Summary of Final Report, BC-353-19
March 2005

FACTORS AFFECTING ANOMALY FORMATION IN DRILLED SHAFTS

PROBLEM STATEMENT

Drilled shafts are large diameter cast-in-place concrete foundations that extend deep into the ground for up to hundreds of feet. As the form-work (typically soil) is rarely removed, the actual shape and quality of the concrete goes largely unverified. In some instances, in which the shafts have been exhumed or at least partially exposed, aberrant conditions have been found. These anomalies have been observed in the form of soil inclusions, concrete segregation, or cross-section reductions.

OBJECTIVES

The overall objectives of this study were to identify factors contributing to anomaly formation in drilled shafts and to establish the degree to which those factors affect the final quality/performance of the foundation. The project involved both laboratory and full-scale construction and testing of drilled shafts.

Laboratory testing investigated: (1) concrete flow of tremie placed concrete, (2) sand accumulation in slurry supported excavations, (3) effects of casing extraction rate, and (4) side shear development as a function of concrete slump loss.

Full-scale testing investigated: (1) effects of concrete coarse aggregate size and rebar spacing on concrete flow, (2) permeability and aggregate distribution in concrete inside and outside the reinforcing cage, (3) side shear development as a function of slump, and (4) the effect of concrete placement rate on the concrete head differential (inside and outside the cage).

FINDINGS AND CONCLUSIONS

This project initially focused on the effects of water table elevation on the integrity of drilled shaft foundations, since many anomalies found upon excavation around test shafts or for footings and their location appeared to coincide with the location of the water table. A review of construction sites where anomalies were exposed showed that anomalies could appear in all locations along the shaft length and that they were apparently caused by numerous construction-related factors. The location of the water table did not contribute to the formation of anomalies in any of the lab scale specimens in the initial lab tests. In fact, when imperfections in the finished shafts were observed, the location of these was almost always markedly different from the location of the water table during casting. Factors such as borehole cleanliness, construction (concrete placement) techniques, slump loss during the pour, slurry properties, and borehole open time seemed to be more critical. Nevertheless, the presence of a water table requires sufficient slurry head over and above the water table and cannot be dismissed as an unimportant construction issue.

It has been believed that as the concrete is being placed in a drilled shaft by a tremie, it rises in a uniform manner scouring the side walls of the borehole as its level increases. For this project, both laboratory and field test programs confirmed the fact that this does not occur. It was observed that there is a differential in the concrete level between the inner and outer portion of the reinforcement cage as the concrete flows from the tremie pipe. (Figure 8-1 helps to illustrate the difference between previously conceived flow and that observed in this project).

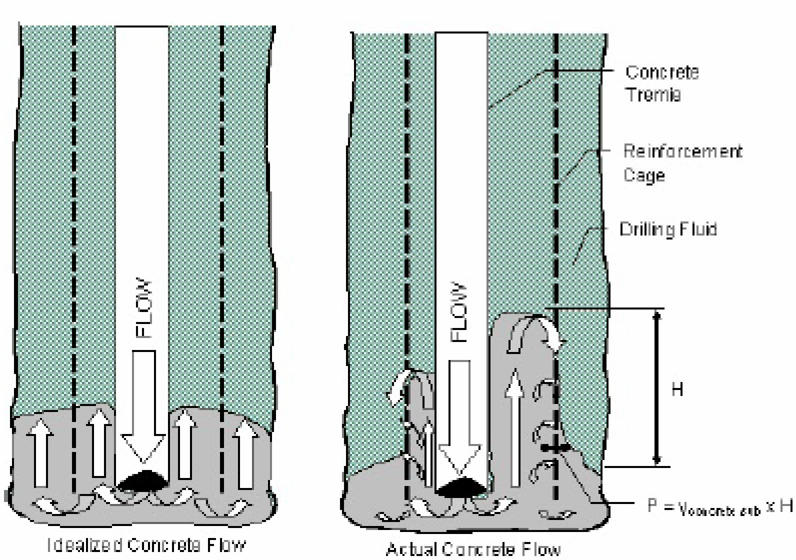

Figure 8-1. Comparison of Idealized Concrete Flow with Observed

As a result of the observed flow of concrete in the borehole, the research resulted in the identification of the following areas of concern and recommendation:

Slump Loss > 4. The side shear capacity of drilled shafts constructed with full length temporary casing are very sensitive to slump loss that occurs during construction. Although FDOT currently allows the slump of drilled shaft concrete to fall to as low as 4 inches during construction, this study showed that with a slump of less than 5 inches there was significant reduction in the mobilized skin friction of the model shafts. A 5 inch slump caused a 50% reduction, and a 4 inch slump caused a 75% reduction.

CSD > 8. Current specifications for maximum coarse aggregate sizes can lead to significant obstruction to the concrete flow through the reinforcing cage. As the size and configuration of rebar in drilled shaft cages cannot always be altered, smaller maximum aggregate diameter may be appropriate to minimize highly irregular concrete flow patterns. A recommended minimum CSD (clear spacing to maximum aggregate diameter ratio) of eight would suffice.

Slurry Sand Content < 4%. Current FDOT specifications allow as much as 4% sand by volume in the drilling slurry at the time of concreting. This study showed that large amounts of sand can be suspended in the slurry but an almost equal amount can fall out of suspension within the first 2 hours (e.g., a 60 foot excavation at 4% sand content can deposit up to 11 inches of accumulation). Once de-sanding operations have commenced, it is not unrealistic to reduce the sand content to 1% or less which is the recommendation of this study. In a related area, slurry properties during excavation are far less important with regard to sand content, provided that sufficient slurry head is maintained. Failure to maintain a stable borehole results in sloughing and a reduction in soil strength. In such cases, the anticipated design capacity is unrelated to actual capacity.

BENEFITS

Drilled shafts are highly dependent on construction techniques as well as concrete properties (both fresh and cured). The findings of this study show that several areas of the present state-of-the-art construction practice have room for improvement with regards to specifications of concrete mix design and slurry properties. The recommended revisions to present specifications will lead to higher quality assurance when addressing both load carrying capacity and concrete integrity/durability.

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