Bridge Hits Take Their Toll

The old Sidney Lanier Bridge sustained numerous ship collisions since it opened in 1956.

The new Sidney Lanier Bridge, spanning the Brunswick River for U. S. Highway 17 in Brunswick, GA, is now one of the largest cable-stayed suspension bridges in the world. It has an overall length of 7,780 ft, a main span length of 1,250 ft, and rises 185 ft above the water on 485-ft tall support towers. Originally opened to traffic in June 1956, the much shorter and lower original bridge deteriorated due to coastal weathering, normal wear, and weakening from ship collisions, prompting the U. S. Coast Guard to declare the structure a hazard to navigation. As a result, the Georgia Department of Transportation (GDOT) initiated design development for the replacement bridge in 1992.

Existing subsurface conditions at the site are highly variable and change significantly from one end of the bridge to the other. These conditions are relatively weak as a result of their southeastern coastal plain location and relatively young geologic age. They are potentially scourable due to river water conditions, and future river channel navigation requirements include deepening the main river channel. Even the rock-like subsurface materials are relatively weak and are further compromised by a stronger thin layer of overlying cap-rock material that exists in only parts of the profile.

The bridge foundations are performing well under the loads of the completed bridge.

Recommendations from GDOT for the replacement structure were clear: explore, evaluate, and analyze subsurface conditions at the bridge site to provide recommendations for foundation design and construction, considering structural dead and live loads; seismic, wind, and ship impact loads; future river channel depths; and potential river scour depths. These recommendations were expected to result in a foundation system that would be structurally and environmentally safe, economical, and sustainable.

MACTEC (www.mactec.com) served as the key design and construction team member working directly with the GDOT Geotechnical Bureau of the Office of Materials and Research. MACTEC provided geotechnical services throughout the design and construction phases of the project. The MACTEC/GDOT engineers formed a partnered geotechnical team from 1993 to 1996 in design and from 1996 to 1998 for construction. Geotechnical engineering services included oversight and review of GDOT subsurface exploration and testing, laboratory testing of soil and rock samples, geotechnical engineering analysis, foundation design and construction recommendations, construction plans and specifications preparation and review, and construction consultation and oversight.

The geotechnical engineering analysis specifically included the following:

- Estimated geotechnical design properties of the subsurface geologic materials.
- An evaluation of various deep foundation alternatives with respect to geotechnical adaptability, constructability, and economic considerations.
- Recommendations for deep foundation design (sizes and types of driven piles and drilled shafts), including compression, tension, and lateral load capacities along with estimated foundation tip elevations.
- Estimates of foundation lateral deflection and settlement performance.
- Compression capacity evaluation for the main tower, anchor pier, and approach span pier foundations.
- Foundation group lateral deflections in response to lateral loading for main tower and anchor pier foundations.
- Foundation group settlements in response to the pier loading and the weight of the artificial ship impact island constructed around the main piers.
- Artificial ship impact island stability evaluation.
- Artificial ship impact island construction-related settlements and their impact on the nearby bents of the existing bridge structure.
- Impact of island and bridge construction sequence on the main tower foundation settlement, foundation downdrag, and superstructure settlement.

The side shear and end bearing capacity of the geologic formations was difficult to predict due to the complex layering of firm soil and weak rock. The deformation performance prediction of the new foundations under load was rigorous. These predictions had to consider the following foundation design and construction issues:

- Storm scour of river bottom
- Future shipping channel deepening
- Wind load
- Seismic (earthquake) load
- Dead load
- Live load (traffic)
- Traction load of structure
- Ship impact load
- Temperature load

The scenic new bridge has wide openings that are easily navigated by ships.

In addition, the foundation design had to consider concrete placement access including available pour time and over-water work as well as foundation inspection, integrity testing, and inspection. Furthermore, the foundation construction had to be sensitive to local wildlife, especially manatees and their protection from entrapment in the coffer dams and injury from marine traffic (a full time manatee watcher was required); sea turtle protection from lights used in night work (special lighting and seasonal work required); and a nearby Wood Stork bird foraging pond (requiring bird screen placement and seasonal work).

