrete ballast was used in the south back span to counter the effect of the span's shorter length. Lightweight concrete was used for the roadway of the two-lane cantilever ramp to minimize the eccentric dead load.

Effective mitigation of impacts to adjoining facilities: Through use of 9'-diameter structural steel isolation casings, bridge foundations were isolated from existing facilities so as not to transfer construction and bridge-loading effects. The 8'-diameter drilled shafts located within the effective zone of influence from the Orange Line tunnel were designed with 9'-diameter steel isolation casings. This allowed the 8' shaft to displace within the casing, preventing soil-structure effects on the tunnel. In addition, detailing of the south tower foundation and construction staging eliminated impacts to the 36" water main.

Steel-composite tower: The upper towers were designed with a steel box core for anchoring of cables. The steel core eliminated the need for post-tensioning in the tower walls and reinforces the concrete outer shell. The core facilitated construction by enabling shop-fabrication of the complex cable-anchor geometry.

Isolated extension of spline girder: HNTB shortened the south back span by an additional 45' to avoid interface with a tunnel at the bridge' s south end. The length reduction was made feasible with an isolated superstructure spline extension to anchor the first three cables of the south back span, the first application of this technique.

Shaping of deck slab openings: Bridge deck openings minimized shadow effects on the river. Finite-element analysis optimized the shaping of the openings to minimize stress concentrations while maximizing open area.

Tower strut post-tensioning: The tensile stresses in the concrete tower strut were negated through extensive post-tensioning. Space and detailing limitations restricted the post-tensioning. Tendon geometries were optimized to give drape (vertical) and sweep (horizontal) profiles to each tendon to match the external force effects. The 22 tendons (55x0.6" giving a 60,000-kip pre-compression force) were the maximum that could practically fit within the strut. Post-tensioning was applied in stages with advancing construction to avoid overstressing the other tower elements. This was the first such application in the United States.

Application of latest cable technologies: The design team provided detailed evaluation of the potential for rain/wind vibration of stay cables and included methods for effective mitigation. The mitigation measures, applied for the first time on a U.S. bridge, consist of cable cross ties, cable-pipe surface modifications and external dampers.

Also marking the first application on a U.S. bridge, the design specified ungrouted stay cables. The elimination of grout increases the efficiency of stay cables by reducing their self weight, cutting costs and allowing for potential future replacement. The first application of cable tensioning one-strand-at-a-time eliminated the need for large stressing jacks.

With its slender towers and light superstructure, the bridge is an example of how geometry, analysis, structural innovation and careful material selection can meet technical challenges on a complex project. The Zakim Bunker Hill Bridge destroys the myth that structural efficiency can be achieved only by sacrificing aesthetic impact.★

Marine Parkway Bridge

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ENGINEERING SOFTWARE
STAAD

DETAILING SOFTWARE
Microstation

This $96-million project rehabilitated and enhanced an existing steel-truss bridge that features the world's longest vehicular vertical lift span and was winner of the 1937 AISC Prize Bridge Award. The project widened the existing roadway deck, improving traffic safety and operational efficiency. More than 3000 tons of structural steel were used in the ¾-mile-long project to increase load-carrying capacity and repair deterioration, while continuously maintaining traffic and lift-span operations.

The Marine Parkway Bridge spans Jamaica Bay between the New York City Boroughs of Brooklyn and Queens. The bridge originally was constructed in 1937 to improve access to public beaches on the Rockaway Peninsula. A 150' vertical clearance over a 500'-wide central channel is provided by the record-breaking 540' vertical lift span. Two 540' through-truss spans flank the lift span. A series of deck-truss spans that taper continuously shallower as they approach the shorelines abut each end of the through-truss spans. The deck-truss spans are single-span, two-span and three-span continuous truss units, ranging in length from 98' to 217'. Due to the tapered arrangement, each span and truss member on each deck-truss span is different. The existing bridge, including its deck, had remained essentially unchanged for more than 60 years. The concrete deck needed replacement and the open-curb drainage system was directing runoff off the side of the bridge, causing corrosion of the supporting members below. In addition, road salts had caused the steel-grid deck on the lift span and through-truss span to deteriorate. Approach truss members also had deteriorated from their proximity to the salt water below. Deferred maintenance during times of budget constraint provided short-term savings but eventually took its toll on this bridge. Corrosion-induced section losses coupled with changes in design codes left the Marine Parkway Bridge with a load rating of less than the desired HS-20.

Deck replacement options were studied in the 1990s, followed by design for a bridge reconstruction, including deck replacement, widening, and substantial strengthening and replacement of truss members to meet current design standards. The construction contract was awarded in 1998, but lane closures did not start until fall 1999 to allow for paint removal, shop-drawing preparation and fabrication. Construction was substan-

tially complete on schedule in May 2002, when all four lanes were opened to traffic.

Widening was accomplished by relocating the sidewalk on the west side of the bridge outboard of the trusses. Since the truss geometry only allowed shifting to the west, the spans became eccentrically loaded. The use of lightweight materials minimized the eccentric load effect. Two lanes of traffic had to remain in service at all times, and the vertical lift span had to remain operational without disruption to navigation for the entire construction period. Work also included lead-paint abatement; repainting of the entire structure; seismic upgrade; electrical work associated with span operation and other systems; and decorative lighting for the helical lift-span towers.

CHALLENGES AND SOLUTIONS

Traffic safety improved: The existing bridge had four 11'-wide lanes and no center median barrier. For safety, the bridge operated with two lanes in the peak traffic direction and one lane in the opposite direction, separated by a buffer lane. By moving the single, 6'-wide sidewalk on the west side of the bridge outside of the through-trusses, roadway widening was possible. The reconfigured and widened roadway deck provides four 12' lanes and a continuous median barrier, so two lanes in each direction can be continuously in service. State-of-the-art roadway lighting and a gantry-mounted traffic-lane control system further improved operational safety.

