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. ★