Innovative Bridge Foundations Reduce Track Outage –
BNSF Bellefontaine Bridge, Bellefontaine, Missouri

Abstract

The Bellefontaine Bridge was constructed over the Missouri River over 100 years ago and is still in use despite its long life. BNSF Railway placed the bridge on the capital replacement list for 2014-2015. A new bridge would have to be constructed along the same alignment as the existing structure because of environmental permitting and the proximity of another bridge that had been built directly to its south.

Keeping an existing bridge in service during creation of a new structure—in a fairly tight right-of-way constrained by wetlands and the DOT structure—would have been challenging enough. In this case, the subsurface conditions, consisting of 50 to 60 feet of weak alluvial deposits overlying another 100 feet of dense sands down to the top of rock at 165 feet below grade, made the installation of new foundations for the structure even more difficult. The project team designed and built an innovative composite foundation consisting of large-diameter drilled shafts through the alluvial material, with micropiles socketed into sound bedrock. This foundation not only minimized costs, but also reduced the risk of movement of the existing shallow pile-supported bridge during construction of the foundations and substructure for the new bridge. The new structure was built beneath the existing bridge, and then short track windows were utilized to complete the superstructure.

This paper discusses the design and construction of the foundation solution, as well as provides load test data.
INTRODUCTION

The BNSF Railway’s Bellefontaine Bridge is located near the mouth of the Missouri River, just north of St. Louis, Missouri. The original bridge was designed by famed engineer George Morrison in the late 1880s as an all-steel, fixed, high-level, open-deck, double-track bridge over the Missouri River. The design was similar to that of several other Morrison-designed bridges over the Missouri River, including the Plattsmouth, Bismarck, Blair, Omaha, Rulo, Sioux City, Nebraska City, and West Memphis bridges. The main river spans consisted of four, 440-foot-long, fixed truss spans with an 877-foot-long approach viaduct (Figure 1). The truss spans were founded on masonry piers, which were constructed atop caissons founded into bedrock below the river. The existing viaduct was comprised of plate girder spans, with two girders per track, and supported by approximately 50-foot-tall steel towers. The viaduct spans were founded on relatively shallow driven wood piles. The piles for these piers are believed to terminate at or near the dense sand layers at approximately 50 feet below grade. Construction of the original bridge began in July 1892; it opened for traffic in December 1893.

![Existing Bridge](image1)

**Figure 1: Existing Bridge**

The capital improvement program for the bridge included replacement of the viaduct spans and repairs as necessary to the main spans. Although the existing bridge was designed as a double-track structure, it was operated with only a single track in service. Since a single-track bridge provides adequate operational capacity for this line, the project team decided that the replacement structure should remain single track.

In order to limit operation impacts during construction and decrease eccentric loading on the truss spans, the center line of the existing active track was shifted 10 feet, thus aligning the new track with the existing bridge.

APPROACH VIADUCT

The new bridge approach totals 876 feet in length. It extends from the east abutment to the first river pier, located on the bank of the Missouri River. As is generally the preference of today’s railroad design engineers, the new structure has been created with a ballast deck system to reduce impact loads and maintenance. The superstructure is comprised of steel deck plate girder spans and precast, concrete, double-cell box beam spans. The deck plate girder spans vary from 74 feet, 9 inches to 121 feet in length, and utilize a steel deck plate that is welded to the girders. Standard BNSF 36-foot-long x 30-inch-deep double-cell beam spans are used at the abutment end of the approach to transition to a shallower structure depth, which allows a precast, concrete abutment to be used in lieu of a larger and more expensive cast-in-place concrete abutment. Span lengths were chosen to allow the piers to be located between the existing steel tower bents. This detail is critical, as it allows for the construction of the foundations and substructure before taking the bridge out of service during the curfew dates specified by the Railroad.

