CASE HISTORY: COMPARISON OF CSL RESULTS TO PHYSICAL OBSERVATIONS

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ABSTRACT

Crosshole Sonic Logging (CSL) non-destructive integrity testing identified anomalous readings near the base of a 6.5-foot diameter drilled shaft rock socket. The anomaly was confirmed to be a defect by subsequent coring and core hole camera inspection. A large void and exposed rebar were visually observed in one of the core hole camera inspections. The center of the shaft was then excavated initially with 3-foot diameter tooling and subsequently with 4-foot diameter tooling as part of the remedial actions to address the defect. While excavating with 3-foot diameter tooling, the shaft defect was not encountered. Excavation with 4-foot diameter tooling revealed the defect, a significant void around the majority of the shaft circumference. The void extended radially from the circumference of the 4-foot diameter excavation to beyond the reinforcement cage to the exposed wall of the rock socket around approximately 80 percent of the shaft circumference. CSL results and observations made during remedial shaft investigation and excavation are in good agreement. The shaft defect, located primarily outside of the reinforcement cage, was effectively identified by CSL testing. Although the defect was confirmed by investigative coring, the remedial excavation demonstrates how the investigative coring could have easily missed the defect. This paper shows how CSL results compare to physical observations made during a rare opportunity to characterize the full extent and nature of a drilled shaft defect originally identified as an anomaly by CSL testing.

Keywords: CSL, Anomaly, Core, Integrity, Remediation, Tremie, Drilled Shaft

INTRODUCTION

The case history presented here pertains to a drilled shaft for a multi-shaft bridge pier in the Midwestern United States. However, the observations presented in this paper are not a result of unique site conditions or the particulars of the project. The lessons learned from this case history are applicable to almost any drilled shaft constructed in the wet.

The overall length of the subject shaft is 22 feet including approximately 12 feet of permanently cased, 7-foot diameter shaft extending to bedrock and approximately 10 feet of uncased, 6.5-foot diameter rock socket. The shaft is designed to resist axial and lateral loads and considers the contributions of side and base resistance in the axial design. Six, 2-inch diameter steel Crosshole Sonic Logging (CSL) tubes are include in the shaft. The bedrock at the shaft location includes beds of sandstone, shale, and limestone. The shaft was drilled using conventional drilling equipment and tooling, and water was used as the drilling fluid. Conventional drilled shaft concrete appropriate for underwater tremie-placement was placed via a 10-inch diameter open hopper tremie.

CSL non-destructive integrity testing identified significant anomalous readings in the approximately bottom 4 feet of the rock socket. 13 of 15 CSL tube combinations tested indicated first arrival time (FAT) delays between 14 and 60 percent and energy reductions between 9.5 and 14.7 dB. An example of the CSL results is included in Figure 1. Tomography analysis of the CSL data was not performed at the discretion of the drilled shaft contractor.

Three core holes were advanced within the interior of the reinforcement cage to further investigate the anomaly. It was not practically possible to perform core drilling outside of the reinforcement cage. The core hole locations were selected by the drilled shaft contractor. Cores 1 and 2 were located with the intent of intercepting the most anomalous readings encountered in the CSL. Core 3 was located on the opposite side of the shaft and was intended to intercept the least anomalous readings encountered in the CSL. The core locations are shown in Figure 2. Cores 1 and 2 confirmed a defect in the anomalous zone in the form of little to no drilling resistance, no concrete recovery, and recovery of sand. Core 3 did not encounter the defect. A submersible camera was inserted in Cores 1 and 2. Sand was observed in the bottom of Core 2. A significant void and exposed reinforcement were observed in Core 1. A screenshot from the Core 1 camera inspection video is included in Figure 3.