Fast-track completion: Emphasis on constructibility during the design phase and shop fabrication of most components facilitated fast-track construction. Preparation prior to the first lane closures allowed for existing paint removal and identification of previously concealed areas of deterioration and development of repair strategies. Simplified, repetitive details and provisions for fit-up tolerances minimized field problems.

Improve structure strength: One of the project goals was to increase live-load capacity to HS-20. Since considerable extra weight was added to the west side of the span, the west-deck trusses required substantial strengthening. East-deck trusses required strengthening primarily to accommodate deterioration. Fifty percent of the 362 west-deck truss members required repair or replacement, while only 15 percent of the east-deck truss members required repair or replacement.

Provide cost-effective long-term solutions: 90,000 sq. ft of lightweight, precast-concrete deck, and 90,000 sq. ft of grid deck were installed, but the project was more than just a deck replacement. The project corrected 60 years of deterioration and extended the life of the structure. First, the structure was cleaned to bare metal by abrasive blasting and repainted. Steel-repair details were prepared based on inspections before and after paint removal. Primary and secondary members were repaired or replaced after deck removal. With the deck removed, access was simplified, member loads were at a minimum, and repairs and bearing replacement were convenient, with workers and equipment mobilized. The existing seismically vulnerable rocker bearings were replaced with 36 multi-rotational bearings, carrying loads up to 2600 kips. The open roadway curb was eliminated and scuppers were installed to deflect water from the steel and limit future corrosion problems.

Minimize deck weight to limit strengthening requirements for the trusses: The new roadway deck on the deck-truss spans is a lightweight concrete deck, precast on galvanized steel stringers. The panels are supported on steel seats installed on the floor beams. This facilitated speedy construction using waterborne equipment, and minimized the effect of traffic vibrations on the concrete during curing. In addition, the deck panels provided a surface for construction access. The entire deck was overlaid with 1½" of high-performance concrete for a smooth transition between deck panels. The through-truss and lift-span decks remained open grid due to weight restrictions. However, the depth of the grid deck was increased and the purlin spacing was doubled to reduce the overall deck weight. The sidewalk deck consists of a lightweight stiffened steel plate with an epoxy overlay. The parapet on the east fascia was fabricated from steel plate, and the median and west barriers were extruded aluminum shapes. The sidewalk railing also was fabricated from lightweight aluminum shapes. Minimizing the new deck weight allowed the existing trusses to remain in service, and no strengthening of the through-trusses was required.

Cost-effective use of steel: In the design phase, weighing the relative value of materials versus labor was a key concern. The need to keep the bridge open to traffic prevented the replacement of entire spans, and time constraints limited repair options. Shop-fabricated steel-repair plate material was inexpensive, and installation costs and scheduling issues controlled. Thicker repair plates were used to maintain existing rivet spacing while meeting fastener spacing, sealing and stitch requirements without adding intermediate bolts in costly field-drilled holes. Relieving the load in a member prior to adding repair plates would have optimized the material requirements by distributing truss self-weight to both the existing and new steel; but it would have required labor-intensive jacking operations at hundreds of truss members. The repair-plate-thickness increase for the sealing and stitch requirements also achieved the desired load-carrying capacity without jacking the load out of the members. Simplified repair details allowed removal of one quarter of the rivets, one connection at a time, without compromising the load-carrying capacity of the structure. Using these details, multiple crews worked simultaneously on the critical-path truss-member-repair work to meet the tight project schedule.

Selective replacement of main-chord members to improve serviceability: Sixteen members on the deck-truss spans with thin cover plates and wide rivet spacing had significantly more bowing between rivets and impacted rust than other members. Replacing these members minimized future maintenance requirements. Plans were prepared for jacking frames for both tension and compression members to relieve the load and allow replacement of members loaded up to 850 kips in tension or compression. Strains were monitored during the jacking operations to assure loading in the new member was similar to the old. The state-of-the-art jacking operation allowed for safe, efficient replacement of entire members under load.

Needs of the community and travelling public were met: Two lanes of traffic were open at all times using staged construction. Lane closures were limited to a 29-month period, impacting only two summer peak traffic seasons. Contractor access was allowed only from the ends of the bridge and from the water for safety reasons and to prevent disrupting the remaining lanes. Construction was accelerated so that the sidewalk was closed for only one summer, and free bicycle shuttles accommodated cyclists.

Lift span remained operational throughout construction: Coast Guard regulations required that the lift span remain operational throughout construction, which only could occur if it remained properly balanced. Because of the center-of-gravity shift from the westward widening, the lift-span counterweights were modified to shift weight from their east to their west ends. The span balance for each component removed and installed during construction on the lift span was tabulated and daily weight adjustments were made. This maintained a proper balance and prevented overstressing the machinery during span operation. The sheave trunnions were post-tensioned to reduce positive stress ranges under the increased loading and to mitigate fatigue concerns as the span opened. Five-inch-diameter-high strength studs were installed through core holes in all eight counterweight sheave trunnions, and they were loaded by sequential turning of jacking bolts to post-tension them. The contractor designed a paint-removal-containment system for the lift-span towers that could be retracted to allow the span to lift. As a result, marine traffic could pass on demand, unhindered by construction activities.

Signature aesthetics preserved and enhanced: The signature helical towers of the lift span and the three long trusses form a centerpiece for the bridge. The tapering deck-truss spans transition between the main spans and the shores of the bay. Repair details did not affect the visual profile of truss members. The relocated sidewalk has clean simple details and an attractive railing. Decorative lighting illuminates the impressive lift-span towers. ★

The Mingo Creek Viaduct
(Joe Montana Bridges)
WASHINGTON COUNTY, PA

OWNER
Pennsylvania Turnpike Commission

ENGINEER
Gannett Fleming, Inc., Pittsburgh

GENERAL CONTRACTOR
Dick Corporation, Pittsburgh

STEEL FABRICATOR/DETAILER
High Steel Structures, Inc.,
Lancaster, PA (AISC member)

CONSTRUCTION MANAGER
Trumbull Corporation Construction Management Services, Pittsburgh

ENGINEERING SOFTWARE
BSDI 3-D finite element analysis

DETAILING SOFTWARE
MicroSystem

The Mingo Creek Viaduct, also known as the Joe Montana Bridges, carries Toll Road 43 over the Mingo Creek Valley and State Route (S.R.) 88 in Washington County, PA. It is the signature structure on the northernmost segment of the Mon-Fayette Expressway. Completed by the Pennsylvania Turnpike Commission (PTC) in April 2002, this 17-mile section of the Mon-Fayette Expressway connects S.R. 51 with Interstate 70 (I-70), closely paralleling the winding path of the Monongahela River. The bridge's rural setting is characterized by deeply incised stream valleys that reach depths of nearly 400'.