The design resulted in four-ft diameter drilled shafts with allowable axial compression load capacity of 800 tons each, and six-ft diameter shafts with an allowable capacity of 1,640 to 1,940 tons each. MACTEC's prediction of the complex behavior of the main tower drilled shaft groups were so accurate (monitored and verified during construction), that it allowed the heavy stone rip-rap ship impact islands to be constructed around and over the foundations early in the construction sequence. This also allowed the contractors to use the islands for land-based construction versus more dangerous and costly over-water construction of the superstructure. This flexibility in the construction sequence saved construction time and money on the project.

Side shear resistance with limited end bearing was predicted utilizing two analytical methods that were compared with each other and with available load test data in similar coastal geologic formations. MACTEC also used 1) wet slurry construction, 2) multiple Osterberg Load Cells, and 3) cross hole sonic integrity testing.

WET SLURRY CONSTRUCTION was used to keep the hole stable for the entire depth of the shaft. This method of construction is used when a dry excavation cannot be maintained, when in-place soil or rock is unstable and deforms or collapses, or when loose material and accumulated water is difficult to remove.

OSTERBERG LOAD CELLS were used on this project and are specialized pressure cells that are placed at the bottom of an excavation for a drilled test pier or pile. Multiple Osterberg Load Cells were used in the bridge foundation test program on three test loaded shafts. At the time, one of the largest loads of 5,686 tons on a four-ft diameter shaft was applied. The Osterberg Load Cell allows this full-size testing without large capacity jacks and complex/bulky and more costly load test frames and reaction elements. The use of multi-levels of Osterberg Load Cells in the drilled shaft load testing also allowed the shearing of specific geologic layers to determine their strength at various strain levels. This allowed the shaft load capacity to be taken primarily in side shear with end bearing providing an additional increase in the safety factor.

CROSS-HOLE SONIC INTEGRITY TESTS were performed in the access tubes installed on the rebar cage. “Shots” are made from a source that generates acoustic energy to an energy receiver in another tube at the same elevation. Both the time of travel from the source tube to the receiver tube and the amount of energy transferred between tubes are indicators of the presence of either sound concrete or defective concrete. Good coverage of the interior of the shaft can usually be achieved, however, little information on concrete outside the cage can be obtained.

Over-water heavy civil construction is always hazardous and dangerous, however, due to the drilled shafts optimizing the available load capacity of the foundation supporting subsurface materials, with fewer foundation elements to install, a less dangerous work environment was created versus that of pile driving or a deep-seated caisson footing. This helped result in no lost time accidents in the 18 months of foundation construction from 1996 to 1998. This construction was complicated and made more hazardous due to a tidal range of seven to ten ft and strong tidal currents in 35- to 40-ft plus deep water.

The drilled shafts saved millions of dollars over more traditional driven piles or deep-seated caisson footings plus the final drilled shaft design (which reduced the length of the drill shaft 10 to 15 percent and raised their tip from -115 ft to -100 ft) and load testing saved an additional $1.5 million over budgeted drilled shaft cost. The reduced length of drilled shafts also saved seven months of foundation construction time.

From a sustainable design viewpoint, the new bridge is a massive concrete, corrosion-resistant structure, designed and built to last in a coastal marine environment. The foundations are designed for future deepening of the river channel to -40 ft mean sea level (msl) from the existing approximately -35 ft msl and for a potential river scour to -54 ft msl.

Environmentally, removal of the old bridge allows an improved ecological and more sustainable environment for native wildlife. The new bridge has less impact on the existing ecological environment due to fewer foundation elements in the water and marshes.

During construction, the drilled shaft foundations provided less impact on the environment versus traditional pile driving. There was less vibration, noise, and less foundation footprint, minimizing impact on manatees, sea turtles, Wood Storks and other birds, and other local wildlife. The old bridge approach earthen embankments were removed to restore previously covered wetlands, resulting in a net positive wetland impact from the foundations of the new bridge versus the old bridge.

