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DESIGN AND CONSTRUCTION OF DRILLED SHAFTS IN KARST ENVIRONMENTS OF FLORIDA

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ABSTRACT

Drilled shafts have been widely used as bridge foundation alternatives for more than a decade in Florida. The majority of the drilled shafts are designed to embed into the underlying limestone. However, many unforeseen conditions have been encountered during the construction of drilled shafts due to karst environments, especially in the Tampa Bay area where sinkhole occurrences are common.

This paper presents a case history of the design and construction of drilled shaft foundations for the I-4/I-275 Downtown Interchange in Tampa, Florida. A two-phase procedure utilized by the Florida Department of Transportation (FDOT) was adopted to minimize the impact of karst environments on drilled shaft construction and contractors' claims, while also considering the project schedule and budget. A total of 315 drilled shafts with total lengths of 3,914 meters were installed for this project. Although the estimated total drilled shaft lengths in the preliminary design phase were only underestimated by 10%, high variability of individual shaft lengths between those estimated during the preliminary and final designs were observed with a maximum difference up to 20 m. The evaluation of the impacts of the karst environments on the drilled shaft design, and the comparison and discussion of the drilled shaft lengths determined during design and as-built are presented.

PROJECT DESCRIPTION

The Florida Department of Transportation (FDOT) District 7 planned operational improvements in Tampa to I-275 from the vicinity of the Hillsborough River to the vicinity of Floribraska Avenue and I-4 from the I-275/I-4 merger to east of 22nd Street. The total project length was approximately 5 kilometers. The project involved improvements to and widening of the existing roadway, including a total of 23 bridge structures for various interchanges and access roads. Structural design included the construction of new bridges and widening of existing bridges. A photo of the project site while under construction is shown in Fig. 1.

Fig. 1. Downtown Tampa Interchange bridge construction.

GENERALIZED SUBSURFACE SOIL CONDITIONS

Hillsborough County is riddled with sinkholes. Many of the lakes formed by sinkholes are in direct hydrologic contact with underlying limestone formations due to breaches in the clay aquitard. The subsurface of Hillsborough County can briefly be described as surficial sands, clay, sandy clays and clayey sands overlying limestone. The limestone formations portray the typical karst environments with cavities and localized soft zones.

A total of 46 Standard Penetration Test (SPT) borings ranging in depths from 15.2 to 30.5 meters including rock cores were performed during the design phase for the subject bridge structures (PSI, 2001). The borings were performed as close as possible to the proposed bridges considering utility and access constraints. The purpose of the preliminary exploration was to provide general subsurface conditions to finalize the selection of the bridge foundation type and then to estimate the total lengths of the production drilled shafts for contract bidding purposes. The generalized soil profile of the project site is shown in Fig. 2. The top boundary of the limestone layer, considered as the bearing layer, ranged from elevation 7.6 to -10.5 meters, National Geodetic Vertical Datum (NGVD) while the SPT N-values ranged from Weight of Rod to more than 50 blows for 25 mm. Unconfined compression and split tensile tests were performed on select rock core samples. The unconfined compression strength of limestone ranged from 0.5 to 82.4 MPa, and the split tensile strength ranged from 4.6 to 37.3 MPa.

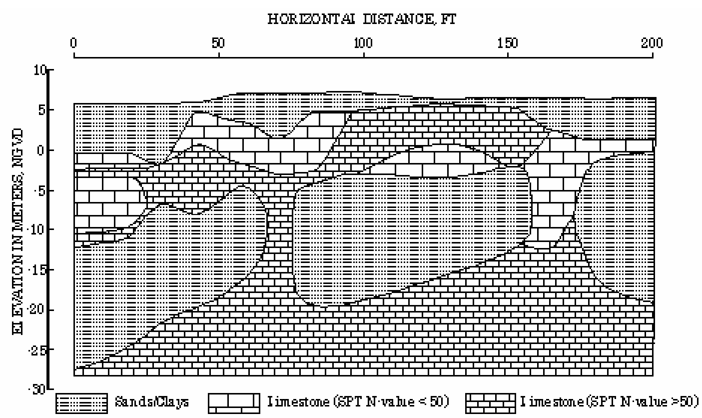

Fig.2. Generalized Soil Profile

DRILLED SHAFT DESIGN METHODOLOGY

Drilled shafts of 915, 1220 and 1525 mm in diameter were selected as the preferred foundation systems for support of the proposed bridges and bridge widenings. Engineering analyses was performed for factored axial loads of 441 to 7574 kN per shaft.

