3-8 TIP POST-GROUTING OF DRILLED SHAFTS

Introduction

Tip post-grouting (also known as base-grouting) is a new technology that has been developed to increase tip resistance of the drilled shafts. This memo concentrates on limitations of application of this technique in Caltrans' projects. Limitations of post-grouting such as necessity of conducting pile load tests and limited contribution of tip resistance require a project-by-project value analysis on cost-effectiveness of tip post-grouting.

The tip post-grouting process utilizes a grout pump capable of supplying necessary pressure to deliver grout to the bottom of the shaft through a grout delivery system consisting of PVC or steel pipes similar to pipes used for Gamma-Gamma-Logging (GGL) and Cross-hole Sonic Logging (CSL) tests. Post-grouting is performed after completion of structural integrity testing (GGL and/or CSL) of concrete and the grout is distributed through a grouting device attached to the bottom of reinforcement cage. Different types of grouting devices have been used by industry or researchers and some have been classified as proprietary systems. A gravel bed may be placed below the grouting device to level the bottom of shaft particularly when the bottom is excavated with a hammer grab that may be used to extract strata within the drill casing. In most projects the Osterberg Cell (O-cell) test has accompanied the post-grouting process to verify axial geotechnical capacity of the shaft.

Advantages of Tip Post-grouting

The main benefit of tip post-grouting in drilled shafts is reduction of short-term settlement required to mobilize the end-bearing resistance. A reduced settlement means that the nominal geotechnical tip resistance of the shaft corresponding to a pre-defined acceptable settlement (Δ) as shown in Figure-1, increases. The solid-line curve shows force-displacement curve for the shaft without any post-grouting. The broken-line curve is the force-displacement curve for post-grouted shaft and shows stiffening of the soil at tip of the shaft due to post-grouting. For a certain displacement such as Δ, the tip resistance developed in post-grouted shaft is significantly higher than un-grouted shaft.

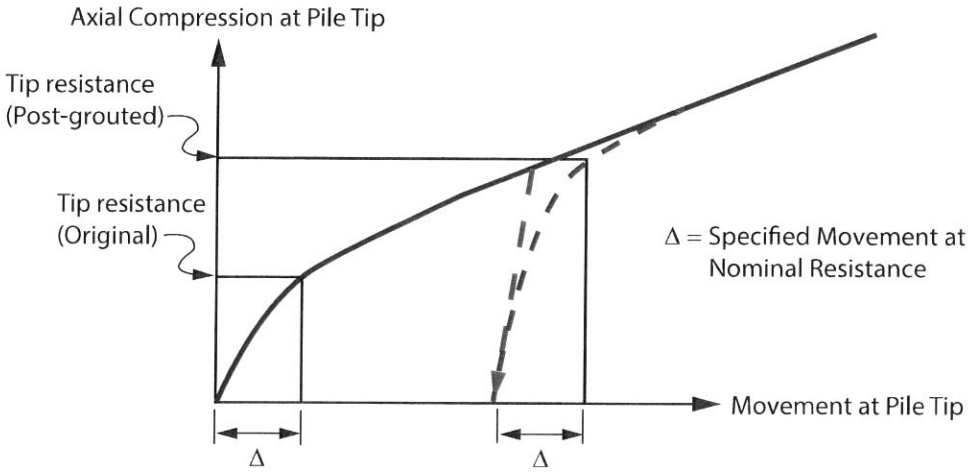

Figure 1 – Effect of post-grouting on shaft resistance

Post-grouting can also result in ground-improvements through permeation of grout into the soil and enlargement of the shaft cross section at the tip, both improving the geotechnical capacity in compression. Application of tip post-grouting has been mostly limited to shafts tipped into granular soil.

If properly used, tip grouting can decrease short-term or immediate settlements of the shaft under service load, and provide higher confidence in the tip nominal resistance estimated based on the static calculation method in the *AASHTO LRFD Bridge Design Specifications* and *California Amendments (AASHTO-CA LRFD BDS)* for un-grouted shafts. In general, the designer can count on nominal tip resistance of any shaft, using resistance factor of 0.5 as specified in the *AASHTO-CA LRFD BDS*. However lack of information on quality of concrete at the tip especially for piles constructed using the wet construction method, and large displacements needed to mobilize the tip resistance have discouraged designers from taking advantage of end bearing in un-grouted shafts.