Lastly, the old bridge metal demolition components were made available for construction of an offshore artificial reef to improve marine habitat, especially fishing. The concrete demolition components are being crushed and recycled into rip-rap and aggre-

Osterberg Load Cell

Establishing the bearing capacity of piles, piers, and shafts is difficult and expensive for engineers to determine. The Osterberg Load Cell allows geotechnical engineers to determine the capacity of drilled shafts, piers, and driven piles. It is used to test for the bearing and skin friction forces that can be developed in the soil through which the shaft, pier, or pile is placed.

The Technology

The Osterberg Load Cell is a specialized pressure cell that is placed at the bottom of the excavation for a drilled test pier or pile. It has a hydraulic line extending from the cell to the top of the excavation. After placement, the pier excavation is filled with concrete.

The cell is designed to expand both upward and downward when it is pressurized by way of the hydraulic line. The downward force from the bottom of the cell is resisted by the bearing stratum while the upward force from the top of the cell is resisted by the weight of the pier and by the skin friction along the sides of the pier. The test pier is instrumented with telltales to measure the upward and downward displacement of the cell.

Large loads can be applied with the Osterberg Load Cell. Test piers can be constructed vertically, slanted, in a building, in water, or in otherwise inaccessible locations

The Benefits

A load test made with the Osterberg Load Cell is different from a conventional load test, since there is a separation of the end bearing and skin friction components for resisting applied loads. Consequently, this test method allows geotechnical engineers to more accurately estimate pier capacity and to design and construct more cost-effective foundations. The expense of unnecessary conservative designs can be reduced and the risk of underdesigned foundations can be minimized.

Status

The Osterberg Load Cell won the 1994 NOVA award. Its implementation for geotechnical assessment in actual job sites has just started to emerge. On February 1997, the firm LOADTEST Inc. (www.loadtest.com) set a world load testing record when applied 15,000 tons to a drilled shaft at the S.R. 20 bridge in Blountstown, FL. Other uses include a load test in a drilled shaft for the Miller Park Stadium Complex in Milwaukee and a load test on a barrette foundation for the Alfaro’s Peak project in Manila, Philippines.

Courtesy Purdue University, Division of Construction Engineering and Management, West Lafayette, IN.

gate for new construction elsewhere.

The new bridge provided both short- and long-term positive economic impacts for the local, state, and regional economy. Short-term economic benefits included construction-related employment as well as secondary economic benefits through the continued purchase of local goods and services. During the approach span's construction, the project required 76 full time equivalents; 60 people (79 percent) were hired from within the state and 16 (21 percent) were from out of the state. In addition, 28 of the 60 people came from the local workforce in Brunswick (39 percent of the 60 in-state people). During the main span construction, the project required 222 full time equivalents; 185 people (83 percent) were hired from within the state and 37 (17 percent) were from out of the state. In addition, 105 of the 185 people came from the local workforce in Brunswick (47 percent of the 185 in-state people).

The construction occurred over eight years (1995 to 2003), during which the local economy sustained positive economic benefits through work force salary and the wage-induced secondary impact of the purchase of goods and services (food, lodging, gas, etc.)

The project also provided substantial long-term economic benefits to the Port of Brunswick. It is estimated that sales revenues will increase by $464 million annually and tax revenues will increase by $15.8 million annually. The dollars generated by the tax revenues will result in an 11-year payback to the taxpayers for the bridge construction. As an intangible long-term benefit, the new bridge will allow the Port of Brunswick to expand and to be competitive in the global shipping industry well into the 21st century. The bridge literally opens the harbor to the largest ships available today.

By removing the old bridge, a safety hazard both to ship navigation and vehicular traffic was eliminated. In 1972 a tragic disaster occurred when an entire span was knocked out resulting in the deaths of ten people in their automobiles. In 1987, another major hit was taken by the bridge from a ship requiring closure of the bridge for repair. A construction worker died in making the repairs. The bridge has actually been hit many times over its life from 1956 to 2003, often demanding closure for repairs. During bridge closure or when the draw span is raised, vehicular traffic is stopped. Therefore, emergency services must be re-routed to nearby Jekyll Island and eastern Colonels Island over a much longer travel distance.

Presently, the bridge foundations are performing well under the loads of the completed bridge. And most importantly, the vehicular traffic drivers, the river navigation pilots, and the general public are satisfied with the new bridge's wide openings, ease of use, and scenic appearance. GE