The deck plate girder spans are supported by seven concrete piers, a steel pile bent, and a precast concrete abutment. The typical pier configuration consists of a 5-foot-deep, hammerhead cap beam, 7-foot-diameter column, and a 10-foot-deep footing. The footing is founded on a hybrid drilled shaft/micropile foundation (Figure 2). The drilled shaft/micropile foundations are located outside the footprint of the existing bridge. The pier's overall height comes to below the existing low steel so as not to impact train operations during construction. Both details limit the impact that bridge construction makes on rail operations and vice versa.
Figure 2: Drilled Shaft/Micropile Elevation
MOVEMENT OF THE EXISTING STRUCTURE

As with many railway bridges, the possibility of settlement needs to be evaluated since the existing structure is still being used during construction of the new bridge. The project team recognized the critical need for aligning the new Bellefontaine Bridge in the same envelope as the existing bridge. For one thing, the bridge was originally designed for Cooper E 15 loading, while the design load for the replacement structure would be E80. In the 1890s, little to no information was available about calculating the design load of a driven wood pile. Additionally, the varying water table, combined with the alluvial soils, are each reason enough for concern, but when combined (albeit managed over time with shimming and jacking), movement of the substructure units was observed.

To reduce the risk of further movement, and thus a possible slow order or stop order, BNSF included several items in the specifications. One requirement was to monitor the bridge’s foundation system during construction. The general contractor fulfilled that need by using a three-dimensional scanning technique as well as traditional surveying methods.

Another significant change to conventional bridge construction was the creation of a composite drilled shaft and micropile foundation. Each of the hybrid foundation systems consisted of an approximately 50-foot-long, permanently cased, 8-foot-diameter drilled shaft. Once it was completed, 13-inch-diameter micropile access holes were drilled through the concrete of the drilled shaft. Within each of these holes, one drilled micropile was drilled and socketed into bedrock at approximately 165 feet below grade. The composite foundation system that was used for the Bellefontaine Bridge was the first of its kind on the BNSF system and, as far as the authors know, the first of its kind on an active railroad track. This system offered many beneficial construction advantages while still retaining important characteristics of each of the individual foundation techniques:

- **Strength** — The drilled shaft portion of the foundation system was designed to resist bending forces generated by lateral loading of the supported structure. These lateral loads included conventional braking forces, seismic loads, and wind loads.
- **Scour resistance** — The girth of the drilled shafts provided ideal resistance in the event of deep scour. During the 1,000-year flood events of 1993, scour holes developed in the area of the viaduct spans to a depth as great as 30 feet below existing grade.
- **No settlement** — For this project, micropiles were well suited for drilling into the dense sands that extend from the tip of the drilled shaft at 50 feet below grade to the top of bedrock at approximately 165 feet below grade. Micropiles are considered a safe method for drilling in high water-table-saturated sands, as they are fully cased and drilled without vibration, which reduces the concern of settlement of the existing bridge foundation.
- **Built-in redundancy** — Since micropiles are relatively slender, they are generally designed to carry axial loads. Because of the heavy wall casing, the axial capacity of the micropiles can be quite good when compared with the cross-section area of the micropile. In this case, the micropiles were designed with a conservative value of 300 kips — below the AREMA-allowed value of approximately 600 kips for the casing section utilized. By utilizing several micropiles rather than a single drilled shaft, the foundation now had built-in redundancy, which is characteristic of well-designed railroad bridges.
- **Reduced costs** — Compared to conventional construction of large-diameter, deep-drilled shafts, the hybrid drilled shaft/micropile system required only drilling of small-diameter holes at deep depths, thereby reducing construction costs.
- **Shorter schedule** — Micropile construction allows projects to be completed faster. Because of restricted access, it is generally only possible to have one drilled shaft rig and the ancillary casing and tooling on site. Given the smaller footprint of the micropile rigs and the ancillary tooling, additional micropile rigs can be utilized to complete the work; in this case, three micropile rigs were used.

