Load Testing Minnesota Bridges

Energy Piles
Slurry Wall Joints
Micropiles and Earthquakes
Testing Foundations for Major Minnesota Bridges

Over the last 10 years, the Minnesota Department of Transportation (Mn/DOT) has had a very active program of replacing many major bridges, large structures spanning the Mississippi River. The deep foundations for these new structures include both drilled shafts and large diameter open-ended driven steel pipe piles. Most of these projects include load tests, both axial and lateral.

The geology of this area of Minnesota includes some interesting foundation challenges, including highly organic and compressible very soft silts and clays to very dense sand and gravel overlying sedimentary bedrocks. In some cases scour requires embedment into rock, and the bedrock formations may range from very soft sandstone to very hard dolomite. Artisian groundwater conditions can sometimes complicate drilled shaft construction, but the rock is otherwise very favorable for drilled shafts. Experience with the open-ended driven steel pipe piles (typically 42 and 48 in. (1.07 and 1.2 m diameter) suggest that these piles most often penetrate even dense granular materials to achieve bearing on rock. Experiences with drilled shafts socketed into the soft sandstones demonstrate that these rocks provide very favorable conditions for drilled shafts, so long as suitable construction practices are followed.

Here we present several recent case histories regarding the foundation design and construction of major bridge projects in the vicinity of Minneapolis, Minn., including the Washota Bridge, the I-35W replacement, the Lafayette Bridge, the Hastings Bridge and the St. Croix Bridge. Some lessons learned from construction and load testing of both types of foundations are described along with implications for design in similar soil and rock conditions.

St. Anthony Falls Bridge, I-35W Over Mississippi River (2007)

This fast-track design-build bridge replacement was necessitated by the disastrous collapse of the old steel truss bridge in 2007 that claimed 13 lives and closed the most heavily traveled bridge in the state. The new bridge is a beautiful segmental concrete structure on drilled shafts socketed into the St. Peter Sandstone beneath the Washota bridge site, the sandstone was at a relatively steep angle. The site was also quite congested with existing utilities and structures, making drilled shafts the foundation alternative.

The sandstone was relatively low strength and low permeability, thus was difficult to characterize because of the absence of RQD (Rock Quality Designation) from core samples. Also, large-scale load test information was not available and the uncertainty existed regarding the expected performance of the $300,000/day (bonus or penalty) incentive contract. The engineers undertook a full load test shaft. The load test shaft was actually performed on a snowy Day, 2007, with on-site delivery of turkey and dressing.
Wakota Bridge, Mississippi River (2004)

Mn/DOT designed the foundations for the Wakota Bridge in South St. Paul to use 42 in (1.07 m) diameter open-ended pipe piles bearing in dense sand, with about 125 ft (38 m) of penetration in the sand. Nominal axial resistance was targeted to be around 1,800 tons (12.2 MN). During initial installation with an APE D-125 diesel hammer, the engineers observed the pile penetration with significantly lower driving resistance than expected, and dynamic testing with signal matching suggested that the piles did not achieve the required nominal resistance. Restrike measurements showed some setup, but the initial test piles did not appear to be on the way to achieving the required resistance, and as a result the engineers extended pile lengths to as much as 190 ft (58 m) to obtain bearing on bedrock.

To better understand the observed behavior, additional test piles were installed and one non-production test pile was used for long term (6 month) setup with both dynamic and rapid (Statamic) load testing. The observations and results of all the test piles suggest that these piles did not plug, even in dense granular materials at substantial depths, and the piles could be driven to bear on rock with significantly higher nominal axial resistance than originally planned. These “lessons learned” would be subsequently implemented on other major river bridge projects.

