CONSTRUCTION OF THE DRILLED SHAFT FOUNDATIONS FOR THE HUEY LONG MISSISSIPPI RIVER BRIDGE, NEW ORLEANS

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The foundations at the Huey P. Long Bridge in New Orleans presented special challenges for construction due to the requirements for very deep drilled shafts in the Mississippi River beneath the existing bridge structure. Drilled shafts were constructed to depths of approximately 200ft in alluvial soils using a rotator system with full-length segmental casing, and base grouted to improve axial resistance. This paper describes the design and construction of the work platform to provide access to the restricted-access site beneath the existing bridge, the approach used to construct the drilled shafts, and the results of a load test program to verify the axial resistance.

INTRODUCTION

The historic Huey P. Long Mississippi River Bridge in New Orleans, Louisiana is a through truss which will be widened with an additional truss on either side of the existing structure (shown in Figure 1). The foundations for the rehabilitated structure include re-use of the existing caissons plus an additional major pier foundation at Pier IVA.

Figure 1: Huey P. Long Mississippi River Bridge (Pier IVA on Right).

Pier IVA, constructed on drilled shafts beneath the existing bridge as illustrated in Figure 2, is designed to support the widened approach structure and resist deep scour and vessel impact forces. Because of the challenging conditions in at this location, the construction team developed a value-engineered alternate approach to the original construction concept which maintained the primary features of the foundation as designed. The paper presents a case history of the design of the temporary works for this pier and the construction, testing, and quality assurance of the permanent foundation.

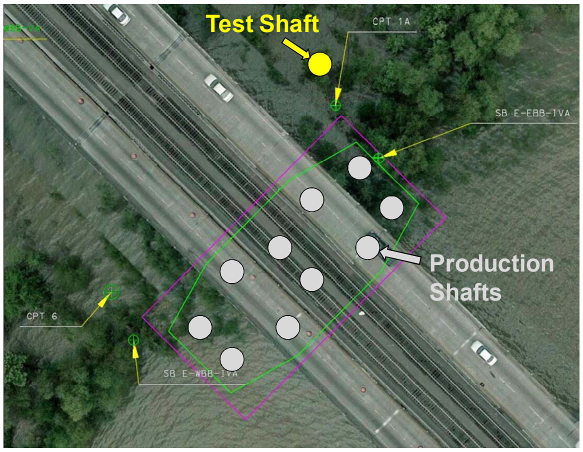

Figure 2: Foundation Plan for Pier IVA.

The Pier IVA foundation was constructed in the river in a restricted headroom environment beneath the existing bridge, on ten 9.2 ft diameter drilled shafts extending to depths over 200 ft into alluvial soils. Construction of the work platform and the footing cofferdam required consideration of the stability of the soft soils between the levee and the channel, and was completed using a system of sheet piling and crushed stone fill. The drilled shafts were constructed using a full length segmental casing installed with a rotator system in order to provide stability for the loose soils during the lengthy process of splicing and placement of reinforcement. Base grouting was used to improve the base resistance and provide a measure of quality assurance in the axial resistance of the drilled shafts. Load test results of a full size test shaft demonstrate the high base resistance achieved, and the good side resistance obtained with the temporary casing system.

SUBSURFACE CONDITIONS

Pier IVA is located on the “batture”, which is the alluvial land between the river at low water stage and the levee. This location is flooded when the river is at high stage, and the work platform was raised to +14ft elevation in order to provide a dry work environment. Any work in this area was subject to considerations of any potential adverse effects upon the stability of the existing levee, which protects the New Orleans area from flooding by the Mississippi River.

Shallow soils are very soft clays and silts, and were underlain at a depth of about 40ft by an old willow mat that had been placed as an erosion protection measure on the original river bed during construction of the caisson foundations in the early 1930’s. This willow mattress was constructed by weaving willow trees that had been cut along the river with steel cables to form a floating mat that was roughly the size of a football field. The mat was then sunk into position around the caisson by adding large stones. The very soft soils overlying the willow mat represent the accumulation of sediments from the last 75 years.

Beneath the surficial soils to below the tip of the drilled shafts at elevation -195ft are loose to dense alluvial sands with occasional layers of soft clay. Groundwater reflects the levels in the river, although fluctuations in groundwater may trail fluctuations in river level by days or weeks so that head differences can occur. A schematic diagram of the subsurface conditions is provided in Figure 3.

CONSTRUCTION OF THE WORK PLATFORM

In order to construct the foundation for Pier IVA, it was necessary to develop a plan to access the site and support the construction equipment. Fluctuating river levels were such that marine construction from barges was not feasible.