The PTC's goal was to build an expressway that would stimulate economic growth in the Mon-Valley, alleviate much of the traffic congestion in Southern Allegheny County, and provide an efficient route for commercial traffic to and from Pittsburgh. Design challenges included: overcoming topographic and geological conditions; mitigating the effects of extensive room-and-pillar coal mining; maintaining operations within the project limits, and spanning the active, 200' Wheeling & Lake Erie Railroad Trestle, listed on the National Register of Historic Places.

PROJECT LOCATION

The chosen alignment carries four lanes of Turnpike traffic 2,400' from hilltop to hilltop, while towering above the valley about 260' below. This makes the viaduct the tallest structure on the Pennsylvania Turnpike system, and the second tallest roadway bridge in the state. The designed height also maintains the 30' vertical clearance above its active trestle mandated by the Wheeling & Lake Erie Railroad Company. The clearance is required to provide space for the rail-mounted crane cars that perform maintenance atop the 200' trestle.

HPS

The Mingo Creek Viaduct was constructed using a new generation of high performance steel (HPS) known as TMCP, or thermo-mechanically controlled roll processing. Because of the excep-

tional strength of HPS, the designer could specify a lower weight structure, which yielded cost savings. HPS's weathering characteristics and toughness ensure that the superstructure's steel girders will be durable and maintenance-free. Plate girders were constructed of A709 Grade 50 and A709 Grade 70 HPS in the positive and negative moment regions, respectively. The PTC realized material savings from this configuration though the elimination of haunches and longitudinal splices. It was the first time the PTC used Grade 70 girders, and turnpike officials implemented a yearly monitoring and testing program focusing on girder corrosion and fatigue.

REPEATABLE CONSTRUCTION DETAILS

The viaduct design incorporated repeatable construction details, which resulted in time and labor savings. The designer found that most local yards carried standard 8'-by-4' forming panels. These dimensions were incorporated into the substructure units of the bridges. Since the footprints of all the piers were nearly identical, the contractor could move and reset the formwork instead of rebuilding it. As the first pour was dried, the forms could be slid up the pier shaft in preparation for the next concrete pour.

EFFECTS OF MINING

The bridge's substructure consists of 16 slender, flared piers and four stub abutments. The piers were founded on drilled shafts and the abutments on piles to transfer the vertical design loads through the mine voids below into competent bedrock. During a two-phase remediation program, mine voids were grouted full at the substructure units to further reduce the threat of localized mine subsidence. The piers were tapered in profile to streamline materials and provide concrete thickness only where the design required it. These elements were proportioned in response to the high thermal forces generated by the viaduct's long, continuous-span, fixed-pier configuration. These durable substructure units were the prototype for all bridges in the 17-mile Mon-Fayette corridor from S.R. 0051 to I-70.

CONSTRUCTION AND ERECTION SIMULATION

To ensure constructability, a complete construction and erection simulation was conducted in the design phase. The simulation included cranes and delivery vehicles, stationed at key locations along the alignment. It located hypothetical haul roads within the project right-of-way and assigned realistic construction gradients to them. These measures provided all construction machinery with adequate access to the entire job site despite difficult terrain.

ERECTION OF GIRDERS

The erection of the 10'-deep weathering steel girders was an intricate process. The field lengths of the Grade 70 and Grade 50 girders were 90' and 120' respectively, and were based on the length of the flatbed trucks that brought them to the site. The Grade 70 girders had a plate-rolling maximum of 50', but shop splices allowed longer lengths to be shipped. The size of the plate girder, the nearly 300' lift, and the slight curvature of the girders combined to make steel erection a challenge.

Erection proceeded with a Manitowoc 21000 crawler crane, which has a capacity of 1,000 tons and a boom height of more than 300'. The crane was brought to the site on 65 tractor-trailer beds. Erection continued without delays for nearly 10 months.

It took 251 truck trips to bring all of the necessary steel to the project site. The resulting structure is a pair of nine-span, parallel-flange girder viaducts on a half-degree horizontal curve, with span lengths varying from 220' to 300'. The bridge is composed of more than 6,154 tons of partially coated weathering-steel. It consists of four, 10'-deep girders in each travel direction, with extra width on the flared piers for a fifth girder. This extra space will facilitate the addition of an extra lane for future re-decking.

AESTHETIC CONSIDERATIONS

The Mingo Creek Valley's rustic setting meant the structure had to be in harmony with the hillsides, while neither obscuring nor being dwarfed by them. The Viaduct relies on the repetition of coherent, structurally efficient forms to blend in with the surrounding forest.

Careful attention was paid to the rise-to-span and height-to-thickness ratios of the piers, so the structure would be proportionate to its environment. The passing driver is presented with panoramic views. ★

NATIONAL AWARD

SPECIAL PURPOSE

Mon-Fayette Toll Plaza

ALLEGHENY COUNTY, PA

OWNER
Pennsylvania Turnpike Commission, Harrisburg, PA

ARCHITECT
Celli-Flynn Brennan Turkall, Inc., Pittsburgh

STRUCTURAL ENGINEER
Wilbur Smith Associates, Pittsburgh

GENERAL CONTRACTOR
A&L, Inc., Belle Vernon, PA

ENGINEERING SOFTWARE
STAAD

DETAILING SOFTWARE
AutoCAD 2000

The new mainline toll plaza on the Mon-Fayette Expressway was designed be a cost-effective and attractive facility that was safe for employees. It would be the first facility on the Pennsylvania Turnpike Commission (PTC) system to accommodate three forms of payment: high-speed electronic toll collection, and both manned and unmanned toll booths. The high-speed lanes were located at the center, and the toll booths and facility building adjoin them peripherally. A pedestrian bridge for safe access across the high-speed lanes creates an architectural statement and provides a structure to sustain the Electronic Toll Collection equipment without obtrusive sign gantries. With the Pedestrian Bridge concept, the Commission chose to present the facility as the "Gateway into Pittsburgh," since this highway will lead motorists toward downtown Pittsburgh.