St. Anthony Falls Bridge, I-35W Over Mississippi River (2007)

This fast-track design-build bridge replacement was necessitated by the disastrous collapse of the old steel truss bridge in 2007, which cost 13 lives and closed the most heavily traveled bridge in Minnesota. The new bridge is a beautiful segmental concrete structure founded on drilled shafts socketed into the St. Peter Sandstone. Unlike the Wakota bridge site, the sandstone was at a relatively shallow depth. The site was also quite congested with existing utilities, drainage structures, and obstructions, making drilled shafts the most feasible foundation alternative.

The sandstone was relatively low strength and, at shallow depths, was difficult to characterize because of the low recovery and RQD (Rock Quality Designation) from core samples. Reliable large-scale load test information was not available and considerable uncertainty existed regarding the expected performance. So, in spite of the $200,000/day (bonus or penalty) incentive to hurry up, the engineers set up a load test shaft. The test provided a further benefit by identifying the zones of artesien groundwater and evaluating the impact on construction operations. The multi-level O-cell load test was actually performed on a snowy Thanksgiving Day, 2007, with on-site delivery of turkey and dressing.

Hastings Bridge, Mississippi River (2011)

Construction on the Hastings Bridge began under a design-build contract in 2011 and traffic is scheduled to switch to the new bridge later this year (2013). The new structure is the third bridge crossing at this location and is a free standing tied-arch erected off-site, floated in and then jacked into position. The span length of 545 ft (166 m) makes it the longest such structure in North America.

The site at Hastings has shallow rock on the south (Hastings) side of the river, with very deep, compressible alluvium.
42 in (1.07 m) diameter test pile being driven in the Mississippi River at Pier 6 with an APE D-125 hammer on the north shore. The project included a bit of everything for foundations, with:

- south approach piers on spread footings
- the south main span foundation on drilled shafts into sandstone on the slope at the river's edge
- north main span foundation and approach piers on open-end pipe piles driven about 180 ft (55 m) into bedrock
- north approach embankment on a pile supported fill

Compared to the pipe piles at the Wakota Bridge, a higher nominal axial resistance was used at Hastings with no difficulties encountered in driving the piles to bear on rock, and both dynamic and rapid (Santamaria) load tests were performed for verification of the higher axial resistance. The new bridge was close to the existing structure at some pier locations. Some piles were as close as 30 ft (9 m) to the existing timber-pile supported piers, but measurements on the old bridge indicated that the new piles had no significant impact on the existing structure.

The Hastings Bridge was impacted over the last 40 years by settlements from the existing north approach embankment, which had resulted in several feet of settlement at the existing north abutment. In addition, the first pier on the bridge south of the north abutment had been subject to rotation from these ground movements with the result that the pier cap at the top of the substructure had to be widened to keep the girders from falling off. The plan was to build the new approach embankment immediately adjacent to the existing fill and abutment, which required some mitigation measures. This location included compressible clay soils to depths of over 150 ft (46 m).

The solution was a pile-supported embankment, composed of 12 in (0.3 m) diameter open-end steel pipe piles, 10 ft (3 m) center-to-center spacing, topped with a 5 ft (1.5 m) diameter cast-in-place concrete cap and overlaid with a geogrid reinforced layer supporting the 45 ft (14 m) fill above. The team used similar piles to support the retaining structures around the perimeter of the new embankment. This system worked quite well and was substantially less expensive than extending the bridge further to the north.

**Lafayette Bridge, Mississippi River (2011)**

This bridge was a conventional design-build contract, but with options for either a steel or concrete superstructure. The lighter steel structure was the winning bid, but the foundations for either option were the same. Using 42 in (1.07 m) diameter open-end steel pipe piles bearing on rock had been used successfully at both Wakota and Hastings. Construction began in late 2011 and is scheduled for completion in 2015.

Piles were driven to refusal through more than 100 ft (30 m) of sand and gravel to bear on hard dolostone bedrock. The dynamic load tests from the APE D-125-32 hammer indicated large capacity on end bearing at end of the initial drive. Interestingly, signal matching analyses of 4-day restrick measurements showed substantial setup in side resistance of more than twice the initial side resistance in sands, with a reduction in base resistance. This is due to the fact that the base resistance indicated at restrike was limited by the available energy from the hammer blow; the pile was not penetrating and the geotechnical nominal axial resistance of the pile on rock exceeded the structural strength of the pile. The concept of superposition of base resistance from initial driving plus side resistance from restrike can be used in this case as verification of higher nominal resistance from dynamic load test measurements.