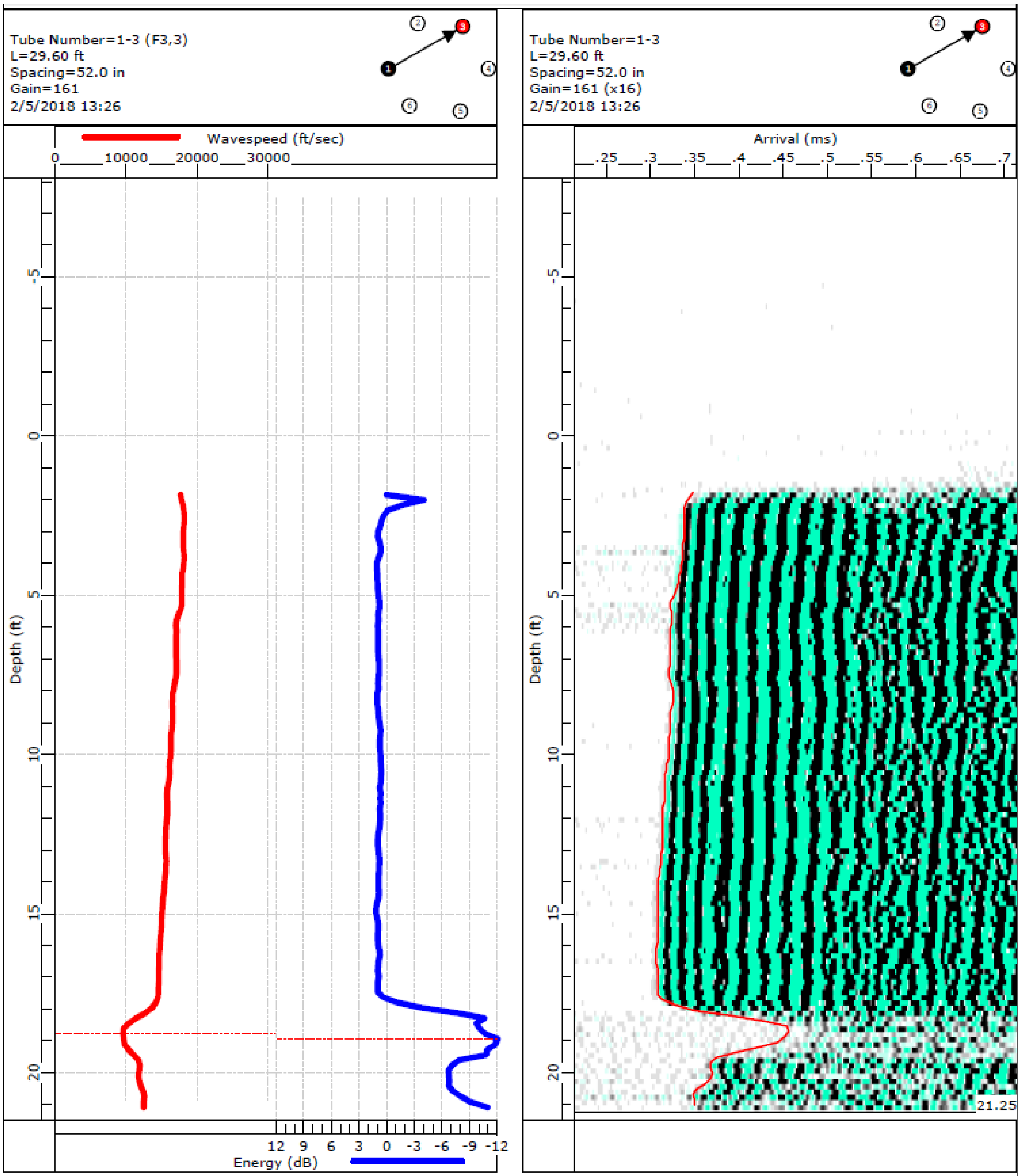

Figure 1. Example of typical CSL results.

