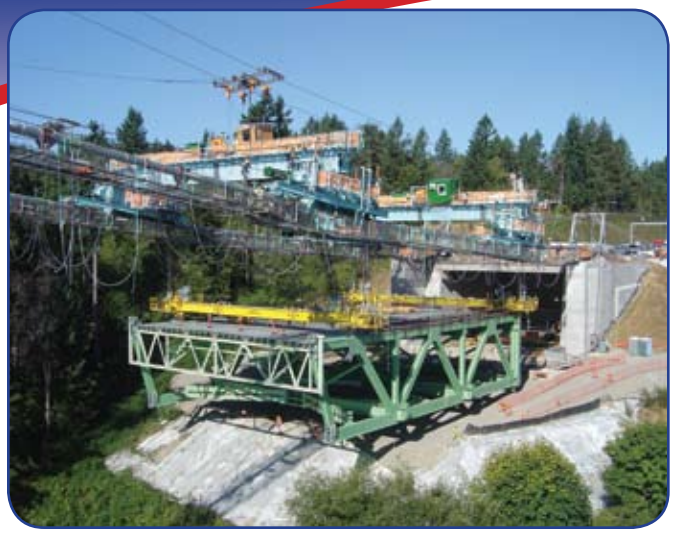
A New Suspension Bridge at the Historic Tacoma Narrows Site

By Joe Viola, P.E. and Tom Spoth, P.E.



Trapezing Segment 1 to Gig Harbor Anchorage

The newest major suspension bridge in the U.S. is rapidly nearing completion in Tacoma, Washington. This new bridge parallels the existing 1950 bridge and also spans a section of the Narrows that holds the remains of the ill fated 1940 collapsed bridge. Featuring a contiguous steel superstructure over one mile in length, this unique fifth longest suspension bridge in the U.S. is scheduled for completion by the summer of 2007. The Owner, the State of Washington Department of Transportation (WSDOT), Design/Builder Tacoma Narrows Constructors (TNC), designers Parsons/HNTB and fabricators from around the world have collaborated since 2002 to deliver the completed bridge in the project's 55-month schedule. At completion, the new transportation facility will have been designed and constructed with an eye towards meeting regional transportation needs well into the future. One such feature is the built-in ability to add a future lower level for light rail transit or highway usage.

Design/Build Procurement with Public-Private Partnership Roots

The project was initially conceived as a Public Private Partnership, but subsequently evolved into a Design/Build contract arrangement with a very strong partnering component. The adopted contracting approach brought an advantage in that the entire project team was able to closely collaborate throughout all design phases, benefiting from insight regarding Owner requirements, shop fabrication preferences, bridge component delivery schemes and the Contractor's erection means and methods. Bi-weekly Task Force meetings were the tool of choice for coordination during the design phase. These meetings were held on-site and included participation from WSDOT, TNC, designers, fabricators, management, environmental, safety and quality. Project direction and design advancement were discussed in an open forum, leading to quick resolution of open items and the ability to lock-in decisions earlier in the design process. This arrangement was key to the design team making all 25 critical milestone submissions – on time and within the quality and expectations of all stakeholders. For example, 30 days following, the Contractor was able to initiate fabrication of the steel cutting edge for the main tower caissons, a milestone necessary for schedule success.

Steel fabrication and erection engineering was subcontracted to Nippon Steel / Kawada Bridge (NSKB) of Japan, with fabrication of the stiffening truss and deck being further sublet to Samsung Heavy Industries (SHI) in Korea. Considering that planning, submittal reviews and fabrication involved entities in Korea, Japan, Parsons' New York office and the Contractor's site office, the effort was a truly international in scope, and in fact at times an around-the-clock effort spanning global time zones. All submittals and approvals were delivered by electronic means.

The project's design team remained integral to the project advancement throughout the bridge erection phases, maintaining close contact with site engineers and supporting TNC throughout. Post-design services included Engineering Support During Construction (ESDC) and Construction Engineering Services (CES). While TNC maintained a lead role on all quality matters, Parsons and WSDOT provided in-house fabrication specialists, certified welding inspectors, and supported the project in a quality assurance role. WSDOT maintained the right of rejection throughout all phases of the project.