The drilled shaft/micropile foundations were constructed by first installing the drilled shaft portion using conventional construction methods (oscillating of the casing was not necessary with the composite system). Once the casing was completed, a reinforcing cage was installed and concrete poured. Shaft
integrity was verified through the use of cross-hole sonic testing of each shaft. With the shaft completed, five holes were drilled through the shaft, within its perimeter, to allow for installation of the micropiles (Figure 3). A total of seven non-production load tests were completed in each of the areas of the bridge to verify that the micropile design and construction technique was adequate for the design loads.

Figure 3: Drilled Shaft/Micropile Cross-Section

QUALITY CONTROL OF MICROPILES AND THE DRILLED SHAFTS

Quality control of the deep foundations was a multi-step process. First, the design engineer of record observed all drilling. The contractor provided drilling logs for each technique. The drilled shaft holes were sounded before being concrete was poured. Once the concrete cured, the shafts were verified with cross-hole sonic logging techniques. Testing showed that the shafts had been completed successfully without any contamination or other defects. For further verification, micropile access holes were drilled into the shafts. Again, no defects were detected. Down-hole hammers were used to percussively drill the concrete in the shafts, as percussive drilling can provide some feedback on the quality of the concrete in the shafts. However, this drilling technique does not provide the same level of information as could be achieved from coring of the concrete. The micropile design was verified by seven, non–production, full-scale compression load tests. Each test was performed in accordance with the ASTM D1143 quick load test procedure. The results indicated that the micropile deflection was very similar to the theoretical deflection. A representative load vs displacement graph has been included (Figure 4).

Cylinders for the concrete in the drilled shafts and the grout in the micropiles were taken in accordance with industry standards to verify the compression strength of the materials.
CONSTRUCTION

The contract for the construction of the new approach bridge was awarded to a general contractor and well-known railroad bridge constructor. Work began in March of 2013. Flooding of the Missouri River delayed the project from the onset. Foundation construction then began with the installation of the drilled shafts. A drilled shaft photo is included to indicate the size of the rig working in the limited site constraints (Figure 5).
The drilled shafts were installed using drilling mud. When the drilling was complete, the reinforcing cages were set in the shafts, and the shafts were tremie-filled with concrete. Temporary casing was placed above the drilled shafts and then backfilled around. This provided access for the micropile rigs to “reach over” the reinforcing bars extending from the top of the drilled shaft. Three drill rigs were able to complete the micropile installation. One drilled through the concrete of the drilled shaft, while the other two rigs drilled the micropile to its target elevation of approximately 170 feet below grade. Both phases of the micropile installation are shown in Figure 6.
Figure 6: Drilling through the Concrete of the Drilled Shaft
Due to limited right-of-way and environmental concerns along portions of the right-of-way, the new deck plate girder spans were erected on falsework adjacent to the existing bridge (Figure 7). The falsework system consisted of steel columns placed atop the new footing with a steel cap beam connected to the pier cap. Hydraulic pistons were situated within the steel cap to allow the spans to be slid into place during their designated change-out window.

Figure 7: Installation of the Micropiles
The spans were required to be fully assembled with track panels placed on the deck prior to the change-out track window. BNSF provided a 48-hour window for installation of the new approach spans. Prior to sliding the new spans in place on the previously constructed piers, the existing superstructure was removed along with the top portion of the existing steel tower bent (Figure 8).

Figure 8: Superstructure Erection
Figure 9: Span Change-Out

After successful installation of the new spans, ballast was placed, and the track panels were bolted together, allowing for train operations to resume. Demolition and removal of the remaining portions of the existing steel tower bents followed, and construction was completed in May of 2014.

SUMMARY

Micropiles have been used consistently on BNSF for the last decade or so. The Bellefontaine Bridge is an example of how innovation of an existing technique can save both money and time. Perhaps even more important, the composite drilled shaft micropile foundation reduced the risk of movement of the existing structure while maintaining the construction schedule. The Railroad was so pleased with this solution that it opted to use it on another structure in the 2016 capital improvement plan.