The bridge is composed of two truss-spans, each 139'-5" in length with steel HSS chord and vertical members, and stainless-steel diagonal tension rods. Vertical curvature (arching) was introduced for aesthetic purposes. Other visual contributions include a curved stainless-steel roof that also serves as a canopy over the toll-booths, HSS steel trusses with full-height glass windows, and a centrally located V-shaped pier. The stairwells are glass-enclosed for safety and to present a pleasing visual experience for PTC customers as they pass through the facility. The creative structural design used thin, stainless-steel rods for the truss diagonal members. This choice provided light, non-intrusive views from within the bridge and added detail as a decorative focal point for travelers viewing the structure.

COST-EFFECTIVE DESIGN

Cost estimates were developed for alternatives that included tunneling concepts versus bridges to facilitate PTC employee pedestrian movements across the high-speed lanes. Based on the cost estimates and past problems with tunnels, an arched steel-bridge structure was considered the most cost-effective solution. Pittsburgh's history as the steel capital of the world would be reflected in the use of steel as the main structural element in the bridge. The total construction cost for the bridge was under $2.25 million. The bridge also allowed monitoring of the facility by one individual from an operations room constructed over the pier. This first for the PTC resulted in economical, life-cycle-operations costs.

PROBLEMS AND SOLUTIONS

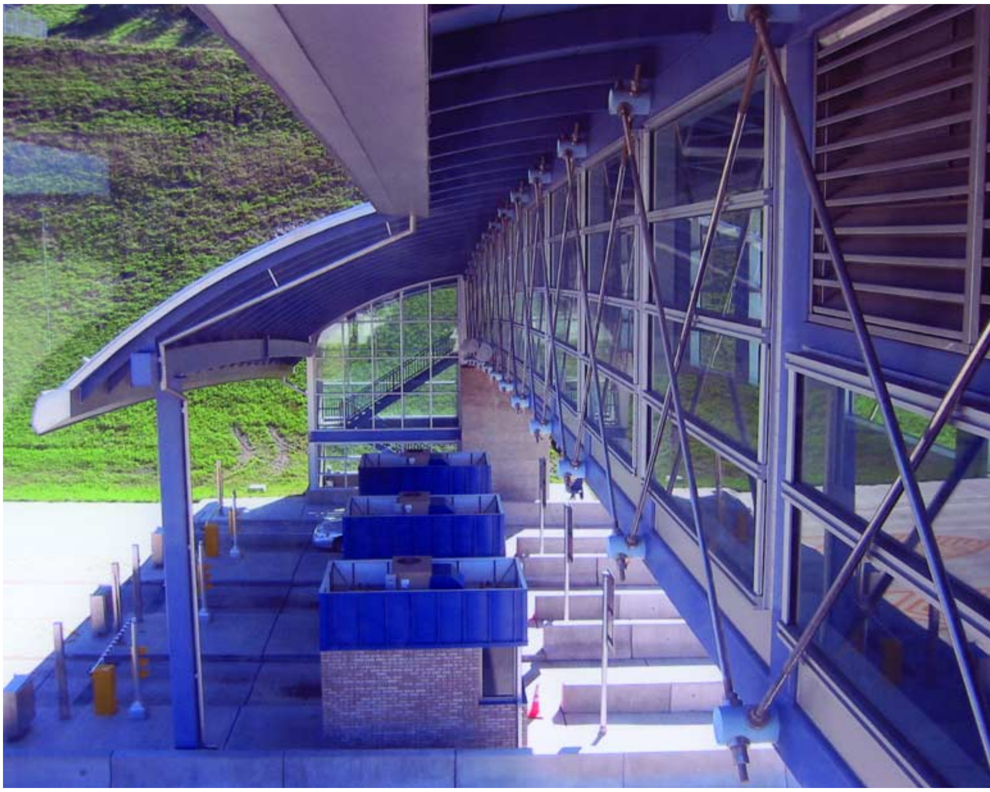
A structural engineering accomplishment of the Mon-Fayette Pedestrian Bridge included the use of stainless-steel rods as the truss-tension and compression diagonals. This use of thin rods provided a light and unobstructed appearance.

The rods were pre-tensioned prior to erection with a larger force than the compression force that would be introduced by the truss loads, thus always keeping the rods in tension. This avoided larger-size members that would have been required based on slenderness ratios and compression forces. Another achievement was the rod connections to the truss that used steel pipe extended through the main-truss HSS members. The use of pipes at the truss joints along with nuts and washers reflected the pin-type connections of traditional trusses, while providing a technical innovation since this truss is not a true pinned truss.

The use of the facility for personnel while traffic traveled below required that items such as the pier would need to be fire-protected to meet local building codes. The structural-steel pier is coated with a 1/8" fire-protective coating that, when subjected to heat, expands to 6" to provide a two-hour fire rating.

The bridge spans are fixed at the stairwells with elastomeric bearing pads and anchor bolts. Both bridge spans expand at the pier, where expansion and contraction is accommodated by the observation-room doorway sills. To prevent cracking of the bridge-window glass, thermoplastic seals were installed to accommodate thermal and wind movements.

