ABSTRACT

The Montana Department of Transportation recently awarded a contract to construct a replacement bridge across the Clark Fork River in Heron, MT. Both abutments and both intermediate bridge bents were to be founded on 6-ft and 8-ft diameter, permanently cased drilled shafts with rock sockets, respectively. Two drilled shafts per substructure location were designed for a total of eight drilled shafts. The original design included 6-ft diameter drilled shafts at the abutments but the Contractor elected to submit a Value Engineering proposal that increased them to 8-ft diameter. On the basis of the subsurface exploration program, extremely challenging subsurface conditions were known to exist, including the potential presence of large boulders within the predominantly sand and gravel soil matrix.

The successful bidder elected to use an oscillator to install the permanent casing to the top of bedrock, while simultaneously removing the spoils from inside the casing with a clam-grab. On seven of the eight shafts, this approach worked well. Unfortunately, on one of the shafts, the casing met refusal on one or more boulders encountered in the predominantly sand and gravel soil overburden. Following several attempts, and despite several variations of approaches, it was determined that the casing could not be advanced beyond the obstruction without unacceptable risks to the pile-supported temporary work trestle (i.e., loss of soil and reduction in pile capacity for the foundations supporting the work trestle).

To mitigate the problematic drilled shaft, a unique solution was designed and successfully constructed. The solution involved the construction of seven 16-in diameter micropiles constructed within the confines of the obstructed casing. The micropiles were drilled to bedrock through the sand, gravel, and boulders and include rock sockets to satisfy axial design requirements. The micropile casing thickness, grade and grout strength were designed to provide adequate flexural strength as well as to satisfy other design requirements. Upon completion of the micropile installation, the upper portion of the drilled shaft above the boulders and within the permanent casing was constructed as usual.

This paper discusses the difficult subsurface conditions at the site, the drilled shaft construction difficulties, and the design and construction of the micropile solution.

INTRODUCTION

The replacement bridge over Cabinet Gorge Reservoir at Heron, Montana, was recently completed and opened to traffic. The project is in Sanders County, which is located in northwestern Montana near the Idaho border as shown in Figure 1. The Cabinet Gorge Reservoir is the result of a dam built on the Clark Fork River a few miles downstream of the bridge project.

The new three-span steel plate girder structure is founded on eight drilled shafts. Both end bents and the two intermediate bridge piers are founded 1x2 groups of drilled shafts oriented transverse to the bridge alignment. Both intermediate piers include a waterline strut at the top of the 8.2-ft inside diameter drilled shafts and individual pier columns on top of both shafts. The drilled shafts include ¾-in wall permanent steel casing to the top of bedrock and 8.0-ft diameter rock sockets beneath the casing.
The bridge was designed by Morrison-Maierle under contract to the Owner, the Montana Department of Transportation. Dick Anderson Construction is the General Contractor that was awarded the bridge construction contract.

Following the successful construction of the first six drilled shafts at the three other substructure locations, the first of the two Pier 2 shafts constructed encountered a large boulder or possibly multiple closely spaced large boulders in the primarily sand and gravel soil overburden during casing installation. The casing met refusal on the boulder(s) and despite substantial efforts to continue advancing the casing, a remediation plan became the only practical and feasible solution. Note that the work was being performed from a temporary trestle bridge supported on driven piles bearing in the sand and gravel overburden. Safety of the work trestle was paramount and became a concern during the efforts to advance the casing through the boulder(s).

![Figure 1: Project location in northwest Montana near the Idaho border.](image)

Dan Brown and Associates was retained by the Owner to develop foundation design alternatives to remediate the problematic drilled shaft. Accordingly, several potential remedies were developed and evaluated until the preferred solution was identified. The selected remediation plan included leaving the partial length permanent casing in place as-installed, installing seven 16-in diameter micropiles cased to
bedrock, and constructing the upper portion of the drilled shaft as designed, with the top of the micropiles encased in the drilled shaft. Condon-Johnson and Associates was awarded a contract to install the foundation remediation described in this paper. The remediation was successfully constructed and the bridge is now open for traffic.