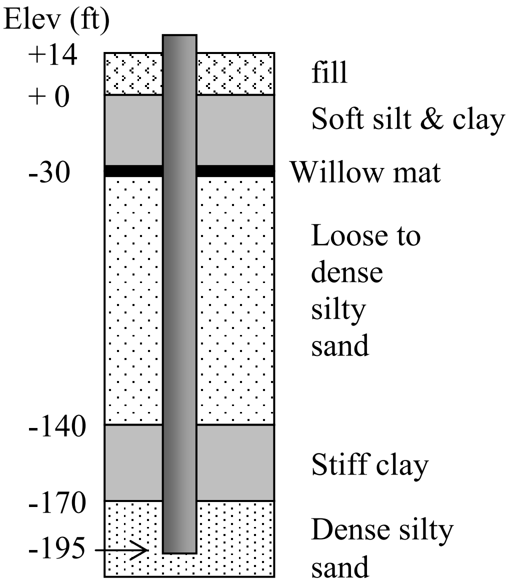

Figure 3: Subsurface Conditions

Construction of a working platform on fill was preferred to a pile-supported work trestle because of issues related to the nearby bridge and levee as well as greater costs and the magnitude of the reaction forces required to support the rotator equipment. Because of the very soft clays and the drop off in elevation toward the river, global stability was a major consideration.

A schematic diagram of the working platform is provided in Figure 4, which shows the existing bridge and piers. The design of the platform included the use of temporary steel sheet piling and geo-grid reinforced, cement-stabilized granular fill in order to provide a computed factor of safety of at least 1.5 for global stability. The sheet piling was installed to the depth of the willow mat beneath the soft clays.

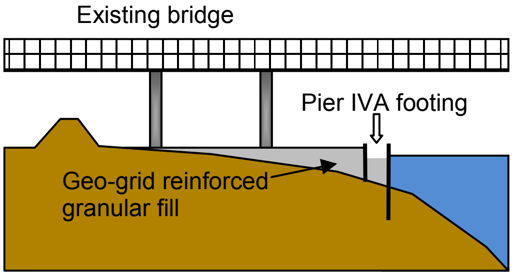

Figure 4: Schematic Diagram of Working Platform.

Laboratory tests of undrained shear strengths of shallow cohesive soils that were provided in the pre-bid geotechnical data appeared to be quite variable, possibly due to effects of sample disturbance and local silt pockets and layers. The construction team performed cone penetration soundings post-award and prior to construction as a supplement to the available information and to further define the stratigraphy and soil properties in this area. The final analyses of stability were based on a c/p ratio of 0.25 in the shallow cohesive soils, where c/p represents the ratio of undrained shear strength to effective vertical stress.

CONSTRUCTION OF THE DRILLED SHAFTS

The construction of the drilled shafts was unusually complicated because of several critical factors, including the length of the shafts, the poor soil conditions, and the location below the existing bridge.

The shafts extended over 200ft below the working platform into unstable soils with high groundwater conditions, a condition which presented a significant risk of a borehole collapse during construction with conventional slurry drilling techniques. In order to achieve excess fluid head above groundwater, surface casing would need to be elevated above the working platform and would further restrict headroom. In addition, the completion of the shaft with placement of the reinforcement and concrete would require at least a couple of days, a time period which exceeds the typical exposure allowance with mineral slurry materials.

Vibratory installation of permanent casing would adversely affect the side resistance, from which a majority of the axial resistance is derived. In any event, the installation of casing in advance of the excavation using a vibratory hammer would be unworkable due to the restricted headroom and the presence of the nearby existing bridge foundations.

The drilled shaft construction included several features that are relatively unusual in this area:

- The drilled shafts were excavated using a fully cased rotator system to maintain stability of the excavation during the entire process.
- The longitudinal reinforcement included an interior frame to provide alignment and support during placement, which required up to four splices due to the restricted headroom conditions.
- The reinforcing cage included a liner near the top so that the excavation for construction of the seal and the tie-in to the footing could be accomplished after completion of the drilled shafts.
- The drilled shafts were pressure grouted to enhance the axial base resistance and mitigate any imperfections in bottom cleaning in the granular soils at a depth of over 200ft below the working platform.

Fully Cased Rotator System

The pre-bid specifications contemplated open-hole drilling with mineral slurry, and did not allow for the use of temporary casing for construction of drilled shafts. However, the rotator system with segmental casing was proposed and accepted as a value-engineered alternate approach to the original construction concept. Photos of the construction system are provided in Figures 5 and 6. In this location, the rotator is mounted into the sheet-pile supported excavation, using the excavation support as a reaction system for the equipment.

