Drilled Shaft Foundations for the Hurricane Deck Bridge (A RCD Story)

Introduction

The Missouri Department of Transportation (MoDOT) recently replaced the Hurricane Deck Bridge that carries Highway 5 traffic across the Osage Arm of the Lake of the Ozarks in Camden County, Missouri. The replacement structure is on a new alignment adjacent to the existing bridge and is founded on large diameter drilled shafts socketed into the bedrock using full-face, casing top mounted, Reverse Circulation Drilling (RCD). This article describes the foundation design and construction for this interesting $32 million bridge replacement project.

The owner is MoDOT, the general contractor was American Bridge, and the design consultant was Parsons. Both Case Foundation and Hayes Drilling acted as sub-contractor to American Bridge to install drilled shaft foundations; Case in the water using RCD equipment and Hayes on the land using traditional rotary drilling equipment. Dan Brown and Associates (DBA) provided foundation engineering and design services as sub-consultant to Parsons.

Foundation Design

Dozens of boreholes including rock coring were drilled form a barge during the design phase. The location of each drilled shaft included at least one boring per shaft. Some of the borings were also logged with an Acoustic Tele-Viewer (ATV) in an effort to further evaluate the *in-situ* quality of the bedrock. This region is known to contain karstic features in the bedrock and the ATV logs provided a reliable means to inspect borehole walls for such features. An example of the ATV results in the bedrock is provided in Figure 1a, along with the corresponding photograph of recovered rock core in Figure 1b.

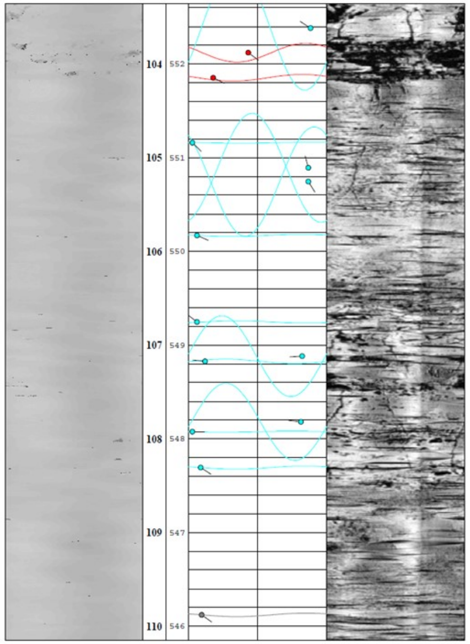

Fig 1a: Representative ATV Results in Dolostone Bedrock

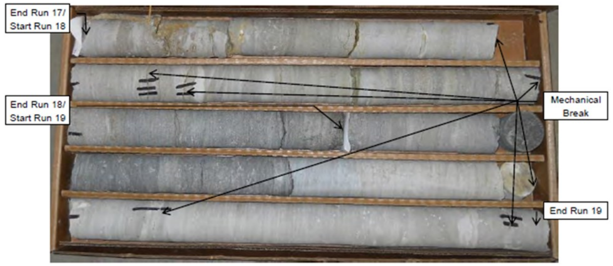

Fig 1b: Corresponding Photograph of recovered Dolostone Bedrock core

The dolostone bedrock was determined to be adequate on the basis of the core results. The average unconfined compressive strength (q_u) of the bedrock cores as measured in the laboratory was 5,680 psi (39162 KN/m^2). As is typical with sedimentary bedrock in the Midwestern United States the q_u of the bedrock cores contained a fair amount of variability and therefore many tests were performed in an effort to quantify the variability. The measured q_u values on the 225 samples tested ranged from 650 psi to 18,420 psi with a standard deviation of 3,090 psi (21305 KN/m^2). The average unit weight of the bedrock core samples prior to testing in the laboratory was 159 pcf (2547 Kg/m^3). Core recovery and Rock Quality Designation (RQD) were both good with the exception of some zones of karst near the surface of the bedrock.

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The bridge design includes eleven two-column bents supported on drilled shafts with rock sockets. The two shafts at each bent were tied together with a waterline strut oriented in the transverse direction of the bridge. Each column was supported by an 8.5ft (2.59m) diameter drilled shaft permanently cased to rock and with an 8ft (2.43m) diameter socket extending about 20ft (6.09m) into dolostone bedrock. The contributions of both side resistance and base resistance generated in the rock socket were included in the calculations of geotechnical axial compressive resistance.

The diameter was controlled by lateral considerations and the relative large unsupported length between the mudline and the waterline strut. The submerged overburden soil was soft and provided little lateral resistance. A schematic of the subsurface profile longitudinal with the bridge is provided in Figure 2 with the bent locations superimposed. At some locations, the water is 80ft (24.38m) deep with only about 10ft (3.04m) of soil above bedrock. Due to the relatively large unsupported shaft length, the structural engineer concluded and specified that the maximum allowable plumbness tolerance was one percent.