Because of the dynamic nature of the Tacoma project, coupled with international procurement, it was necessary to have an in-place procedure to accommodate process improvements and value engineering opportunities. The procedure was implemented through the project's Quality Managing Plan and was managed by TNC, with technical support being provided through the ESDC engineering phase. This process allowed a tie to be formed from construction activities back to the design team for designer response, as it related to design intent and conformance with project standards. Communications were by way of three document types: Field Change Requests (FCRs), Field Change Notices (FCNs), and Requests for Information (RFIs). In addition, the designers revised the Issue for Construction Plans as necessary for work implementation and to serve as the as-built project record. Full time on-site coordination of submittal reviews, resolution of engineering matters and implementation of the Quality Assurance process was an integral aspect to the overall success of ESDC and CES efforts.

Design Features

The new bridge was designed for three highway lanes, two full shoulders and a bicycle-pedestrian path. However, on opening day it will be striped for four lanes, with the forth lane having been added to accommodate traffic from a local on-ramp that was included in the project scope during construction. True to form, the design of this major suspension bridge focuses on efficient use of materials, minimum weight, and effective fabrication and construction techniques. To that end, the New Tacoma Narrows Bridge has incorporated the following features:

Structure Segment lifted from Transport Vessel

- A lightweight orthotropic steel deck that is integral with the stiffening truss for effective global response to service and extreme load cases
- Tapered floorbeams for efficient use of materials and weight savings
- Trapezoidal orthotropic deck ribs with proven fatigue endurance details
- HPS 70W steel for the orthotropic deck and truss in areas of high demand
- Truss bottom chords with integral maintenance traveler support features
- Truss verticals only at even panel points
- Main cable strand anchoring system that minimizes permanent materials
- Articulated center tie design
- Lower lateral system with integral maintenance access walkways
- One each upper and lower maintenance travelers that can traverse the entire bridge, end to end
- 5,400-foot continuous superstructure with expansion joints only at the anchorages
- Gravity anchorages using a 20-foot deep base shear key for improved sliding resistance and minimum mass concrete
- Granular fill used for ballast in the anchorages to further reduce the concrete quantity

The bridge is also an excellent example of efficient use of deep water gravity caissons that were sunk to a level of 187 and 213 feet below mean low water and serve to support the towers. The towers are only the second use of reinforced concrete towers for a major suspension bridge in a high seismic zone, the first being the New Carquinez Bridge in California.

A Strong Foundation

The two new bridge towers are supported on deep-water caissons, each equipped with an 18-foot tall steel cutting edge at its base, and massive steel air domes that served to maintain buoyancy during construction. Each caisson was floated into position, anchored in place and then gradually "sunk" into place on the Narrows sea floor. After landing on the sea floor, the dredge chambers were flooded, the air domes removed and then 3 months of dredging commenced. Once the caisson cut into the sea floor and reached the specified tip elevation, the bottom was sealed with concrete. The west tower caisson is founded at elevation -190 feet and the east caisson at elevation -216 feet. Seven-knot tidal flows and unpredictable vortices spun off of the adjacent existing bridge piers made working conditions particularly challenging. The construction team persevered to overcome the site difficulties, and they landed the caissons well within stringent construction tolerances defined for position and verticality. Global positioning and other controls were in place to ensure precision as the caisson work progressed.

Once constructed, the caissons were topped with 15-foot thick distribution slabs designed to distribute the loads from the tower pedestals into the walls of the caisson dredge wells.

Caisson Construction

The heavily reinforced concrete towers rise from the caisson tops reaching an elevation of 505 feet. Each leg of each tower is rectangular in cross section and is of a single open cell construction. The tower leg walls are 4 feet at their thickest point and they employ three post tensioned cross struts. Anchored to the top of each tower leg are 32-ton steel saddle castings that cradle the main cables as they pass over the tower tops on their way to the land-side anchorages.