This new plaza, with its featured pedestrian bridge, meets the original design goals of form, function and cost effectiveness. ★



NATIONAL STEEL BRIDGE ALLIANCE PRIZE BRIDGE COMPETITION

NATIONAL AWARD

MEDIUM SPAN

US 59–Houston Gateway

HOUSTON

OWNER/STRUCTURAL ENGINEER
Texas Department of Transportation

ARCHITECT
Rey de la Reza Architects, Inc., Houston

ENGINEERING SOFTWARE
ANSYS, STAAD, StruCAD*3D

GENERAL CONTRACTOR
Williams Brothers Construction Company, Inc., Houston

STEEL DETAILER
Tensor Engineering Co., Indian Harbor Beach, FL
(AISC member, NISD member)

The Southwest Freeway (US 59) is located near downtown Houston. In 1998, construction began for the addition of two high-occupancy vehicle lanes and two travel lanes as part of an effort to increase capacity throughout the corridor. Four continuous post-tensioned concrete bridges spanning the freeway first needed to be replaced to provide space for a cross section, and to accommodate construction traffic control for the 250,000 vehicles per day that use the freeway. Increasing vertical clearance also was key: Due to deficient clearance under the bridge, high loads frequently struck the existing Hazard Street underpass, and its outside lane and sidewalk had been closed to traffic for more than a year as a result.

BRIDGE DESCRIPTION

The new steel tied-arch bridges clear span 224' over the freeway. They carry two lanes of traffic, two bicycle lanes, a utility parapet in each direction, and sidewalks outside of each arch. Their total widths are 60' each. The arches, 45' apart, are fabricated from steel plate and braced with rectangular HSS. The deck is composed of full-width precast and prestressed panels that are post-tensioned longitudinally and overlaid with composite concrete.

The bridge is founded on soldier-pile retaining walls on each side of the depressed section. Forty-eight-inch-diameter drilled shafts spaced at 5' were used for the retaining wall. Each bridge crosses the freeway at a small but slightly different skew angle. TxDOT engineers avoided complicated detailing of skewed bridges by increasing the bridge length slightly and recessing the square ends of the bridges into the embankment at each end. All four superstructures are exact duplicates, resulting in economies in design, fabrication, and construction.

DESIGN CHALLENGES

The structural solution was constrained by several primary design challenges. The surface profile of the streets above the freeway had to be maintained due to residential driveways immediately adjacent to the bridge ends. The existing freeway surface could not be lowered because of the storm-drainage system just under the pavement. It was not possible to replace the drainage system because exceptionally high road-user costs dictated that four lanes of traffic in each direction had to be maintained throughout the

project during peak hours. Additionally, traffic control and lane configurations did not allow columns within the freeway limits. In order to provide increased clearance below the new bridges, minimize roadway user costs, and avoid skewed ends, a structural system was needed that could clear an 218' span with an apparent structure depth of 1', about the thickness of typical concrete pavement on Houston freeways. Essentially, a system was needed to suspend the pavement from above without floor beams.

DESIGN SOLUTION

Tied arches were chosen as the structural system for aesthetic reasons, and steel was cost-effective, quick and simple to erect.

Only one weekend closure was required for each bridge. There were no other traffic impacts during construction. To maintain freeway traffic under the bridges during all phases of construction, the arches were located to fit within the existing bridge width so that the existing bridges could serve as work platforms. Even though one existing bridge was damaged due to multiple impacts over the years, the lightweight steel arches still could be shored from the bridge deck. The length of the new bridges enabled construction of the abutments without affecting the existing bridges or impacting traffic. Once the steel arches were in place, straddling the existing bridges, the contractor used explosives to drop the old bridges down to freeway pavement level. Workers broke up the concrete using conventional methods. The speed of steel erection also enabled TxDOT engineers to minimize the duration of street closures.

The full-width precast segments that form the deck are incarnations of precast slab beams commonly used in Texas coastal areas for their shallow structure depth. Instead of resting on bearings at abutments, designers suspended them from the arch-tie beams using bolts. The precast deck segments were installed over active traffic lanes during the same-weekend freeway closure that was used for demolition of the existing bridges.

The arch-tie beam was encased in concrete with reinforcing steel embedded in the precast segments, lapped with reinforcing steel surrounding the tie beams. The bridge deck is crowned at centerline of roadway, enabling the precast segments to be thickened where the dead-load moment is largest. The precast deck segments were post-tensioned longitudinally to eliminate tension in the concrete.

Designers solved the issue of differential camber in prestressed concrete elements placed side-by-side by placing a 4" composite overlay over the segments. Volumetric change in the deck and its effect on the steel structure was resolved by stipulating completion of all deck concrete work and steel post-tensioning before encasing the arch tie in concrete. The deck was allowed to move relative to the arch tie by slotting the bolt holes in the arch tie and using neoprene washers under steel-plate washers. This allowed the 3'-long panel bolts to rotate with minimal bending.

The arches and tie beams are box sections with thin webs. Lateral bracing was required along the arch for stability. Bracing could have been avoided with thicker webs but at the expense of increased steel weight. The bridges were originally detailed with X-bracing. A Vierendeel system was substituted for aesthetic reasons. Further analysis during construction revealed that the Vierendeel system was inadequate under wind loading, and X-bracing was added to the already erected Vierendeel braces. The X-brace nodes are cylindrical sections. The circular or semicircular top and bottom plates are welded to the arch rib. The HSS braces are welded to the top and bottom plates, similar to a gusset-plate connection. Finally, the circumference is enclosed and seal-welded all around. This fully field-welded detail enabled all braces to be cut square, and allowed for axial and rotational fabrication error along three axes.

Detailing the structural steel at the junction of the arch with the arch tie was a challenge. Post-tensioning of the arch tie provided redundancy and virtually eliminated tension in the tie. This allayed concerns of tie-beam problems, but necessitated passing the arch-tie flanges through the junction with the arch rib. Designers labeled this detail a "knee joint" and conducted extensive finite-element analysis and detailing of it. They evaluated many configurations and plate arrangements to control high local stresses and ensure a smooth flow of stress to the bearings. The final configuration required large partial-penetration welds at the intersection of the bottom plate of the arch rib with the top plate of the tie. This weld was modified and reduced in size at the fabricator's request due to difficulties in attaining a quality weld of such size.