The rotator casing system provided several advantages for this project:

- The excavation was fully supported by the casing during the entire construction period so that the risk of a borehole collapse was eliminated.
- Excavation through the buried willow mat and other obstructions (buried logs) posed no significant issue because the rotating casing is able to core through the obstruction.
- There was no need for mineral slurry and the accompanying holding tanks and slurry cleaning and handling equipment. The shafts were excavated using river water with the addition of a small amount of polymer slurry material.
- With the elimination of mineral slurry, the potential for contamination of the sidewall and adverse effects on side resistance was avoided.

- The spoils could be easily handled, as a hammer-grab excavated the soil within the casing as illustrated in Figure 7 and immediately deposited it into a waiting truck to be hauled off-site.
- With a full exchange of the drilling fluid within the casing (dirty fluid was pumped into an adjacent barge), the cased hole minimized the risk of soil inclusions and contamination of the concrete during completion of the shaft.

Figure 5: Rotator Placed into Excavation within the Working Platform

Figure 6: Rotator with Segmental Casing, using Excavation Support as Reaction

Figure 7: Excavation within the Casing Using a Hammer-grab

The depth and loose granular nature of the soils presented a significant concern with the plan to use the rotator system, because of the risk that the casing could become stuck due to excessive friction. This concern was amplified by the time required to set the reinforcement due to the splices necessitated by the restricted headroom. No such problems occurred during construction, as the experienced operators were careful to proceed at a slow and steady pace and always kept the casing moving throughout the entire operation until the casing was removed. A soil plug was maintained at all times within the casing as the excavation was advanced, and the casing kept charged with fluid to maintain a head of fluid inside the casing in excess of the groundwater head.

<u>Completion of the Base of the Excavation</u>

The pre-bid specifications also required that the base of the shaft be flat, level, and cleaned so that no more than ½ inch of loose material remained over at least 50% of the base area and no more than 1-1/2 inch anywhere over the base of the shaft as determined with a down-hole camera inspection. The construction team considered that this specification was not practically achievable and used the load test shaft to demonstrate the suitability of an alternate approach to completion of the base of the shaft. In addition to the cleanliness issue, the most efficient means to excavate the shaft within the casing is with the hammer-grab which does not leave a flat, level base as might be the case with a rotary tool.

The completion of the shaft base was accomplished as follows:

- After the casing is at the target elevation a few feet below the shaft tip elevation, excavate to the base of the casing using the hammer-grab.
- Remove any loose soil using an airlift pump, and continue to operate this system until a full exchange of drilling fluid within the excavation is completed.
- After the required inspection using the down-hole camera, place one to two feet of clean gravel bedding material into the shaft excavation.
- Use the tamper/brush to swab the inside of the casing and tamp the gravel bed to a flat, level condition. A photo of the tamp device is provided in Figure 8.

Figure 8: Tool Used to Tamp the Gravel Pad and Brush the Casing Interior

Based on the conditions observed in the load test shaft, the presence of up to 3 inches of un-removed granular soil at the base of the shaft was concluded to be acceptable. Of course, each shaft was to be base-grouted after completion, which mitigates any detrimental effects of a small amount of granular soil at the base of the shaft.

The gravel bedding material served two purposes: it provided a grout distribution medium for the subsequent base-grouting operations, and it provided a means to achieve a firm, level surface onto which the reinforcing cage rest.

Base-Grouting

The base-grouting operation was performed after the shaft was completed and crosshole sonic logging (CSL) testing was deemed acceptable. The CSL tubes were used as the plumbing hardware for the grouting operation by connecting pairs of tubes across the base of the reinforcing cage with a sleeve-port system in the connection. This system provided four independent grouting circuits, as illustrated in the photo of Figure 9. A thin metal cover plate was also provided to separate the sleeve-port system from the concrete.

Figure 9: Sleeve-port Base Grouting System

During the grouting operations, each separate grout circuit was pressurized and a careful log maintained of grouting pressure, volume, and measured upward movements of the drilled shaft. The target grout pressure was 650 psi for each shaft, but because these shafts were so deep, grout pressures of up to 800 psi were easily achieved with no significant upward shaft movement. Grout pressure was achieved in each circuit and then released after a period of only a few minutes.

Reinforcing Cage

The reinforcing cage had several significant construction challenges. With the base-grouting and rotator casing methods, the cage was designed to be self-standing and not suspended from the top of the excavation. In addition, the cage had to be assembled and placed in a restricted headroom environment, with as many as four splices during installation. The amount of longitudinal reinforcement was substantial because of the flexural strength required for the vessel impact forces on the foundation, and the completed reinforcing cage had a weight of approximately 160 kips.