**St. Croix River Crossing (2013)**

The St. Croix Bridge will be the largest bridge project in Mn/DOT history, with five river piers supporting an extradosed structure spanning between Minnesota and Wisconsin. There was a long and difficult planning process and it finally took an Act of Congress (literally) to obtain permits to begin construction. It includes a pair of columns, each of which is supported on the river by a single pile. The drilled shafts will bear within the relatively weak, soft, organic soils of the Wisconsin Deformational Ban. The organic layers are overlain across much of the channel with a thick deposit of soft black organic sediments, and drilled shafts will be driven through the organic strata to the muck layer below. The organic materials, being isotropic, provide only limited lateral support in the structure for vessel collision, ice and wind loads. The organic conditions include sand and gravel overlayers covering extensive areas of organic materials. The barbed piers will be founded on driven piles. Construction of the piers was started in the fall of 2013 and the whole project is expected to be completed by 2015.

During the early planning for this bridge in the 1990s, Mn/DOT performed a load test on a 4 ft (1.2 m) diameter drilled shaft in the organic layer near the Minnesota shore of the Mississippi River. The test results were relatively disappointing, and there were some delays in maintaining the stability of the excavating the shaft bore. Workers used water as the drilling fluid.

In the light of the much more favorable load test results of the I-35W project, the engineers conducted a new deep-end load test program in 2012. The recent load test program was performed on a larger and more representative test shaft, with greater scrutiny and control on the construction process. Pile engineers also included driven test piles at a lateral load test to the drilled shaft extended through the soft organic sediments. Casing extended to the tip of the sandstone layer. A 14-inummer of soil was excavated under a plastic wrap to maintain water pressure maintained at all times. Workers cleaned the bottom of the excavation using an airlift and inspecting with a downhole camera. A self-consolidating concrete mix was used to complete
the 45 ft (14 m) fill above. The team used similar piles to retaining structures around the perimeter of the new fill. This system worked quite well and was substantially more than extending the bridge further to the north.

Bridge, Mississippi River (2011) was a conventional design-build contract, but with either a steel or concrete superstructure. The lighter steel was the winning bid, but the foundations for either were the same, using 42 in (1.07 m) diameter open-end piles bearing on rock that had been used successfully at a and Hastings. Construction began in late 2011 and is near completion in 2013.

Preparing to pour the test shaft by tremie using the wet construction method

As a result, average unit side resistance of 30 ksf (1.4 MPa) and base resistance of 400 ksf (19 MPa) were mobilized during the load test. These values are substantially higher than the 1995 test results and provided great savings to the project during final design. The organic soils also provided greater lateral soil resistance than anticipated and these results helped reduce flexural demands in the drilled shafts for design. The successful test installation provided the basis for developing reliable site-specific special provisions for construction of the production foundations.

Sandstone: Franconia Formation

Conclusion

The history of load testing on these five major bridge projects traces improvements in reliability, constructability and cost-effectiveness with foundation design and construction. The key component to continuing improvements is the rational incorporation of load testing into major projects for the long-term benefit of the agency and future projects. The load tests performed constitute “testing with a purpose.” Tests were not considered just a simple verification that the design was OK, but were actually used to obtain useful measurements that could lead to improvements. When surprising results were obtained on pipe piles at Wakota, engineers performed additional tests to help understand the behavior—tests that paid dividends at subsequent projects. The drilled shaft load tests at I-35W and St. Croix helped improve the design and quality assurance during construction. The benefit from this investment in load testing will pay dividends to Minnesota taxpayers for many years.

An extensive version of this article will appear in a future issue of DFI Journal.