COST SAVINGS

The bridge cost of $150.00 per square foot is higher than conventional bridge construction in the Houston area, but the structural system employed in these bridges saved many times the cost of the bridges in roadway-user costs. Steel framing and the precast segmental deck enabled all four bridges to be built in sequence within 14 months.

AESTHETICS

TxDOT engineers engaged an architect to help ensure that the project would enhance the community. Brick-paved sidewalks and an ornamental fence add to the attractive tied arches. Red concrete differentiates bicycle lanes from traffic lanes, and exposed aggregate finish was specified for the tie-beam encasement. The shape of the arch was reinforced by adding a continuous cap with integral fiber-optic lighting, and red finials were added at the ends of each arch.

The original freeway split the community in two parts when it was built in 1961. The previous bridges were inadequate for pedestrian traffic and led to a sense of separation. The new landmark bridges beckon pedestrian traffic and have restored the feeling of one community. ★

MERIT AWARDS

Long Span: SH-67 Realignment – Arequa Gulch Bridge, Cripple Creek, CO

Each day, 90-ton mine-haul trucks crossed Colorado State Highway 67 (SH-67) where it bisected Cripple Creek & Victor (CC&V) Gold Mine, interfering with operations and impeding development. Mine operations presented safety concerns to travelers and the highway's location impeded the mine's operations and development plans. To address these issues, CC&V and the Colorado Department of Transportation (CDOT) developed one of the state's largest public/private partnerships to realign SH-67. CC&V sponsored and managed the design and construction with CDOT reviewing the design and construction operations at key milestones. Ultimately the new roadway was swapped with the existing SH-67 alignment, resulting in a win-win-win for CC&V, CDOT, and travelers.

OWNER
Colorado Department of Transportation

STRUCTURAL ENGINEER
HDR Engineering, Inc., Denver

ENGINEERING SOFTWARE
SIMON

BRIDGE CONTRACTOR
Edward Kraemer & Sons, Inc., Castle Rock, CO

STEEL FABRICATOR
Trinity Industries, Houston (AISC member)

Movable Span: Sixth Street Viaduct, Milwaukee

OWNER
City of Milwaukee Department of Public Works

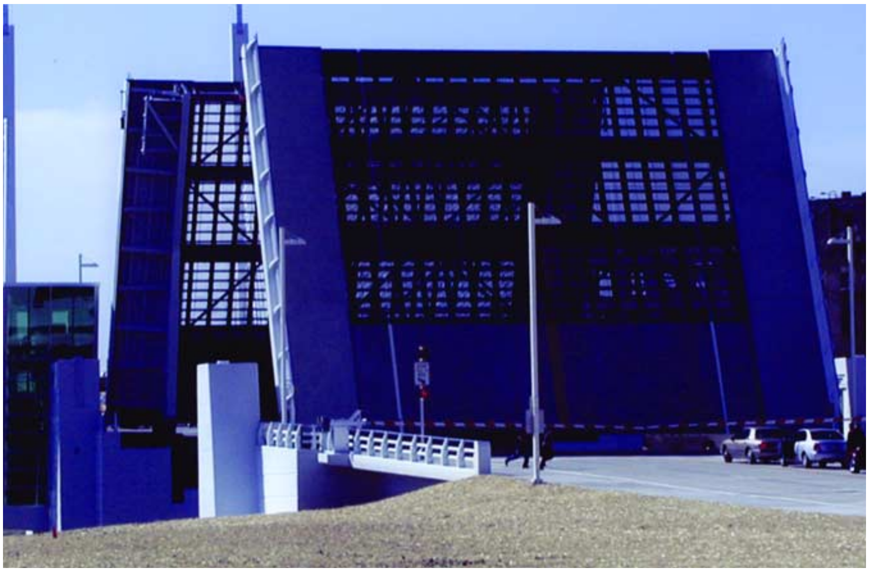
ARCHITECT/STRUCTURAL ENGINEER
HNTB Corporation, New York City

ENGINEERING SOFTWARE
GTStrudl

GENERAL CONTRACTOR
Milwaukee Gateway Partners, Milwaukee

STEEL FABRICATOR
PDM Bridge, Eau Claire, WI (AISC member)

STEEL DETAILER
Tensor Engineering Co., Indian Harbor Beach, FL (AISC/NISD member)



The Sixth Street Viaduct was a design-build project that replaced approximately 2,500' of bridge in downtown Milwaukee. The project includes two double-leaf bascules and two cable-stayed bridges whose design and construction were completed within just 24 months. Careful planning and coordination was required to meet the schedule for this complex bridge. The Sixth Street Viaduct is Wisconsin's first design-build project.

Major Span: William H. Natcher Bridge, Between Owensboro, KY and Rockport, IN

OWNER
Kentucky Transportation Cabinet

STRUCTURAL ENGINEER
Parsons Brinckerhoff Quade & Douglass, Inc., New York City

STRUCTURAL ENGINEERING SOFTWARE
LARSA

GENERAL CONTRACTOR/ERECTOR
Traylor Bros., Inc., Evansville, IN

STEEL FABRICATOR
Vincennes Steel Corporation, Vincennes, IN (AISC member)

STEEL DETAILER
Tensor Engineering Co., Indian Harbor Beach, FL (AISC, NISD member)

STAY CABLE SUPPLIER
VSL, Hanover, MD

WIND TUNNEL TESTING
Rowan Williams Davies & Irwin, Guelph, Ontario

The William H. Natcher Bridge over the Ohio River carries Route 231 between Owensboro, KY, and Rockport, IN. The four-lane, 4,505'-long bridge includes 2,200' of cable-stayed spans and approximately 3 miles of approach embankment and relief structures. One of the longest cable-stayed bridges in the U.S., the Natcher Bridge features a 1,200' main span and distinctive diamond-shaped concrete towers that enhance the structure's aerodynamic stability. The bridge features innovations designed to minimize environmental impact, reduce costs, simplify construction, and to ensure that the structure will be easy to inspect and maintain.