A key feature of the fabrication and placement of the reinforcement was the use of an internal tubular steel frame to strengthen the cage for self-standing and to provide a guide during splices. This frame, shown in the photo of Figure 10, included circular steel bands which were pre-drilled with holes of u-bolts to provide alignment for each individual bar and CSL tube.

Figure 10: Back-bone Frame for Reinforcing Cage

Even with all of the features described above, placement of the cage into the shaft excavation was as much as a two day process because of the time required to complete the splice connection operations over the hole (see Figure 11). During this period, the casing had to be rotated periodically to ensure that it did not become stuck.

Figure 11: Splicing Reinforcing Cage

The top of each reinforcing cage was fitted with a 25ft length of corrugated metal pipe which was designed to fit inside the rotator casing and act as an isolation casing above the top of the shaft (see photo in Figure 12).

Because the footing was required to be embedded below the river bed, the top of shaft was cut off well below the working platform. The isolation casing contained the reinforcement above top of shaft that would subsequently form the structural connection into the footing after the seal was excavated and completed.

Figure 12: Isolation Casing Attached to Uppermost Section of Reinforcing Cage

Concrete

The concrete mix design was developed with a special emphasis on workability and retention of workability for the duration of the tremie concrete placement operations. This mix, which could be termed a “high-performance” concrete mix based on the performance requirements of the fresh concrete has the characteristics of a self-consolidating concrete (SCC). Some special features of this mix include the following:

- Approximately 35% of the Portland cement was replaced by ground granulated blast furnace slag, which serves to improve workability and consistency, reduce the heat of hydration, reduce bleeding and segregation, and delay the initial set of the concrete. As an added bonus, this material reduces the carbon footprint of the project!
- Pea-gravel size coarse aggregate improved workability and passing ability.
- The fine aggregate (sand) represented approximately 50% of the total aggregate in the mix.

- Extensive addition of water-reducing and hydration control admixtures was used to improve and maintain workability.
- Viscosity-modifying admixture was used to reduce segregation and bleeding.

A photo of the fresh concrete is provided in Figure 13.

Figure 13: Drilled Shaft Concrete with Good Workability

The key features of the concrete construction operations for the drilled shafts on this project were:

- the fully cased hole with positive fluid pressure maintained at all times,
- full exchange of the drilling fluid so that no significant suspended solids were present,
- concrete mix which was proportioned with emphasis on workability and minimal segregation and bleeding tendencies,
- adequate hydration control admixtures were included to ensure that workability was maintained throughout the concrete placement operation, even considering the hot weather operations and the notoriously difficult New Orleans traffic,
- careful attention to concrete placement techniques with the tremie and casing withdrawal.

As a result, the load test shaft and all 10 production drilled shafts were completed with no significant anomalies in the CSL test results. A typical velocity plot is illustrated in Figure 14 The project management considered this to be a highly successful job.