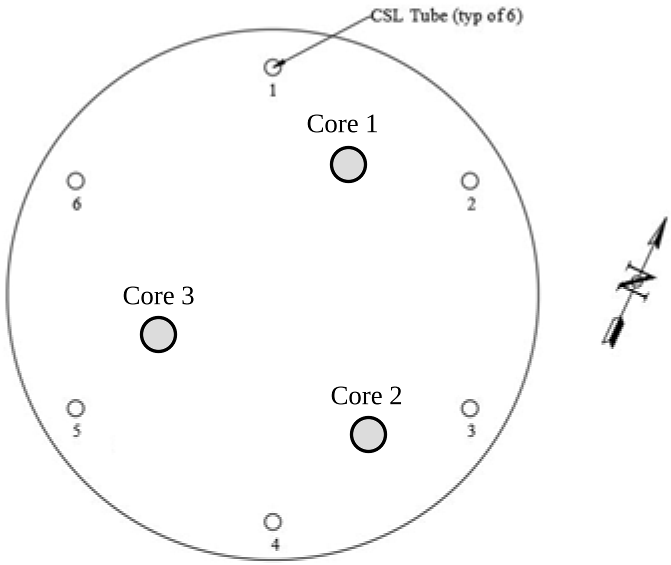

Figure 2. Core and CSL tube locations.

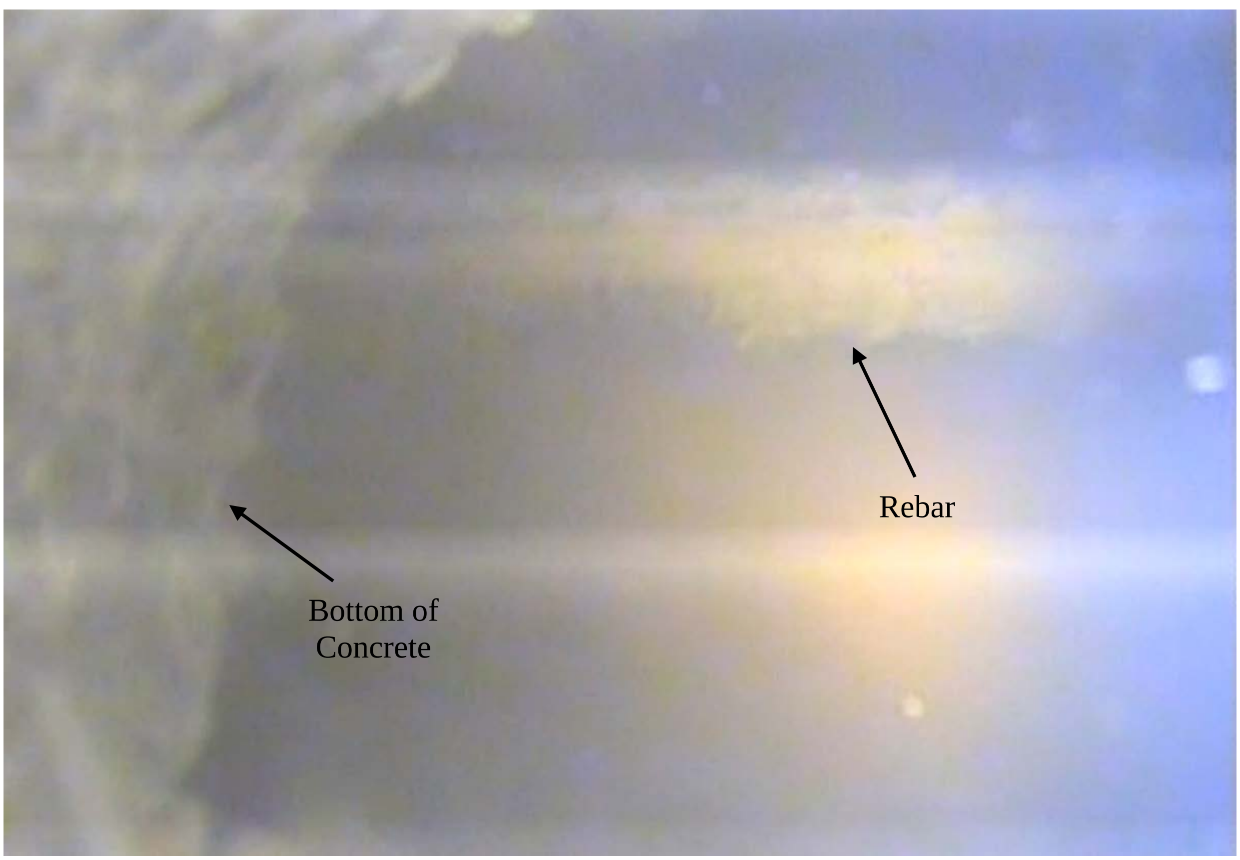

Figure 3. Screenshot from Core 1 camera inspection.