Major Span: Gene Hartzell Memorial Bridge, near Easton, PA

The Gene Hartzell Memorial Bridge was part of a roadway project that extends S.R. 33 south to connect with Interstate Route 78. Possible locations for the new, 1870' bridge over the Lehigh River were limited due to environmental and right-of-way concerns. Also, the bridge had to span an active railroad to the south, the Lehigh canal and its towpath, and a public bikeway to the north. The four-span truss configuration was developed to optimize the structural-span lengths while still meeting these restrictions. Steel met aesthetic goals and provided light lifts with small profiles, minimizing wind concerns.

The community indicated a desire for the bridge to have an "old time" aesthetic. The truss bridge provides a superstructure from another era yet incorporates modern design concepts.

OWNER
Pennsylvania Department of Transportation

STRUCTURAL ENGINEER
URS Corporation, King of Prussia, PA

STRUCTURAL ENGINEERING SOFTWARE
GTStrudl

STEEL FABRICATOR
PDM Bridge, Eau Claire, WI (AISC Member)

STEEL DETAILER
Tensor Engineering, Indian Harbor Beach, FL (AISC, NISD member)

STEEL ERECTOR
American Bridge Manufacturing, Coraopolis, PA (AISC member)

MERIT AWARDS

Railroad: Henry Ford Grade Separation

The challenge of the Henry Ford Grade Separation was to design a cost-effective grade separation in a key portion of a $2.4-billion program–in an area that is congested with mixed-use port traffic, has three existing mainline railroad tracks that cannot be disturbed, required soil remediation and required the spanning of a water channel and intersection. Some of the major issues confronting the project were finding an economical foundation solution to building in a high-seismic zone; overcoming tight construction staging spaces; and coordinating with up to six local transportation agencies at once, all while mitigating construction impacts on existing vehicular and rail traffic.

OWNER
Alameda Corridor Transportation Authority

STRUCTURAL ENGINEER
HNTB Corporation, Santa Ana, CA

GENERAL CONTRACTOR
Shimmick Construction Company, Inc., joint venture with Obayashi Corporation, Hayward, CA.

ENGINEERING SOFTWARE
GTStrudl

STEEL ERECTOR
Adams & Smith, Inc., Lindon, UT (AISC member)

Reconstructed: East Carquinez Bridge, Vallejo, CA

The Carquinez Bridge, located near San Francisco is a 3,350'-long steel cantilever through-truss structure. The existing structure, completed in 1958, was the first highway bridge in the United States to use high-strength (T-1) steel, the first to use welded built-up members, and the first to use high-strength bolted connections. In 1994, the bridge was determined to be vulnerable to collapse during an earthquake. From 1995 to 1997, the project team developed a design to prevent collapse of the structure during the maximum credible earthquake. The retrofit was constructed from 1998 to 2002. The outcome was a successful $85-million bridge reconstruction for the tens of thousands of motorists in the Bay area who travel daily on this major artery.

OWNER
California Department of Transportation

STRUCTURAL ENGINEER
CH2M Hill, Sacramento

ENGINEERING SOFTWARE
ADINA

GENERAL CONTRACTOR
Balfour Beatty Constr., Inc., London, UK

STEEL ERECTOR
Christie Constructors, Inc., Richmond, CA (NEA members)

Reconstructed: Strawberry Mansion Bridge, Philadelphia

The original Strawberry Mansion Bridge was built in 1897 by the Fairmount Park Transportation Company, and spans the Schuylkill River in Philadelphia. The newly rehabilitated, 1,250'-long bridge consists of six deck-truss approach spans and four steel-arch-truss river spans. The capacity of the structure was increased to HS-20 live load by using a lightweight deck and strengthening the truss members. Severe section losses to truss members necessitated complex and sequenced strengthening while the bridge was open to traffic. Replacement of the arch trusses' vertical and horizontal gusset plates at the deteriorated connections required temporary support systems for unloading and loading the connections. At abandoned trolley-track locations, a 27'-wide by 800'-long promenade was employed. The promenade is surrounded with original and replicated railings, trolley catenary portals, ornamental light poles and fixtures. Also included in the project was the erection of 14 historic signs along an 8½-mile route that passes beneath the structure.

OWNER
City of Philadelphia, Department of Streets, Bridge Division

SPONSOR
Philadelphia Department of Transportation

GENERAL CONTRACTOR
IA Construction Corp., Concordville, PA

ARCHITECT
Susan Maxwell Architects, Philadelphia

STRUCTURAL ENGINEER
Lichtenstein Consulting Engineers, Inc., Langhorne, PA

ENGINEERING SOFTWARE
STAADPro (STAAD-III)

Medium Span: Fort Meigs Memorial Bridge, Maumee & Perrysburg, OH

The Ohio Department of Transportation designed the new Fort Meigs Memorial Bridge, crossing the Maumee River in northwestern Ohio, to replace an existing bridge almost 75 years old. The bridge connects the City of Maumee in Lucas County and the City of Perrysburg in Wood County, and carries U.S. Route 20 and State Route 25 traffic across the river

The previous structure was a seven-span, filled-spandrel concrete-arch bridge constructed in 1927-1928. The bridge had deteriorated, resulting in crumbling concrete along both sides and closing the sidewalk on the upstream side. The two-lane bridge was functionally deficient to carry the current traffic volume of 29,000 vehicles per day. There were sharp curves on the roadway approaches at both ends of the bridge. The new $9.2-million replacement bridge is a seven-span, variable-depth, haunched, horizontally curved steel-girder structure with a composite, reinforced-concrete deck and substructure. The bridge is located on a sweeping five-degree, horizontally curved alignment to eliminate the sharp curves on each end.