The main cables, each 20½ inches in diameter, are secured to cast steel strand shoes at the face of each main anchor block. The reinforced concrete gravity anchorages weigh upwards of 83,000 tons each in order to resist the pull of the main cables. The anchorages also contained structural fill used as ballast and at their deepest point the anchorages extend to a depth 89 feet below the roadway surface. The anchorages are also configured with an exclusion zone between each main cable which is void of permanent structural works in order to accommodate future light transit or roadway facilities.

Overview from Tacoma Anchorage

Main Cables and "the Ropes" (Suspenders)

8,816 zinc coated high strength steel wires, each a little thinner than a pencil (0.196-inch diameter) were "air-spun" into 19 strands to form each main cable. These strands were then hydraulically compacted into a 20½-inch diameter cable cross section, and outfitted with cast steel cable bands to hold the compacted shape and to receive the vertical suspender ropes.

Each main cable wire loops around one of 19 strand shoes held back to the mass concrete foundation of the anchorages with 4½-inch diameter high strength steel threaded anchor rods. Two anchor rods per strand shoe pass through steel pipe grout tubes, and their nuts bear against an anchor frame at the rear face of the anchorage. Once the full weight of the bridge is bearing on the cables, the steel pipes will be filled with grout to protect the 60-foot length of rod from corrosion.

In addition to the cable bands, which hold suspenders at their proper position along the main cables, there is a unique cast steel fitting at mid-span to secure the cables and deck in the same relative position, thus sharing

the burden from longitudinal and transverse displacements of the stiffening truss. This feature, referred to as a center tie, is framed into outrigger struts on the sides of the deck and thus tied into the stiffening truss framing. Since the loads transferred are sizable, the number of bolts necessary to provide adequate clamping force to the main cable required a three-part articulated cable band casting with a total length over 21 feet.

Lifting Gantries and Erection of Structure Segments at Midspan

The vertical suspender ropes are 1⅝- or 1⅞-inch zinc coated steel wire rope often referred to as Bridge Rope. Typically the suspender ropes loop over the cable bands; however, near the anchorages they are pinned both top and bottom to allow relative rotation as the bridge expands and contracts, and to aid construction. To further mitigate the potential for bending fatigue in the ropes, the suspender brackets nearer the anchorages are located at the bottom chord of the stiffening truss. This maximizes the effective length and minimizes the rotation experienced. Excessive rotation for shorter ropes has been the cause of long-term wire breaks in older suspension bridges, and the arrangement selected overcomes the undesirable situation.

The Deck and Stiffening Truss System

The suspended superstructure consists of an orthotropic deck made integral with the top chord of the stiffening truss. Like any other bridge with an integral deck, this arrangement proves very efficient, saving steel and structure weight, an important factor in long-span suspension bridges.

In general, shop welded fabrication and field bolted splices were the chosen method of construction. There were many similar "means and methods" choices necessary along the way, and these were greatly facilitated by the presence of TNC staff at each major design office throughout the design phase.

Several grades of steel were used for different elements of the structure. In general, AASHTO M270 Grade 50 was the material of choice for the deck and truss system. In areas of higher demand, particularly near the towers, HPS Grade 70W was specified to avoid the need to change plate thickness that would have unnecessarily altered the advantages of repetitive details that simplified fabrication. A small quantity of HPS Grade 50W with improved through-thickness ductility ("Z-grade") was used at the suspender bracket bottom flange to mitigate the potential for lamellar tearing at this critical connection.

Fabrication began with early trials on key elements such as the 80% partial joint penetration (PJP) welds for the deck U-ribs, a weld type that would be repeated for a total length of about 60 miles. Any efficiency gained in these joints would translate into savings, and the necessary quality was achieved through reliable and repeatable procedures. Since the insides of the U-ribs are forever inaccessible for visual inspection or repair once the welds were placed, the procedures selected needed to be refined to produce the same high-quality results time and time again, without burn-through or lack of penetration. Preliminary weld trials began at NSKB even as design was underway, and job control tests verified quality until the last rib was welded.