REMEDIAL ACTIONS

An observational method approach was employed during remediation of the shaft. The approach included excavating the center of the shaft to the depth of the anomalous zone and assessing the extent and nature of the defect. In addition to observations of the actual drilling behavior, assessment was to be made on a visual basis either directly under dry conditions or indirect by camera under wet conditions. Remedial actions were then to be determined based on the visual observations.

Initially, the center of the shaft was excavated using 3-foot diameter tooling. The hole was advanced to approximately 2 feet above the shaft tip. The hole was advanced in the dry through the upper approximately 12 feet of concrete. Then, the hole was flooded with water and advanced in the wet to prevent sudden hydraulic infiltration upon encountering the anticipated defect. After reaching the target depth, the hole was slowly dewatered in stages to check for hydraulic infiltration. No significant infiltration was observed and the hole was eventually fully dewatered, allowing for direct visual inspection. No defect was observed. A photograph of the dewatered 3-foot diameter hole is included in Figure 4. Note that there was some water seeping out of Core 1 just outside of the 3-ft diameter hole, as can be seen in Figure 4.

The 3-foot diameter hole was then enlarged using 4-foot diameter tooling in the dry. Upon completion of the diameter expansion, approximately 1.5 foot of water was present in the hole and the top of a void was visible around the circumference of the hole from approximately the 11 o'clock position to the 6 o'clock position, where CSL Tube 1 is the 12 o'clock position (Figure 5). The hole was dewatered as much as possible and visually inspected with a camera (Figure 6). On the basis of the visual observations, pieces of concrete of unknown quality were trapped between the reinforcement cage and wall of the rock socket. Vertically, the top of the void was approximately 4.1 feet above the base of the socket.

To remediate the shaft, a 30.5-foot long, 4-foot diameter socket was extended below the tip of the existing shaft. The new socket replaced the axial side and base resistance provided by the bottom 5-feet of existing 6.5-foot diameter socket, which was neglected for remedial design. The remedial socket included a reinforcing cage with 4 CSL tubes designed by the project's structural designer. The remedial socket was drilled and poured using typical procedures for the project's drilled shafts.

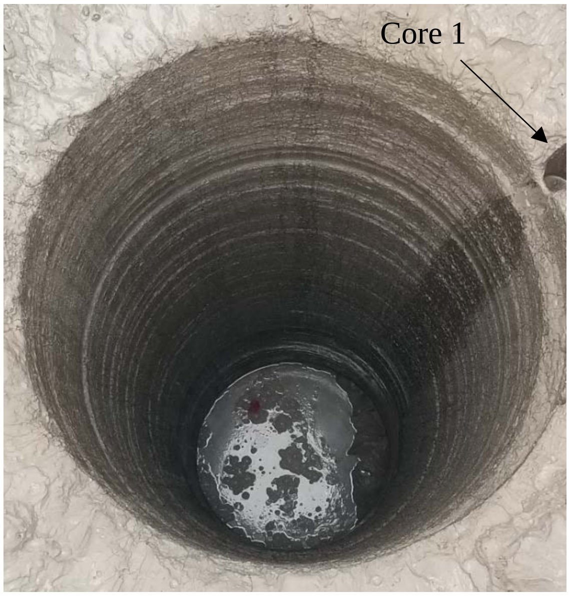

Figure 4. 3-ft diameter excavation.