Discussion of the site conditions, design, and construction of the foundation remediation are included in the following sections.

SUBSURFACE CONDITIONS

A generalized site plan is shown in Figure 2 and a generalized soil profile is shown in Figure 3. Where the problematic drilled shaft is located, the water depth is approximately 40 ft; the normal pool elevation is around Elevation 2,178 ft and the mudline is around Elevation 2,138 ft. Beneath the mudline is a 25-ft thick stratum of loose to medium dense silty gravel. Beneath the silty gravel is at least one but possibly multiple boulders with a vertical dimension of approximately 20 ft. A similar argillite rock boulder encountered in an exploratory boring near the drilled shaft indicated an average measured uniaxial compressive strength of 17,761 psi. The measured values for the nine uniaxial strength tests on HQ3 core samples recovered from the boulder ranged from 12,415 psi to 25,555 psi with a standard deviation of 4,163 psi. Recovery and Rock Quality Designation (RQD) were generally 100 percent.

Figure 2: Generalized site plan.

Beneath the boulder is 80 ft of predominantly dense to very dense, poorly graded gravel with isolated layers of hard clay and dense sand. Argillite bedrock exists beneath the soil overburden; the top of the bedrock is at approximately Elevation 2,013 ft.

FOUNDATION REMEDIATION DESIGN

Preliminary analyses were developed for multiple remediation options. The team evaluated all the potential paths forward and ultimately selected the preferred alternative considering relative risk, schedule, and cost. Upon selection of the preferred remediation option, a two-phase analysis was performed. The computer software GROUP was utilized to first evaluate the three dimensional factored force effects acting on each drilled shaft at Pier 2. In this first phase of analysis, beneath the partial length permanent casing, the problematic drilled shaft was assigned an equivalent bending stiffness
representative of the proposed micropile group. Therefore, the foundation response under lateral load was slightly different between the two foundations supporting Pier 2. This initial effort using GROUP was necessary to ascertain the demand acting on the problematic drilled shaft, which was different than the original design due to the change in stiffness beneath the permanent casing.

Figure 3: Generalized soil profile.

Once the three dimensional factored force effects acting on the problematic drilled shaft were determined, a second GROUP model was developed to evaluate the three dimensional factored force effects acting on each individual micropile. This allowed the specific structural and geotechnical design aspects of the micropiles to be completed.

The resulting configuration of the micropiles is shown in Figures 4 and 5. As can be seen, the permanent casing of the problematic drilled shaft terminated at the top of the boulder. Through this casing, a group of seven micropiles were installed prior to placement of the reinforcing cage and concrete inside the permanent casing; i.e., the micropiles were installed in advance of the shaft concrete. The tops of the micropiles were ultimately cast into the upper portion of the drilled shaft above the boulder. The working platform elevation was effectively the top of the temporary trestle bridge deck around Elevation 2,190 ft. This resulted in a total micropile depth of just over 200 ft at the time of installation, but the tops were later cut to final length. It is noted that prior to placement of the concrete in the drilled shaft, the upper 75 feet of the micropiles were temporarily unsupported.

The micropiles included 16-in diameter, 5/8-in wall, minimum 50 ksi yield strength permanent pipe installed to bedrock. A 20 ft uncased socket was constructed in the bedrock for each micropile. A sanded grout with a minimum uniaxial compressive strength of 7,000 psi was also used. The reinforcement included a single, full-length, 3-in diameter Grade 75 all-thread center bar. The center bar was necessary to transfer the uplift resistance developed in the socket. A cross-sectional view of an individual micropile through the cased section is provided in Figure 6.
Figure 4: Drilled shaft repair design; elevation view.
It is noted that determining the micropile layout was an iterative process in which slight variations in location, diameter, pipe wall thickness, grout strength, and verticality all produced noticeable influences on the results. In addition, the final group configuration is non-symmetrical and was optimized considering the three-dimensional loading. Also, given the relatively tall configuration of Pier 2 and the large unsupported foundation length above the mudline, tight tolerances on verticality were necessary.

