POST GROUTING DRILLED SHAFT TIPS

PROBLEM STATEMENT

In the early 1960s, efforts began to obtain more usable tip capacity of drilled shafts using pressure grouting below the shaft tip. In 1975, Gouvenot and Gabiax presented the results of a test program in which post grouting large diameter shafts led to increased ultimate load capacities of up to three times in sands and clays. Consequently, post grouting techniques became a routine construction process in many parts of the world (Bruce, 1986). The post grouting process entails (1) installation of grout pipes (during conventional cage preparation) that extend to the bottom of the shaft reinforcement cage, and (2) injection, after the concrete in the shaft has cured, of high pressure grout beneath the tip of the shaft to both densify the in-situ soil and compress any debris left by the drilling process. By essentially preloading the soil beneath the tip, end bearing capacities can be realized within the service displacement limits.

Although the capacity of conventional ungrouted shafts are bounded by the maximum contribution of end bearing and skin friction components, these values are not fully realized because of flaws introduced by full-scale construction techniques. Three mechanisms, or combinations thereof, are responsible for the excessive shaft displacement required to develop bearing capacity in sands and clays: (1) strain incompatibilities that typically exist between the end bearing and side friction components in relation to service displacement criteria, (2) disturbance of the shaft toe zone by normal construction procedures in cohesionless soils, and (3) construction methods and processes that may leave soft debris/deposits at the bottom of the excavation.

Depending on soil type and drilling method, any or all of the above mechanisms may occur at a given excavation. However, each scenario can be mitigated by a procedure, relatively unused in the United States, whereby post grouting is performed beneath the shaft tips. This grouting concept accommodates the trend toward large diameter drilled shafts due to lateral load considerations, while allowing for the end bearing component to contribute to the useful capacity of the shaft. However, no rational design procedure for post grouted drilled shafts had been published prior to this study.

OBJECTIVES

This study was conducted in two phases. The objective in **Phase I** was to conduct an experimental study to evaluate the effects of post grouting drilled shaft tips in sand on the bearing capacity. Both model-scale and full-scale tests were conducted on drilled shafts whose tips had been grouted using various grouting systems, including (1) flat jack (rubber confined), (2) sleeve port (tube-a-manchette), and (3) sleeve port systems with and without a backing plate. Post grouting was conducted at three sites with cohesionless soils: Site I, shelly sand; Site II, silty sand; and Site III, cemented coquina/sand.

In **Phase II**, the objectives included (1) reviewing construction sites where post grouted shafts may be a plausible alternative, (2) instrumenting and monitoring grout tests and load tests of grouted and ungrouted shafts, (3) developing design software for shafts with post grouted tips, and (4) updating the database of post grouted shaft performances.

FINDINGS AND CONCLUSIONS

Phase I: In the model tests, a total of twenty four 1/10 scale shaft specimens were cast and tested in a Frustum Confining Vessel (FCV). This vessel provided the means to simulate soil pressure distributions similar to those expected in the field. Comparisons were made between shafts cast without post grouting (controls) and those grouted using a flat jack type grouting cell. Improvement was found to be somewhat proportional to grout take, but more closely proportional to the maximum sustained grouting pressure.

In the full-scale tests, a total of twelve shafts were load tested at three sites in three soil types (all were intended to be cohesionless soils). At Sites I and II, 24" diameter shafts were cast in shelly sand and silty sand, respectively. At Site III, 48" diameter shafts were cast in sandy cemented coquina. Eight of the load tests were conducted on grouted shafts and four on ungrouted controls. One shaft at Site III could not be fully mobilized in side shear or end bearing after grouting; hence, the full benefit could not be ascertained. However, the findings of these tests were similar to those found in the model scale tests in that the improvement was most closely proportional to maximum sustained grouting pressure. Based on the test results, design recommendations were prepared for the use of post grouted shafts that use a grout pressure index (max sustained grout pressure / calculated bearing capacity) and the acceptable service limit displacement as expressed in percent shaft diameter (disp. / Diam.*100%). Construction, grout mix, and grouting guidelines were prepared utilizing literature values as well as those found to be successful in this study.

Phase II: Twenty five sites were reviewed for applicability to post grouted drilled shaft tips. These sites spanned seven states and involved eight state or federal agencies. In each case, boring logs were made available by either the contractor or the overseeing agency from which design curves were generated. All design curves showed both the ungrouted and the grouted capacity of drilled shafts. In many cases, multiple diameter options were requested. Predicted improvement from using post grouted rather than conventional shafts ranged from 195 to 1266% (avg. 578%) for sites with shafts tipped in sand and 3% to 91% (avg.37%) for sites with shafts tipped in clay. These improvements were determined at a permissible displacement.

The entire research project involved the instrumentation, grouting, and load testing of 8 full-scale test programs. These programs involved 26 test shafts tipped in sand, clay, and silt. Improvements ranged from 41 to 743% in various soil types and consistencies. Further, the response of 174 production shafts were recorded via field survey notes and reviewed for quality assurance. The satisfactory performance of every post grouted shaft was thereby verified.

Researchers developed software (*Shaft 1-2-3*) capable of predicting the capacity of conventional and post grouted shafts. The software uses the correlations developed in Phase I to determine the post grouted end bearing. Those correlations were subsequently updated with new data sets obtained during Phase II. The software provides several methods for determining side shear and conventional end bearing capacity. All predicted capacity values (grouted and ungrouted) are displacement dependent and not ultimate.

BENEFITS

The primary benefit of this research is the development of a rational design approach that makes use of the substantial end bearing improvement available when drilled shaft tips are post grouted. Several sites reviewed and tested during Phase II completed the construction of all production shafts where both grout pressure and shaft uplift were recorded. This information provided a cost-effective form of capacity verification/quality assurance unmatched by other QA/QC methods. The full benefit of 100% verification will have far reaching effects with regards to the Load and Resistance Factor Design (LRFD) approach for drilled shafts. Thereby, an increased resistance factor is likely to be afforded to future designs.

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