Design and Verification Parameters

It is believed that maximum anticipated grout pressure, volume of the grout, and actual movement at the pile cut-off point are indicators of the increase in the shaft tip resistance. Survey levels and other equipment record upward movement of the shaft. Water-to-cement (WC) ratio of the grout has been also reported as a parameter that can be altered within certain limits during construction to facilitate the grouting process. Researchers have also attached strain gauges to the lower portion of the reinforcement cage to monitor stresses during post-grouting. Test pile(s) are required to validate application of the technique for a specific location. The number of test piles depends on geotechnical variations of the site and will be discussed in the type selection meeting.

Constraints and Required Improvements

Considering the variety in grouting devices used in the past, selection of the grouting device can be challenging (some devices may be proprietary). The device must be readily available and its performance must be consistent. Furthermore, an accepted design procedure is needed to estimate the nominal tip (end) resistance of the grouted shaft. Most current methods use a multiplier to relate the nominal resistance of a certain size grouted shaft to the nominal resistance of the un-grouted shaft of the same size. Given an adequate number of data points for geotechnical resistance of post-grouted shafts, a resistance factor can be calibrated in compliance with LRFD methodology.

Construction QC & QA must be attentive to the following construction-related items, some of which may need further investigation and/or improvement:

- Acceptable grout pressure has been reported as 400-600 psi. With higher grout pressures the risk of leakage or clogging of the grouting system increases. Although the relationship of grout pressure, grout volume, and cut-off movement may vary from project-to-project, any turbulence in the trend of the pressure plot may be an indicator of a flaw. In general, the pressure must be stable and reasonable.
- Although grout pressure is an indicator of the load, there is no direct correlation between grout pressure and load. The load depends on the area of the shaft at the tip-and that is unknown.
- Volume of the grout can be an indicator of side resistance mobilization and/or penetration of the grout into the side of the shaft.
- Upward movement of the shaft at its cut-off point should be limited to 1/8 to 1/4 of an inch. For shafts with high side resistance, displacement may be negligible. However, for shafts with limited side resistance, the shaft may reach the displacement limit before minimum grout pressure is reached. Movement in the excess of 0.5 in. is discouraged.
- A typical water-to-cement ratio (W/C) of 0.4-0.55 (by weight) for grout has been recommended. During construction, the ratio may be altered to control the grouting process.
- Redundancy in the grouting system has been highly recommended to avoid delays due to clogging or breakage of the system.
- Staged grouting has been used within a specific time limit for following reasons:
  - Grout pressure is not reached during initial grouting.
  - Soil is different compared to the geological information used in design.
  - Problems (clogging/breakage) that may happen in grouting equipment.
- The secondary grouting is used as a remedy or it may be used to produce higher grout pressure. The time interval between stages of grouting will allow the initial grout to cure,

- Submittals for the entire process of post grouting are required and need to address:
  - Grout materials
  - Delivery system components
  - Measurement and verification system components
  - Construction process
  - QA measures
  - Qualification and experience required for grouting personnel and inspector

Limitations for Use of Tip Post-grouting in Caltrans' Projects

As a new technology, there is not an adequate performance record for tip grouting. Transportation agencies have developed their own construction specifications to enforce required quality measures, however there are no formal AASHTO or FHWA design and construction specifications for post-grouting. Considering the above, application of tip grouting to foundation systems with low redundancy may be risky with adverse effects to cost and schedule of projects. Therefore, application of tip post-grouting is not permitted for systems with low redundancy including Types I and II shafts, pile groups supporting single column bents, and pile extensions. Tip post-grouting may be used for high-redundancy systems on a case-by-case basis and at the discretion of the geotechnical designer, however application of the technique together with any performance criteria (such as load testing) must be discussed and approved at the type selection meeting.

Application of tip post-grouting to redundant foundation systems together with future research will pave the way for further application, development of in-house design procedures, and development of construction specifications. The limitations set herein for application of post-grouting will be eliminated upon development and release of peer-reviewed design and construction specifications. Constraints listed in this document will be discussed and addressed during development of such specifications and before full implementation of the technique.

References

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