DRISI
Caltrans Division of Research, Innovation and System Information

Research Results

Seismic: Reliable Post Grouting Techniques to Improve Shaft End-Bearing

Design methods and QA/QC procedures to improve the reliability of post grouting techniques

Geotechnical/ Structures

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Project Title:
Deployment of Post Grouting Techniques to Improve Drilled Shaft End-Bearing Resistance

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WHAT WAS THE NEED?

Post-grouting of drilled shafts has been shown to increase the capacity and stiffness of drilled shafts, resulting in substantial cost savings. The technology has failed to gain widespread acceptance in the U.S., however, due to questions of reliability, current design procedures were empirically based on a small number of projects. The relative contribution of various improvement mechanisms was unknown.

Caltrans needed a theoretical framework from which to assess potential improvement mechanisms. This framework should also include use of various measurements that are either routinely collected during post grouting operations or could be in the future. These measurements could then be used to verify performance of post-grouted drilled shafts (PGDS) and improve reliability. Ultimately, guidance on PGDS construction practice and the use of various instrumentation methods was needed.

WHAT WAS OUR GOAL?

The goal of this research was to develop design and construction guidance for PGDS, including detailed quality assurance/ quality control (QA/QC) procedures that include use of in-shaft instrumentation. Guidance should include detailed recommendations on use of instrumentation, interpretation of results, and acceptance criteria. Design guidance should also include load and resistance factors design (LRFD) for PGDS. Project objectives were extended to include evaluation of new thermal profiling techniques for assessing shaft integrity.

WHAT DID WE DO?

A large field-testing program was initiated at a test site 30 miles north of Sacramento. This program included the construction of 4 three-foot diameter test shafts and 9 five-foot diameter reaction shafts, each about 40-feet in length. All but the control shaft was post grouted using one of three methods: (1) Sleeve-port system, (2) Flat jack, and (3) RIM Cell. All shafts were extensively instrumented using vibrating-wire strain gauges and continuous profile fiber-optic strain measurements. Following post-grouting each test shaft was load-tested using a traditional reaction frame and hydraulic jacks.

To assess the effectiveness of thermal profiling methods several shafts included sand bags to mimic defects in the concrete. These shafts included multiple temperature wires connected to automated data loggers. Temperature measurements were also made using continuous fiber optic cabling.

WHAT WAS THE OUTCOME?

The field test was one of the first cases where drill shafts were instrumented to measure strain during the post-grouting process. Prior grouting efforts assumed that the grout pressure, measured at the surface, fully loaded the base of the shaft (i.e. the grout acted as a fluid). The field tests showed conclusively that in the case of the sleeve-port system and the flat-jack system that once the grout reached a pressure of approximately 250 to 350 psi it ceased to act as a fluid. Higher grout pressures were not fully transferred to the base of the shaft.

This was an important finding since the normal assumption of fluid behavior could substantially overestimate shaft preloading. In the case of the RIM Cell results were difficult to interpret because the grout pump was too large for the relatively small RIM Cell. Results did suggest that the RIM Cell was more effective at transferring the grout pressure to the shaft. Overall, the field-grouting indicated that instrumenting the shaft for strain is critical for QA. Without these measurements there is no way to be sure that the preloading of the shaft tip assumed for design is in fact actually reach the shaft.

Following the field-testing an LRFD-based design framework was developed for post-grouting. The framework considers post-grouting as a partial O-Cell type load test that establishes minimum levels of side and tip resistance. Depending on the level of load transferred to the shaft base during grouting, higher resistance factors can be used for design.

Finally, thermal analysis methods to identify defects were evaluated against cross-hole sonic and gamma-gamma logging methods. All methods struggled to identify the position of the sand bags unless positioned directly next to an inspection pipe. The volume of the sand bags was too small to have a significant effect on the local heat of hydration. Overall, gamma-gamma logging was most accurate in the outer reinforced region of the shaft.

WHAT IS THE BENEFIT?

The guidance recommendations resulting from this project address the advantages and disadvantages of different grout distribution systems, necessary instrumentation to ensure preloading of the tip, grout mix design, and QA/QC procedures. Importantly, the recommendations include a practical design procedure that is compatible with current American Association of State Highway and Transportation Officials (AASHTO) LRFD drilled shaft design procedures.

This guidance should enable Department of Transportation's to allow design and construction of post-grouted shafts when appropriate. In many instances post-grouting will result in more cost effective shaft designs while maintaining the reliability goals recommended by AASHTO.

IMAGES

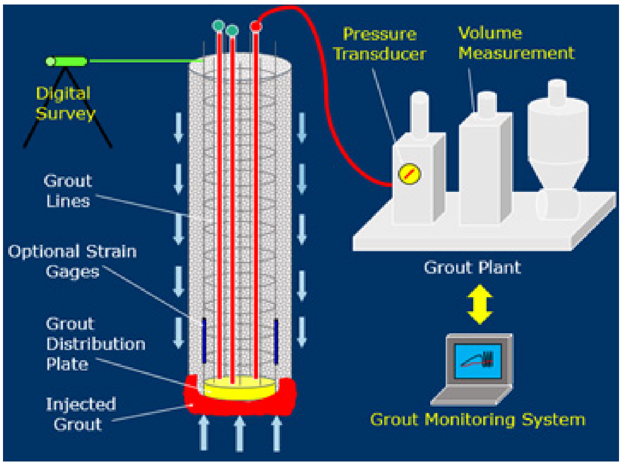

Image 1: 2015 FHWA PGDS workshop presentation, Oakland CA. Source: Mike Muchard (Applied Foundation Testing)

Image 2: RIM Cell test shaft

Image 3: Sleeve-port system

Image 4: TIP wires for thermal measurement

Image 5: Drilled shaft construction