The Load Factor Design (LFD) method was used for both preliminary and final drilled shaft design. The ultimate axial compression capacities were calculated using the FHWA Method (1999) with the design unit skin friction of limestone determined by McVay's Method (1992) in conjunction with the statistical analysis of the Unconfined Compression and Split Tensile Strength test results of rock samples with consideration of the average recovery of rock cores.

A two-phase procedure was used in the design and construction of the proposed drilled shafts due to the extreme variability of the depths and strength properties of the underlying limestone formation. In phase 1 (design phase), a limited field exploration and laboratory testing program was performed to provide design criteria and estimate total lengths for the drilled shafts for estimating construction cost. In phase 2 (construction phase), a pilot hole boring was performed at each drilled shaft location to verify or modify the proposed drilled shaft lengths.

Using FDOT guidelines as stated in the Soils and Foundations Handbook (2006) and a statistical analysis of the limestone properties for this project, performed during the design phase, the average ultimate unit skin friction was estimated as 1440 kPa for refusal materials with the SPT N-values over 100. The average ultimate unit skin friction (1440 kPa) minus one standard deviation (470 kPa) corresponded to a SPT N-value of 50 (970 kPa). Limestone with a SPT N-value less than 25 was treated as clay and Terzaghi and Peck's method (1967) was used to estimate the undrained shear strength from the SPT N-value. Accordingly, a relationship between ultimate unit skin friction of the soft limestones and clays and the SPT N-value was established as shown in fig. 3 and used to determine the production drilled shaft length once the pilot hole was completed.

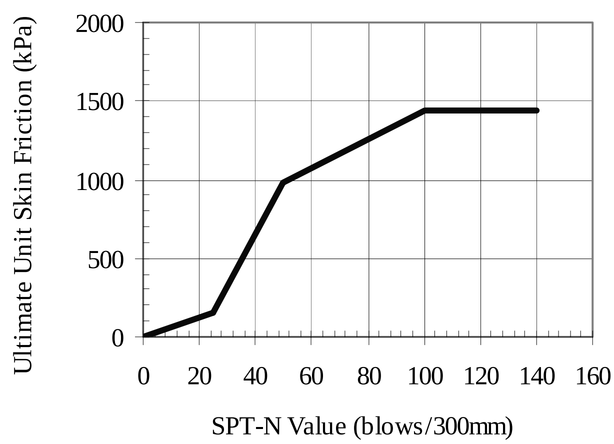

Fig. 3. Correlation of SPT N-Value versus Ultimate Unit Skin Friction

During the construction phase, a pilot hole boring was performed at the exact location of each proposed drilled shaft and the production shaft length was then re-evaluated based on the pilot hole information and the design criteria established during the phase I (design) phase. To keep on the critical path, in general, the final production shaft length was provided to the contractor within 24 hours after the corresponding pilot hole was completed. A total of 315 pilot hole borings (SPT's without rock cores) were performed during the construction phase.

COMPARISON OF ESTIMATED DRILLED SHAFT LENGTHS

Limited SPT borings were performed during the design phase due to schedule and drilling access constraints. Therefore, the anticipated drilled shaft lengths were estimated on a bridge pier/ bent basis. The length varied from 3 to 30 meters with total shaft lengths equal to 3,625 meters for the 315 drilled shafts. The final production shaft lengths (as-built) determined based on the pilot hole information performed at every shaft location during the construction phase, ranged from 5 to 33 meters with total lengths of 3,914 meters. Figure 4 compares the estimated preliminary design and final design drilled shaft lengths. Figure 5 presents the frequencies of the ratios of final design lengths to preliminary shaft lengths. Statistically, the average shaft lengths and total lengths estimated from both the preliminary and final design phases were very close. Through examination of the individual shaft length, there were 211 out of 315 production shafts or 67% of the total drilled shafts that required longer lengths during construction with a maximum difference in length up to 21 meters.

