Your CSL Results Are In – WHAT TO DO NEXT

(ADAPTED BY GINA BEIM FROM WEBSTER ET AL., PILE AND SHAFT INTEGRITY TEST RESULTS, CLASSIFICATION, ACCEPTANCE AND/OR REJECTION, TRB 2011 ANNUAL MEETING)

The concrete quality of concrete shafts is frequently as much of concern as their geotechnical quality. Geotechnical quality is generally assessed by load testing of test shafts, assumed to have been installed in representative soil layers and with construction methods identical to production ones. However, each production shaft is unique, and its quality may need to be evaluated by code or to follow best practices. Several methods exist to evaluate the structural integrity of a shaft after the concrete has hardened. The commonly employed Cross-Hole Sonic Logging (CSL, ASTM 6760-08) requires sending out a high-frequency pulse in one inspection tube and measuring its arrival time in a neighbouring tube (Figure 1). If the wave arrives later than expected, or if it is of significantly-reduced signal strength, then concrete located between the tubes is assessed as lower quality. The inspection tubes are usually mounted inside and along the reinforcement cage and, therefore, generally do not give information about a defect in the concrete cover. However, defects such as major soil inclusions in the concrete, such as "soft toes" (concrete/mud mixture) or conical pile toes can be easily detected.

Figure 1 – CSL: Inserting probe into inspection tube.

At first sight, CSL data interpretation is very simple. Strongly reduced signal strength and/or a late signal First Arrival Time (FAT) in the majority of profiles at the same depth suggest defective concrete (Table 1). However, before accepting, repairing, rejecting, or further testing the shaft a more thorough analysis of the data is required.

Category	FAT Increase	AND/OR	Signal Reduction	Comment
G	Up to 10%	AND	<6 db	Good
Q	10 to 20%	AND	<9 db	Questionable
P/F	21 to 30%	OR	9 to 12 db	Poor/Flaw
P/D	>30%	OR	>12 db	Poor/Defect

Table 1: Shaft Classification based on CSL results.

The magnitude and extent of an FAT increase or a Signal Energy reduction over the cross section has to be assessed, as well as the cross section location: shafts with only good and questionable cross sections require no further action. If a shaft has been designed without consideration of end bearing (as a pure friction pile) then a flaw or defect near the bottom of the pile can be ignored. In a shaft with four inspection tubes, a FAT reduction in only one diagonal affects a small portion of the cross section and, even if of the P/D type, requires no further investigation. Flaws should be addressed if they are indicated in more than 50 per cent of the profiles and defects must be addressed if they are indicated in more than one profile.

Addressing a flaw or defect should include, at a minimum, an evaluation by tomography (a 3-D assessment of the whole shaft, Figure 2) to more precisely localize and quantify the area of concern prior to resorting to retesting after further concrete hardening, excavation, or core drilling with pressure grouting.

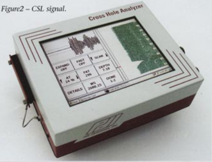

Figure2 – CSL signal.

All photos courtesy of Pile Dynamics, Inc.

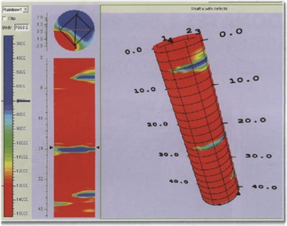

Figure 3 – Tomography analysis.

Defects indicated over the entire cross section usually require repair or shaft replacement but depending on the location of the problem area, a reduced capacity may also be considered. Most likely, a flawed or defective shaft will be repaired after core drilling (which would verify the CSL findings), washing out the defective zone and then pressure grouting it. Following that, or if a reduced capacity is an acceptable solution, a dynamic load test may be performed to not only evaluate the geotechnical capacity, but also the structural strength of the shaft. In the spirit of the Load Resistance Factor Design (LRFD) design approach, it may be sufficient to subject the test shafts to a load lower than what the normal factor of safety would require, as long as all questionable shafts are load tested and one or more properly constructed ones is tested for comparison.

GRL engineers recount a situation in which CSL results for a 10-metre-long shaft indicated an apparent flaw at the toe. The 1,070 millimetre diameter-cased shaft section extended to a depth of approximately 3.4 metres with approximately 2.1 metres drilled into rock. Below this, the shaft diameter decreased to 900 millimetres with 3.7 metres through rock and then 2.9 metres into a silt layer. The apparent flaw was indicated in all six CSL profiles by FAT delays above 20 per cent (P/F) and extended over 0.3 metres of the shaft bottom. Before a decision was reached, dynamic load testing with a Pile Driving Analyzer® was performed to determine the bearing capacity of the shaft. The test required constructing an extension above the top of the shaft and using a 15 ton ram (approximately two per cent of the required ultimate – or nominal – resistance) with guiding frame to apply dynamic loads of various energy levels to the shaft. A total of six impacts were applied with drop heights ranging from 300 to 110 millimetres. The total set of the shaft after the six impacts was approximately three millimetres; the average set per blow was quite small. As in any Dynamic Load Test, force and velocity records were obtained, and test data was evaluated by modeling the actual shaft dimensions and performing CAPWAP® analysis. The analysis indicated mobilized capacities between 5800 to 6800 kN for the higher drop heights. These results were considered sufficient evidence that the shaft met the ultimate load requirement of 6600 kN. In this case, therefore, all was well and no further mitigation was required. ■

Figure 4 – APPLE (red ram) and Pile Driving Analyzer (blue and white instrument) used in dynamic load testing.