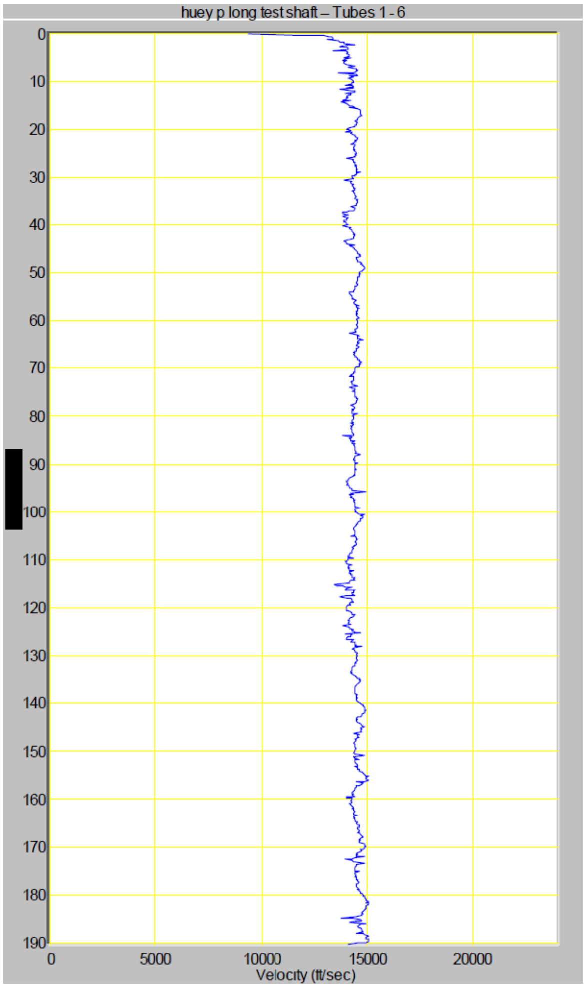

Figure 14: Typical CSL Test Results

LOAD TEST SHAFT CONSTRUCTION AND RESULTS

The first shaft completed on the project served a dual purpose as a demonstration of the construction means and methods and a verification of performance. Several aspects of the construction as outlined previously deviated from the existing standards and specifications of the LaDOTD and were beyond the local base of experience. Because of these factors, the constructors encumbered some risk related to the performance of the load test, a risk which would normally be attributed to the design.

Construction of the load test was successfully completed without incident. The rotator penetrated the willow mat and several other buried logs with no impact on the productivity of the operation. The nature of the soils during excavation could be readily inspected from the hammer-grab. The camera inspection of the shaft base indicated that up to 3 inches of granular sediment could be detected at the base of the shaft, despite repeated attempts to achieve greater cleaning with the air-lift and a variety of other tools. After final acceptance of the excavation, a full exchange of the drilling fluid was performed. Approximately 3 days elapsed between completion of the excavation and completion of concrete placement.

The load test shaft was base grouted to a maximum pressure of approximately 800 psi through all four circuits, with an observed upward movement of the top of shaft of 0.08 inches.

The load test shaft was completed using Osterberg cells placed near the base of the shaft (about 5ft above the base), with the results illustrated on Figure 15. The strain gauges suggest that the side resistance was extremely low (about 300psf) in the upper 60ft of the shaft and ranged from 1.5 to 2.4ksf in the lower 150ft. The base resistance was fully mobilized at approximately 132ksf at a displacement of 5.5 inches, or about 5% of the shaft diameter. This base resistance equals a unit pressure which is approximately 22% greater than the applied base grout pressure.

CONCLUSIONS

This case history of the construction of the drilled shaft foundations for the Huey P. Long Bridge demonstrates the extraordinary capabilities of modern construction equipment and techniques. Current infrastructure projects present challenges that require careful planning and execution with a coordinated effort of engineers and constructors. Construction of items such as a temporary work platform requires engineering design and attention to critical surrounding structures. An emphasis on constructability is necessary in planning the foundation design and in selection of materials such as the concrete mix. Specifications used in previous years for routine construction may require adjustment for large and complex projects such as the one illustrated in this case history. The use of innovative solutions such as base grouting can be used to improve performance. Load test shafts can serve as a means of verification of non-standard means and methods and modern integrity test methods such as CSL offer quality assurance to the owner of a reliable and well-constructed foundation system.

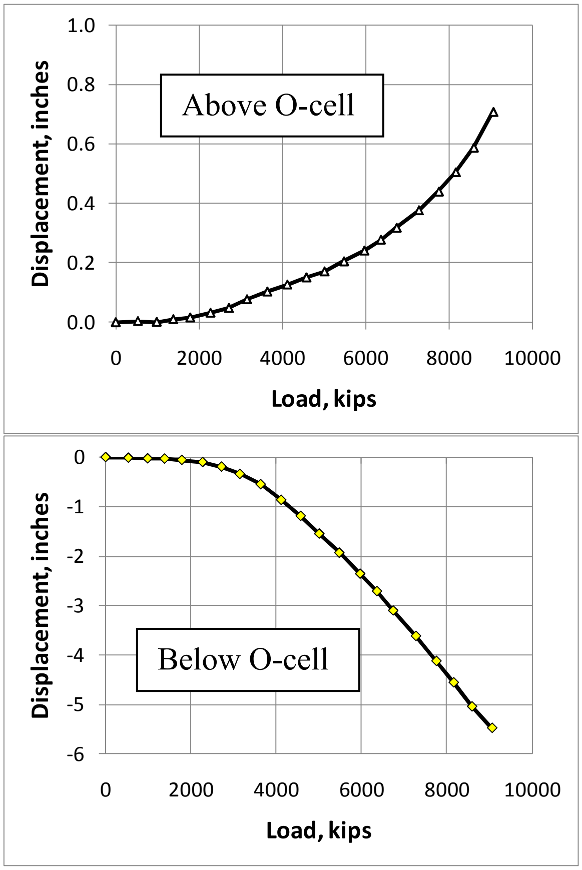

Figure 16: Axial Resistance from O-cell

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