The distribution of final design shaft tip elevations is shown in fig. 6 with the majority located within the range of 5 to –5 meters, NGVD. However, in some localized areas tip elevations reached as deep as -20 to -25 meters, NGVD. For a site located in a karst environment it is not surprising to see this dramatic difference in elevations of the bearing stratum. If the two-phase approach was not implemented on this project there would have been a high potential for excessive settlements or punching failures from the drilled shafts not reaching competent bearing material based on the preliminary design or possibly drilled shaft installed deeper than necessary increasing construction time by drilling deeper into hard bearing material.

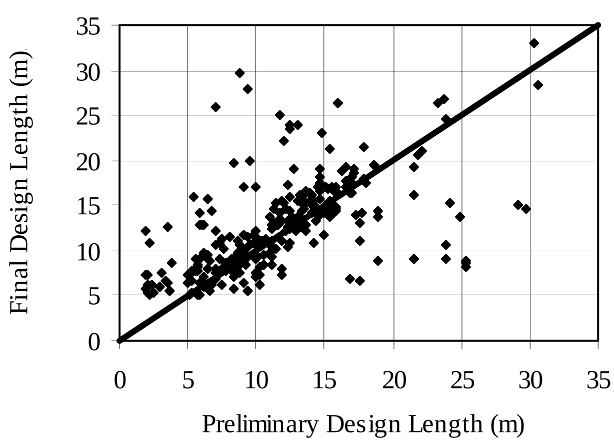

Fig. 4. Comparison of Preliminary Design vs. Final Design Drilled Shaft Lengths

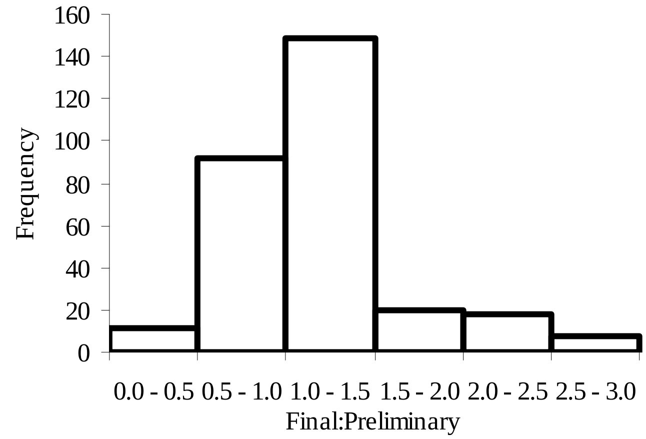

Fig. 5. Frequency of Ratio of Final Design to Preliminary Design Drilled Shaft Lengths

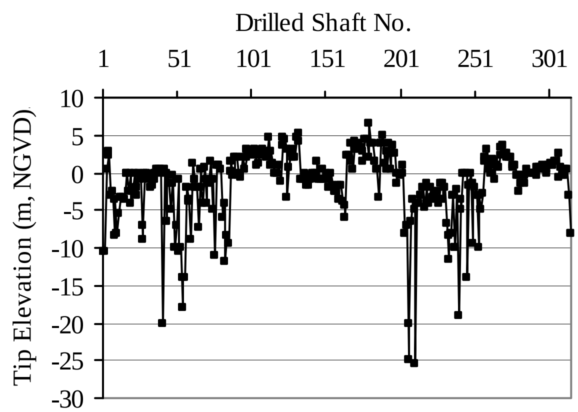

Fig. 6. Distribution of Final Drilled Shaft Tip Elevations

DISCUSSION AND CONCLUSIONS

The construction of drilled shafts in karst environments is a great challenge to the engineer. This challenge is mainly due to the extreme variability in bearing stratum elevations. Unlike driven piles where capacity can be verified by the hammer blow count during the pile driving operation, the construction of drilled shafts primarily rely on predetermined lengths from the design phase and field judgment of the inspectors during shaft excavation.

