DRISI
Caltrans Division of Research, Innovation and System Information

Research Results

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

Fiber optic instrumentation of post grouted shafts to improve reliability

Geotechnical/ Structures

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Project Title:
Post Grouting to Enhance the Capacity of Foundations

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Task Manager:
Anhdan Le
Senior Research Engineer
anhdan.le@dot.ca.gov

WHAT WAS THE NEED?

A major impediment to the use of post-grouted drilled shafts has been the inability to verify the quality of the post-grouted tip and the added capacity the grouting is supposed to provide. Since use of post-grouting can result in significant cost savings, developing design guidance and suitable quality assurance protocols has been a research priority.

Task 2865 – Seismic: Reliable Post Grouting Techniques to Improve Shaft End-Bearing, was created to develop design guidelines and specifications for post –grouting. Task 2865 focused on issues of grout delivery, grout mix design, and use of various field measurements such as grout pressure and volume to infer capacity improvement.

This study addressed the need for strain measurements in the near-tip region of the shaft to quantify preloading caused by post-grouting. The primary focus was the use of fiber-optic sensing to make distributed strain measurements along the entire length of the shaft.

WHAT WAS OUR GOAL?

The goal was to evaluate distributed fiber-optic based strain measurements as a method to quantify the transfer of load caused by grout pressure into the grouted shaft. This same method was also evaluated as a means to measure shaft temperature. Regions of low shaft temperature during curing can indicate poor concrete or voids.

WHAT DID WE DO?

A research project with University of California, Berkeley was initiated that focused on the trial application of distributed strain sensing using fiber optic methods. This technique was applied to four test shafts and nine reaction shafts that were post grouted and load-tested under Task 2865. Temperature measurements were also collected in each shaft.

Strain measurements were compared with point measurements made using vibrating wire strain gauges. Fiber-optic cable installation methods and requirements, cable splicing, and use fiber-optic interrogators were evaluated. Finally, lab based measurements were used to investigate how changing strain during sampling periods affects strain estimates.

WHAT WAS THE OUTCOME?

All four test shafts and nine reaction shafts were successfully instrumented for strain using fiber-optic cables. To facilitate strain measurement using the interrogator device, each shaft relied on a single fiber-optic cable that extended down one side of the shaft (zip-tied to the rebar cage), looped around the base, extended upward on the opposite side, looped at the top, and then repeated again but shifted clockwise 90 degrees. Thus, each shaft had four lines of continuous strain measurements positioned at 12, 3, 6, and 9 o'clock.

Unlike conventional strain gauges that can be read instantaneously, the distributed fiber-optic method requires an extended period of sampling. The research team found that best results were achieved using sampling periods of about 5 minutes. The need for sampling is an important consideration when evaluating the suitability of distributed fiber-optic strain sensing. If strain is expected to vary significantly during the sampling period, distributed fiber-optic strain sensing will be unable to accurately resolve the strain.

In the field-testing, the researcher found that during the post-grouting process, comparisons between distributed fiber-optic strain sensing and conventional strain gauges were difficult since the grout loads had large variation during the 5-minute sampling intervals. On load-tested shafts, load levels were mostly constant during sampling periods. In this case there was excellent agreement between point measurements using vibrating wire strain gauges and distributed fiber-optic measurements.

Following the field-testing program additional fiber-optic strain measurements were taken in the lab to investigate the impact of variable strain during the sampling period. It was found that the reported strain was somewhat random since the interrogator performs a sequential frequency sweep during the sampling process looking for the best frequency. The reported strain will correspond to the strain level that occurred during the sampling at the best frequency.

WHAT IS THE BENEFIT?

This project investigated the benefits as well as the challenges of employing distributed fiber-optic sensing to estimate strain during post-grouting or during a load-test. The advantages are substantial: with a single fiber-optic cable, strain can be measured along the entire length of the shaft, and by looping the cable through the shaft several times, these measurements can be made at several locations.

Installation of the cabling was not difficult but splicing fiber-optic cables in the field requires patience. Fiber-optic cable costs are modest at about $5/ft. The primary disadvantage of distributed fiber-optic sensing is the relatively long sampling period. In some circumstances this can delay construction operations.

If strain varies during the sampling period, the reported strain will fall, somewhat randomly, between the minimum and maximum strain during the sampling period. Currently, interrogator devices are expensive (over $100k) but the prices are expected to fall in the near future. Furthermore, interrogators with much faster sampling are under development. Though these devices will sacrifice resolution to achieve the shorter sampling period, the impact for most civil applications will be small.

IMAGES

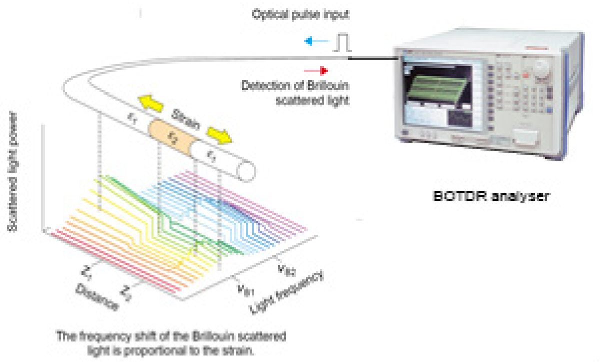

Image 1: Fiber optic strain measurement

Image 2: Fiber-optic interrogator (on right). Conventional strain gauge cabling in gray (1 cable per strain-gauge.)