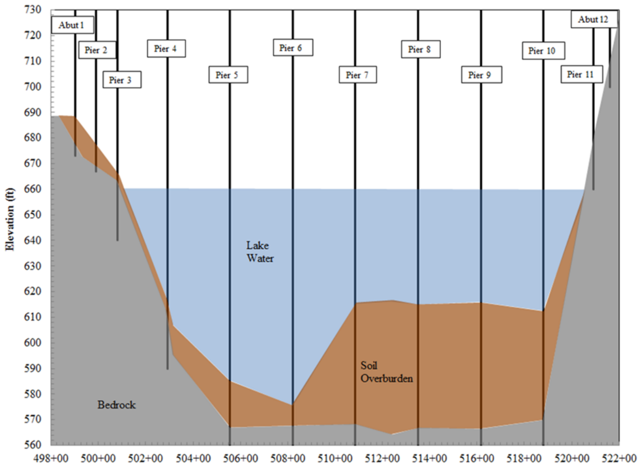

Fig 2: Subsurface Profile.

The socket length was controlled by axial considerations and less favorable bedrock conditions were encountered at some shaft locations. The core recovery and RQD at some locations indicated soil-filled solution cavities and poor-quality bedrock at a few of the shafts near the surface of the bedrock.

Fig 3a: Reverse Circulation Drill Rig

Fig 3b: Reverse Circulation Drill Rig

Foundation Construction

The drilled shafts at Bents 4 through 10 were constructed by Case Foundation under subcontract to American Bridge. These locations represent the over-water bents and included a total of 14 shafts. The drilled shafts necessary to support the bents on land were constructed by Hayes Drilling under subcontract to American Bridge.

After installing the permanent casing into bedrock and removing the soil overburden inside the casing, Case Foundation drilled the rock sockets with an RCD rig. The rig was mounted to the top of the permanent casing as shown in Figures 3a and 3b and the excavation was advance using a full-face cutter assembly as shown in Figure 4.

Fig 4: Full-Face Cutter Assembly

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The configuration of drill rig and cutting tool combined to make what was essentially a large plumb bob. This proved beneficial in achieving the maximum one percent vertical tolerance specified in the construction documents.

Another benefit of the reverse circulation drilling method is that an airlift is constantly working to remove cuttings. This process results in a very clean excavation which greatly reduces the risks of post-construction integrity test anomalies as well as provides more reliable base resistance.

Following the excavation of the drilled shaft, standard MoDOT drilled shaft construction specifications required each rock socket be visually inspected with a television camera. The socket walls and base were viewed with the camera and indicated a very clean excavation and rock socket conditions commensurate with the design.

At one shaft location, a clay-filled solution cavity was encountered that required mitigation. The cavity was approximately 2-3ft (0.61-0.91m) in vertical dimension and the top of the cavity was approximately 5ft (1.52m) beneath the top of bedrock. Upon encountering this feature, the drill stem advanced rapidly as would be expected when transitioning from bedrock to clay. The drill assembly was immediately retrieved to prevent potential loss of the tool.

A previously agreed upon contingency plan was instituted immediately to mitigate the issue. This contingency plan was included in the drilled shaft installation plan and proved very valuable. Because the risk of encountering such features were made known early in the project, the Owner, Engineer, and Contractor were able to rapidly respond to the issue and successfully and efficiently mitigate the problem under fair financial terms. A well out thought installation plan provided by the Contractor in combination with a thorough identification and description of construction risks by the Engineer helped the Owner feel comfortable agreeing to the financial terms of the possible mitigation effort prior to the commencement of construction. A photograph of the completed Hurricane Deck replacement bridge is provided below in Figures 5.

Fig 5: Photograph of New Hurricane Deck Bridge

Summary

Several aspects of foundation engineering were necessary during the design phase of this interesting bridge replacement project. The final selected foundation elements included drilled shafts with rock sockets and one instance of a spread footing bearing on shallow bedrock.

During the investigation of the existing caissons, ATV testing proved very beneficial, particularly in zones with low core recovery or RQD.

A comprehensive drilled shaft installation plan agreed upon by all parties in advance of the construction can and did yield benefit. A good plan should include a consideration of the anticipated risks and an agreement on how to proceed if difficulties associated with those risks are encountered. A good faith effort is necessary by the Contractor and a willingness to share risk is necessary by the Owner, along with a competent and experienced design engineer retained throughout the entire design and construction process.

– ***Paul J. Axtell,*** P.E., D.GE – Dan Brown & Associates, Overland Park, KS