Prior to submitting the final released for construction remediation documents, multiple meetings involving the Designer, Owner, General Contractor, and Specialty Sub-Contractor were held to optimize the design. During these meetings, the preliminary micropile design was presented and detailed discussions ensued to ensure the remediation plan was optimal with respect to the available construction equipment and materials. The availability of the pipe was perhaps the biggest factor in these discussions as approximately 1,200 ft of permanent pipe was required in relatively remote northwestern Montana. Accordingly, upon checking the lead time on a few various pipe diameters, wall thicknesses, and grades of steel, it was concluded that the 16-in by 5/8-in Grade 50 pipe was the preferred material. Using this information, the final design was performed using the iterative process described above and the final released for construction documents were submitted.

During design development, a sacrificial demonstration pile and a load testing program were considered but not performed. It was agreed that the critical and controlling issues regarding the micropile constructability and performance was the presence of the boulder just beneath the permanent casing and the need to work from an elevated work platform over the river (temporary trestle bridge). These conditions could not be replicated in a test program. Furthermore, with respect to an axial load test, the lateral considerations, namely flexure and shear, effectively controlled the design of the micropiles.

Figure 5: Cross-section B (through permanent cased drilled shaft section).
FOUNDATION REMEDIATION CONSTRUCTION

Construction of the group of micropiles within the confines of the permanent casing was performed from the temporary work trestle, as shown in Figure 7. A Foremost DR-24 dual rotary drill rig owned and operated by Layne was utilized for the installation, as shown in Figure 8. A dual rotary drill was the preferred rig due to the strict requirements related to verticality. It was postulated that the ability to turn the micropile casing independently of the drill stem would allow more control of the verticality.

Figure 6: Cross-section of 16-in diameter micropile in the permanently cased zone.

Figure 7: Overview of project site, micropile rig and service crane.
The micropile pipe included a cutting ring welded to the base, as shown in Figure 9. Down-the-hole pneumatic hammer drill heads rotating independently of the casing were utilized and both were advanced at the same rate. Reverse circulation methods were used to extract the cuttings.
Aside from the substructure geometry, the relatively slender dimensions of the micropiles relative to the drilled shaft accentuated the need for maintaining verticality during installation. Accordingly, a very robust template was constructed and temporarily attached to the inside of the permanent drilled shaft casing along its entire length. In addition, the installation method included a partial length, oversized temporary casing through the boulder. The combination of the template and temporary casing provided sufficient annular space to accommodate minor adjustments to the permanent micropile casings. This allowed precise control of the verticality and was very effective.

Upon completion of each micropile, the temporary casing was removed. Prior to retrieval of the temporary casing, a cement-bentonite mix was tremie placed in the annular space between the OD of the permanent pipe and the ID of the temporary casing. The cement-bentonite mix was designed to replicate the stiffness of the surrounding soil, thereby preventing the potential for hard spots that may attract elevated shear forces.

An unforeseen difficulty that arose during construction involved the permanent micropile pipe seam. The pipe included a straight seam along the longitudinal axis of the pipe sections. The weld bead of the seam protruded approximately ¼ to ½ inch into the ID of the pipe. This resulted in difficulties installing and removing the down-the-hole tools. Ultimately, this weld bead had to be removed by mechanical means prior to installation. A photograph of the seam protrusion is included in Figure 10.

Upon the successful installation of the seven micropiles, the temporary template inside the permanent drilled shaft casing was removed. Following that, a typical drilled shaft reinforcing cage was placed around the micropiles to the bottom of the permanent casing and concrete was tremie-placed as usual. The finished foundation is shown in Figures 11 and 12 prior to construction of the water line strut.
Figure 11: Plan view of completed drilled shaft repair prior to construction of the pier cap.

Figure 12: Completed foundations prior to construction of the pier cap.
SUMMARY

A group of micropiles constructed inside the confines of a drilled shaft permanent casing that met early refusal was successfully designed and constructed to remediate the difficulties associated with the drilled shaft construction. The associated design was complex and required an iterative approach involving multiple degrees of freedom. Early involvement by the Contractor was essential to not only the constructability but also the optimization of the solution.

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