Deep Foundations for A Rail Bridge Replacement

A rail bridge replacement in Sandpoint, Idaho, presented a host of challenges that resulted in a deep foundation solution. **Jacobs Associates** provided foundation design and engineering services during construction of the bridge under contract to BNSF Railway. The site included difficult soft soils to great depths. Train traffic had to be maintained during construction, and there were site and permitting constraints.

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The 4,800-ft-long railroad bridge spans Lake Pend Oreille in the Idaho Panhandle, providing an essential commerce link between the Pacific Northwest and Chicago. It is part of BNSF's main line and carries a high density of traffic—35 to 45 heavy freight trains plus two passenger trains pass across the bridge daily. For BNSF, this is a vital transcontinental link, one that cannot be disrupted, and thus dictated that the bridge be replaced under live-track conditions.

Originally built by Northern Pacific Railway as part of the first northern transcontinental railroad, the bridge was founded on timber piles driven to about 50 ft, supporting a concrete pier and spaced 50 ft for most of the length of the bridge. Portions of the bridge were replaced in the late 1950s or early 1960s. Replacement piers were supported on 90-ft pipe piles. By 2008, the bridge was functioning past the originally intended service life, and track maintenance across the bridge had become an increasing nuisance. Several of the existing piers had settled and rotated, causing track problems for the high-speed freight trains.

Site Issues

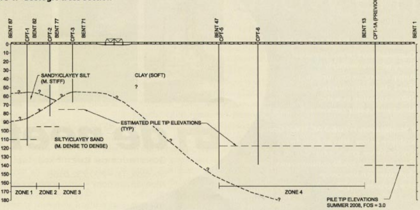
Lake Pend Oreille is located at the site of the ancient and geologically significant Lake Missoula, the source of floodwaters inundating much of the Columbia Basin. Flooding left deposits of gravel and cobbles as far away as Portland, Ore. As a result, Lake Pend Oreille is filled with more than 300 ft of soft silty clay. Beneath the clay lies a deposit of sand that becomes denser with increasing depth. The sand layer was not encountered on the east (in railway directions, railway east is geographic north, and railway west is geographic south) end of the bridge. The top of the sand on the west end varies from about 75 to 100 ft below the top of the clay.

The wide-ranging ground behavior was one of the project challenges. The clays are soft, exhibiting low shear strength, and are highly compressible. Their residual shear strength is much less than the peak shear strength. These attributes make a decidedly unfavorable geotechnical environment for supporting heavy structures. Conversely, on the west end, foundations bearing in the sand will have excellent load/settlement behavior.

Construction

Construction took place during the summers of 2008 and 2009. The 12 piers on the east end of the bridge were replaced in 2008, and 16 piers on the west end of the bridge were replaced in 2009. BNSF is monitoring the remaining portion of the bridge, and the company has decided not to replace any more of the bridge.

Figure 1: Geologic cross section



Because of the soft clay at the east end and the large train loads, Jacobs Associates determined that closed-end pipe piles would be the best choice, geotechnically, because these piles would limit the pile embedment. Our analyses indicated that 600 kip (ultimate) could be achieved with embedment below the mud line of about 130 ft. The pipe piles were closed with flat plates, and the contractor welded a short stinger on the bottom of the plates.

On the west end, we considered open-end pipe piles to facilitate penetration into the sand, but ultimately continued with closed-end pipe piles. We determined that 565-kip piles could be achieved with total penetrations ranging from 84 to 110 ft below mud line, depending on the depth to the sand. Conical tips were used to close the piles on the west end.

Capacity vs Depth Image

New piers were placed halfway between the existing bridge piers. Each pier group consisted of six piles, driven at a 1-1/2H:12V batter. In each pile group, there were two piles driven in the center between the rails. There were also two piles driven outside of each rail. BNSF maintenance crews temporarily shifted ties to drive the center piles. The outer piles could be driven without shifting ties.

The steel pipe was supplied by BNSF in 50- to 60-ft sections. On the east end, the contractor elected to splice a 50-ft piece and a 60-ft piece, and drive a 110-ft section. The last 50-ft piece was spliced in the air, then driven to the required embedment. The method only allowed for driving two piles per day. On the west end, the contractor chose to make all the splices in the yard prior to lifting into place and to drive a long pile without splicing in the air. Using this method, production increased to an average of about three piles per day.

Piles were driven with a combination of vibratory hammers and impact hammers. The vibratory hammers used for pile driving on the east end included an ICE-44 and an APE 200, and impact pile drivers included an ICE 120S diesel hammer and a Junttan HHK-5A hydraulic hammer. On the west end, the piles were driven to about 55 ft with an APE 250 vibratory hammer and then driven to the required tip elevation and driving criteria with an APE D50-32 diesel hammer.