OWNER
Ohio Department of Transportation

GENERAL CONTRACTOR
Mosser Construction, Inc., Fremont, OH

STRUCTURAL ENGINEER
Adache Ciuni Lynn Associates, Inc., Cleveland

ENGINEERING SOFTWARE
C-Bridge

STEEL FABRICATOR
PDM Bridge, Eau Claire, WI
(AISC member)

STEEL DETAILER
Tensor Engineering, Indian Harbor Beach, FL (AISC member, NISD member)

MERIT AWARDS

Short Span: 21st Avenue Pedestrian Bridge, Nashville, TN

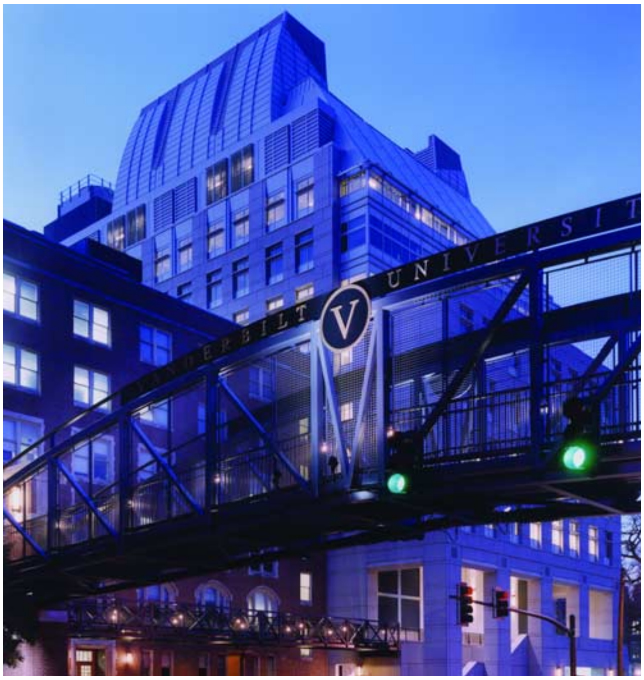


Photo © Anton Grassl

In 1979 Vanderbilt University acquired Peabody College, a neighboring institution. The busy 21st Avenue South divided the two campuses and caused a number of safety concerns due to the heightened foot traffic across the busy corridor. The design team was presented with the challenge of successfully linking the two main campuses across the four-lane thoroughfare. A modified bow-truss design was chosen as the main span to act as a signature landmark. The brick and cast-stone piers anchor the main span that defines the structure as a gateway. The bridge not only provides safe passage above a busy street but also gives identity to the institution.

OWNER
Vanderbilt University, Nashville

ARCHITECT
William Wilson Associated Architects, Inc., Boston

GENERAL CONTRACTOR
Centex Rodgers, Inc., Nashville

CONSULTANT
Carpenter-Wright Engineers, PLLC, Nashville

Special Purpose: Berkeley Pedestrian and Bicycle Overcrossing, Berkeley, CA

The Berkeley pedestrian and bicycle overcrossing provides access between the City of Berkeley's Aquatic Park and the Eastshore Regional Park (Berkeley Marina) to pedestrians, bicyclists, and people with disabilities. The new bridge, completed in February 2002, crosses the Interstate 80 freeway with a tied-arch span of 293', with curved box-girder ramps at each end. Its dramatic clear span across one of the most congested freeways in North America provides access for users not served by previous facilities, an architectural landmark for the City of Berkeley, and excellent vistas of parklands and cityscapes.

OWNER
City of Berkeley

ARCHITECT
MacDonald Architects,
San Francisco

STRUCTURAL ENGINEER
OPAC Consulting Engineers, Inc., San Francisco

ENGINEERING SOFTWARE
SAP 2000

GENERAL CONTRACTOR
C.C. Myers, Inc.,
Rancho Cordova, CA

STEEL FABRICATOR
Universal Structural, Inc., Vancouver, WA
(AISC member)

STEEL DETAILER
Wasatch Detailing Corporation, Salt Lake City, UT (AISC member)

DETAILING SOFTWARE
AutoCAD 2002

STEEL ERECTOR
Adams & Smith, Lindon, UT
(AISC member)

CONSULTANT
Lin Tung-Yen China, Inc., San Francisco

Special Purpose: Millennium Bridge, Denver, CO

In the late 1990s, the City of Denver began a massive redevelopment project to revive Lower Downtown (LoDo) Denver and the adjacent Northwest Neighborhoods. To foster urban renewal in the area, the 16th Street Mall was designed to link the LoDo district and the valley. The Millennium Bridge, a cable-stayed pedestrian structure located along the Mall, is the central focus and visual marker on the vista down 16th street. The bridge's 200', 110-ton steel mast rises distinctively above the Platte Valley on the northwest edge of downtown. The bridge carries pedestrian traffic over the Consolidated Main Line tracks and a light rail corridor.

OWNER
Central Platte Valley Metropolitan District, Denver

ARCHITECT
ArchitectureDenver, Denver

STRUCTURAL ENGINEER
Arup, New York City

GENERAL CONTRACTOR
Edward Kraemer & Sons, Inc., Castle Rock, CO

CONSULTING FIRM
Ewbank, Inc., Phoenix

Short Span: Spanish Oaks Golf Course Bridge, Bee Caves, TX

In designing the Spanish Oaks Golf Course Bridge at Hole #18, the landscape architect envisioned a structural steel pedestrian/golf cart bridge spanning over a man-made reflecting pond. The end result was a variable-depth arched-steel truss spanning to limestone-clad bents and abutments.

The bridge consists of a 100' main span with two 45' approach spans. A weathering steel railing, consisting of HSS $2\times2\times\frac{3}{16}$ posts, $\frac{1}{2}$"$\times$2"-plate top-and-bottom rails, and $\frac{1}{4}$"$\times1\frac{3}{8}$" plate balusters, completes the bridge aesthetic. Steel angle frames provide the structural support for stone pilasters that project above the deck at the abutments and interior bents.

OWNER
CCNG Development Co., L.P., Austin

STRUCTURAL ENGINEER
Pickett, Kelm & Associates, Austin

GENERAL CONTRACTOR
JC Evans Construction, Leander, TX

ENGINEERING SOFTWARE
RISA-3D

STEEL FABRICATOR
Hirschfeld Steel Co, Inc. Abilene, TX (AISC member)

CIVIL ENGINEER
Murfee Engineering, Austin

LANDSCAPE ARCHITECT
Bosse Compton & Turner, Austin