High Wire Act

One of the most fascinating parts of building a suspension bridge is getting all the superstructure segments up in the air. As the 450-ton segment blocks (46 in all,) arrived by sea transport, they were off-loaded by strand jacks and lifted into position. Alternatively, the block segment was transferred to a barge which then ferried the segments into the main channel of the narrows for lifting into place. Over-land segments at each end of the bridge were lifted near the shoreline and then transferred to their final position by "trapeezing" the segments along the bridge using temporary suspension cables.

The heavy lifting is accomplished by overhead lifting gantries that literally walk the main cables between lifts. A lifting cycle begins with the gantries lifting the block segment vertically from the water level to an elevation where suspender ropes can be attached. Once this is accomplished, the gantry lets out on the lifting strands until the weight of the block is suspended by vertical suspender ropes at the cable bands. The gantry is then repositioned ahead of the support points and readied to lift the segment forward. This procedure is repeated as necessary until all segments are in their final positions.

Segment placement was also a balancing act in yet another way. To prevent over-bending the towers or slipping of the cables through the tower saddles, the amount of weight in each span was kept in relative balance. Alternatively, ballast could be added as desired to equilibrate any undesirable imbalance.

The Final Chapter

Although the ink is still drying on the final chapters of the Tacoma Narrows project, the project record will show that dedicated professionals from all corners of the industry – and the world – can accomplish greatness in the spirit of partnership. The coming decades will see more major projects of this type, and we are compelled to hold this project up as an example to the industry that challenges can be overcome and success achieved through commitment to a common project goal.▪

View from Tacoma Tower

Gig Harbor Tower

The New Tacoma Narrows Bridge "by the Numbers"

Caissons and Distribution Caps:
Concrete – 62,000 cubic yards
Reinforcing Steel – 12.5 million pounds
Structural Steel Cutting Edges – 1.5 million pounds

Towers:
Topped out at Elevation 510 feet
Concrete – 17,000 cubic yards
Reinforcing Steel – 5.5 million pounds

Anchorages:
Concrete – 41,000 cubic yards
Reinforcing Steel – 1.9 million pounds

Superstructure:
Main Span of 2800 feet
Side Spans of 1200 and 1400 feet
Contiguous length of 5400 feet
Structural Steel – 35.5 million pounds
Main Cables – 10.4 million pounds

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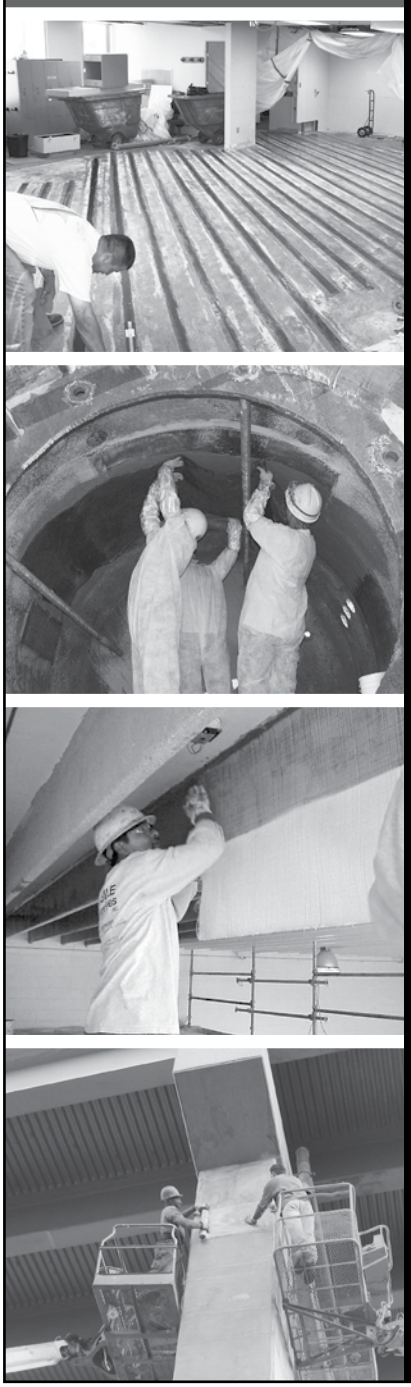

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