Because of limited budgets, schedule and accessibility constraints of performing SPT borings at the proposed shaft location during the design phase, the production shaft lengths is typically set on a pier/bent basis. A minor modification in drilled shaft lengths might be expected. For uniform soil stratum, it might not pose significant risk to set a uniform depth for an entire pier/bent. However, for karst environments, due to the uncertainty in bearing layer elevations, a localized soft zone or cavity may be encountered and require a significantly deeper shaft. As shown in fig. 7 of this case history, even within the same bridge pier/bent, extreme disparities in drilled shaft tip elevations were observed up to a difference of 20 meters.

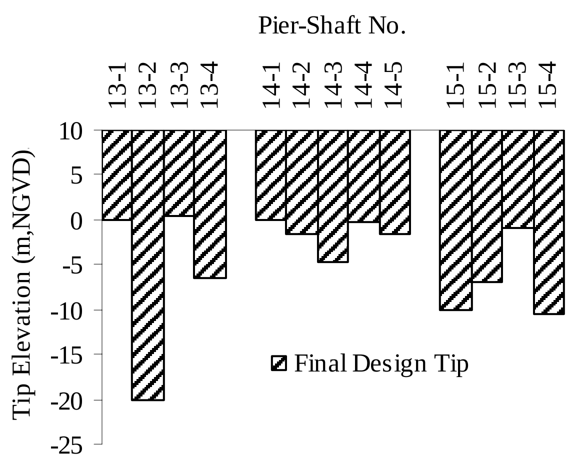

Fig. 7. Final Drilled Shaft Tip Elevations for Bridge No. 100110

Although the shaft length can be revised based on soil conditions encountered during shaft excavation, very often the contractor starts to assemble the reinforcement cage when the shaft excavation begins using the predetermined length. If the length changes significantly; then the contractor needs to assemble another reinforcement cage causing a construction delay and/or claim.

In addition, even though the type of materials could be classified from the shaft excavation, the consistency or relative density of the bearing materials could not be quantified. As encountered in the subject project, the consistency (SPT N-value) of the limerock material ranged from weight of hammer to more than 50 blows for 25mm. Therefore, by examining the material type only it was extremely difficult to impossible to estimate the shaft capacity. Thus, it was important to have a boring performed at each shaft location. However, many proposed shaft locations were not accessible during the design phase and SPT borings could only be performed during the construction phase.

It is obvious from the demonstration of this case history that a two-phase design-construction approach is essential to successful drilled shaft construction in karst environments. The first (design) phase would provide information on the design of the drilled shaft foundation layout, design capacity and establish criteria for determining production drilled shaft lengths in the second (construction) phase. During the second (construction) phase, a pilot hole boring would be performed at the exact drilled shaft location and the boring information provided to the designer to determine the final production shaft lengths. Any soft layers detected and deeper shafts were cased to prevent bridge failure. It required a great effort in coordination among the designer, CEI and Contractor to have a successful drilled shaft construction.

REFERENCES

Florida Department of Transportation [2006]. “Determination of Design Skin Friction for Drilled Shafts in the Florida Limestone”, *Soils and Foundation Handbook*, Appendix A.

McVay, M. C., Townsend, F.C., and Williams, R.C. [1992]. “Design of Socketed Drilled Shafts in Limestone.” *ASCE Journal of Geotechnical Engineering.*, 118 (10).

O’Neal, M. [1999]. “Drilled Shafts: Construction Procedures and Design Methods.” *Publication No. FHWA-IF-99-025.*

Professional Service Industries, Inc. [2001]. *”Final Geotechnical Structures Report, Engineering Services Report, I-275/I-4 Operational and Safety Interchange Modifications”*, Submitted to the Florida Department of Transportation.

Terzaghi, K. and Peck, R.B. [1967]. *“Soil Mechanics in Engineering Practice”*., 2nd Edition, John Wiley and Sons, Inc., N.Y.