ACKNOWLEDGMENTS

BNSF Railway
St. Louis Bridge

LIST OF FIGURES

Figure 1: Existing Bridge
Figure 2: Drilled Shaft/Micropile Elevation
Figure 3: Drilled Shaft/Micropile Cross-Section
Figure 4: Static Pile Load Test Plot — Total Movement
Figure 5: Drilled Shaft Installation
Figure 6: Drilling through the Concrete of the Drilled Shaft
Figure 7: Installation of the Micropiles
Figure 8: Superstructure Erection
Figure 9: Span Change-Out
Deep Foundations – the BNSF Bellefontaine Bridge

Jeff Jobe, PE, SE
Jeffrey Hill, PE

AREMA 2016 Annual Conference & Exposition
Presentation Outline

- Historical Bridge information
- Project Overview
- Installation of Foundations
- Cost Savings Solutions

Project location, Just north of St Louis on the Missouri River

AREMA 2016 Annual Conference & Exposition

Canadian TCRR 1885

US Completion of TCRR 1869

Construction of the Bellefontaine Bridge, ca 1890

Area of interest, the Viaduct Section

Project Constraints

- Restricted ROW with Wetlands
- Existing structure, concerns for movement,
- Alignment could not be changed
- 50’ of Alluvium over Dense Sands, Rock at 165’
- Proximity of new and old foundations

The Viaduct section prior to construction, note wetlands and limited access

© AREMA 2016®
And the main river spans with the MODOT bridge in the background.

Existing Bridge Foundations

Viaduct Section

30’ Deep Wood Piles Estimated

Main River Spans

Caissons to Rock,

Concerns with wood piles

Scour from the 1993 Flooding

Observed previous movement

Sensitivity to Vibration during construction

Liquefaction

Concerns with existing structure

End of service life

Code Rating

Maintenance

Overview of proposed construction

Wetland permitting

Limit impact to RR Operations

Reduce downtime

Same alignment

Overview of proposed construction

Construct Foundations between existing tower bents

Complete substructure between existing tower bents

Switch out superstructure during short change out window
New Composite Foundations, Drilled Shaft & Micropile

Drilled Shafts, 7’ diameter x 50’ long, perm steel casing
Micropiles constructed inside reinforcing cage
Micropiles socketed into rock at 165’ below grade

Micropile but not micro loads

High Axial Capacities Up to 1000 kips plus
Ideal for difficult drilling conditions
Less Spoil and no Vibration
Fully Cased
Included in AREMA, Chapter 8

Micropiles combine casing materials, steel reinforcement, and cement grout

* Casing - steel pipe
  - API N80 & ASTM A252
  - 80 ksi yield
  - Flush joint threads
* Steel reinforcement
  - ASTM A615, Gr. 60 & 75 & 95
  - ASTM A722, Gr. 150
  - Mechanical coupling
* Cement grout
  - Neat cement – ASTM C150
  - W/C ratio of 0.45
  - 4000 psi (min)

Composite Foundations, Micropile

9 5/8” OD casing, 0.545” Wall
Socketed 5’ into limestone
Design limited by deflections

Drilled Shaft

Approximately 50’ depth
Through Alluvium to sand
Length designed to conservatively extend beyond zero moment at tip
7’ Diameter, 1” thick permanent casing, conventional reinforcing

Micropiles will use rotary drilling methods with various drill bits

Drill through anything
So boulders cobbles and sewer lines – no problem
Old ties, rails etc
Bits tailored for work at hand

© AREMA 2016®
Construction, Drilled Shaft Rig installing Casing

Casing advancement limited due to concern with movement of bridge

Lesson Learned: Utilize Sleeve on shaft rebar cage.

Lesson Learned: Less (piles) is More

Rebar cages with Sleeves from subsequent project

Micropile installation, drilling through the concrete

Micropile load test to 680 kips

Micropile Load Test Program, 1 load test for each of 7 “zones”
Summary of Specialty foundation techniques

Strength – Girth of Shafts for Scour, lateral resistance, bending capacity

Settlement – reduction in risk of settlement of existing structure

Redundancy – 5 micropiles provide increase in redundancy, decrease in foundation risk

Schedule Savings

Cost and Risk Savings

Questions?