For the west end only, Jacobs Associates developed pile driving criteria that included minimum pile penetration per the plans, and 30 blows per foot with a stroke of about 7 ft for the APE D50-32 hammer. On the east end, we determined that as long as the pile was driven to the tip elevations shown on the plans, the piles would achieve the required capacity. On both ends, a Pile Driving Analyzer (PDA) was used on selected piles.

Once the piles in a pier group were driven, the contractor placed reinforced concrete in the piles to improve lateral load capacity. On the east end, only the upper 50 ft of the pile were filled with concrete. The entire pile length on the west end was filled with concrete, although only the upper 50 ft were reinforced. After backfilling, pier caps were placed on each pile group. Then box girders were placed on the pier caps. A ballasted track structure was placed on the box girders, and the piles were in service.

Problems and Solutions

Maintaining train traffic across the bridge was an important requirement during reconstruction of the bridge, known as Bridge 3.9. BNSF arranged for train-free windows in which to drive the piles. Each window lasted 5 to 7 hours, Sunday through Friday. Pier caps could be placed during these same hours. The bridge sections were placed during planned track outages lasting 10 hours or so.

Pile setup occurred over a period of 30 to 40 days on the east end. We believe this was due to several reasons: significant increases of excess pore pressures in the clay as a consequence of closed-end pipe pile driving; and slow dissipation of those excess pore pressures. Adjacent pile driving also caused excess pore pressures, which prolonged the setup time. Jacobs engineers observed increases in excess pore pressures between adjacent piles in a pier group near the top of the piles. However, because of the pile batter and the pile depth, we also observed increases in excess pore pressure at the pile tips from piles in adjacent piers.

Figure 2: Pile driving on the West End

The long setup time created obvious schedule problems for the BNSF. The pier caps could not be placed until the piles reached a minimum capacity, and bridge sections could not be placed until a higher capacity was reached. These capacities were not reached for several weeks, resulting in a much longer construction schedule. Various drainage measures were considered to accelerate the pile setup. We determined that setup would take about 30 to 40 days, regardless of other drainage measures.

At the west end, the piles were founded in sand and the PDA testing indicated that setup would occur there in several days rather than several weeks.

Jacobs relied heavily on dynamic pile testing throughout each phase of pile driving. Robert Miner Dynamic Testing (Manchester, Wash.) completed PDA on selected piles. Sixteen PDA tests were performed on both the east and west ends of the bridge. The results of the PDA testing allowed us and BNSF to evaluate pile capacity over time and to determine when it was appropriate to load piles and put them into service.

On the east end, we identified several production piles as piles we would test several times over a period of weeks. We also installed a test pile adjacent to an existing pier, but laterally offset from the bridge. Testing of this pile confirmed that setup did occur over several weeks. For the other production piles, the PDA testing confirmed that setup was occurring, but at a reduced rate because of effects from adjacent pile driving.

On the west end, the PDA testing confirmed design assumptions regarding soil engineering properties and behavior of the sand layer. The sand layer contributed a significant amount of end bearing and shaft resistance, but increased only moderately due to setup. There was, however, a significant increase in shaft resistance through the clay as expected.

In order to maximize pile production during the daily train-free windows, the PDA testing was scheduled to be completed outside of the windows between trains. The piles selected for PDA testing were located on the same side of the bridge as the contractor's barge or work trestle.

Closing Remarks

In spite of the serious geologic constraints, BNSF will have a new bridge with reduced maintenance and enhanced service. The Pile Driving Analyzer proved to be a valuable tool during production pile driving, allowing the piles to be loaded as soon as possible.

Jacobs Associates thanks the BNSF for permission to use and publish this information. We also acknowledge Hanson Professional Services Inc. (the bridge designer), American Civil Constructors/Hurlen (the east end contractor) and Advanced American Construction, Inc. (the west end contractor) for their cooperation.

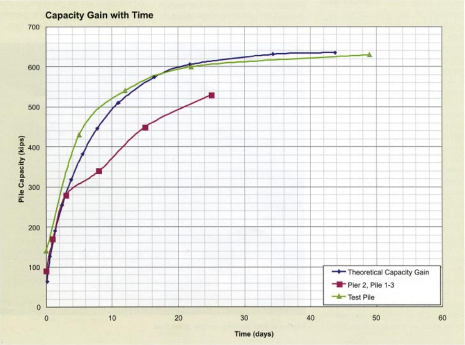


Figure 3: Selected PDA results from East End