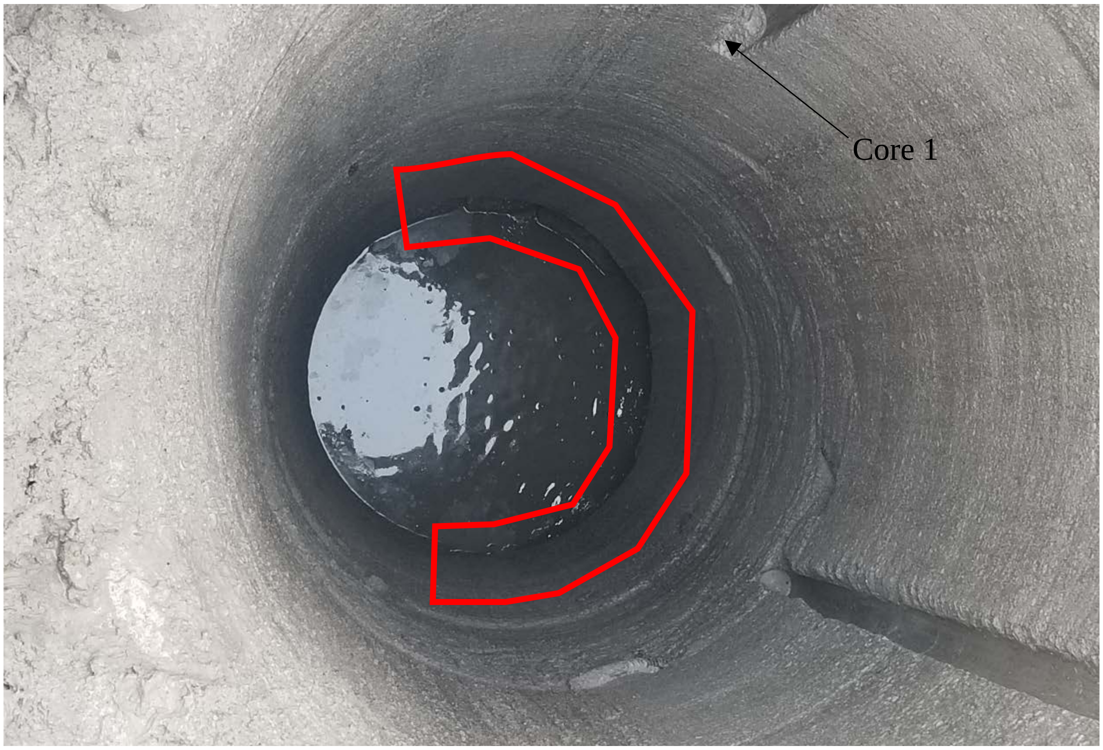

Figure 5. 4-ft diameter excavation, visible void outlined in red.

Figure 6. Camera inspection of side wall, exposed rebar visible.

DISCUSSION

Good agreement exists between the void observed in the 4-foot diameter excavation and the CSL results. This is shown in Figure 7 by comparing the maximum FAT delays between tube pairs and the observed void from Figure 5 super-imposed on the CSL results. Note that from the physical observations, the defect is primarily around outside of the shaft, as the 3-foot diameter excavation did not encounter the defect. Despite the defect being in the zone where CSL is often considered ineffective, CSL successfully detected the defect in this case. Although the results well match the physical observations, it was difficult to predict the nature and extent of the defect from CSL alone. Possibly, tomography analysis of the CSL data would have provided a better prediction of the extent and location of the defect. From the perspective of the drilling contractor, tomography analysis was unlikely to result in reduced remedial cost and was therefore not performed.

Cores 1 and 2 encountered the defect, while Core 3 did not, which also matches well to the physical observations. Had Cores 1 and 2 been performed slightly more towards the center of the shaft, it is unlikely the defect would not have been encountered by any of the cores.

The defect is believed to be the result of either a significant amount of loose material at the base at the onset of concrete placement or mixing of the first load of concrete with water in the shaft. There is no indication in the construction records as to the cause of the defect; however, the location of the defect around the outside of the shaft near the base suggests an issue at the onset of concrete placement based on documented fluid concrete flow patterns (Böhle and Pulsfort 2014 and Brown, Bailey, and Schindler 2005) and numerical modeling of concrete flow (Beckhaus et al 2018). The brown colored (1st batch) concrete in Figure 8 from Böhle and Pulsfort (2014) illustrates this point.

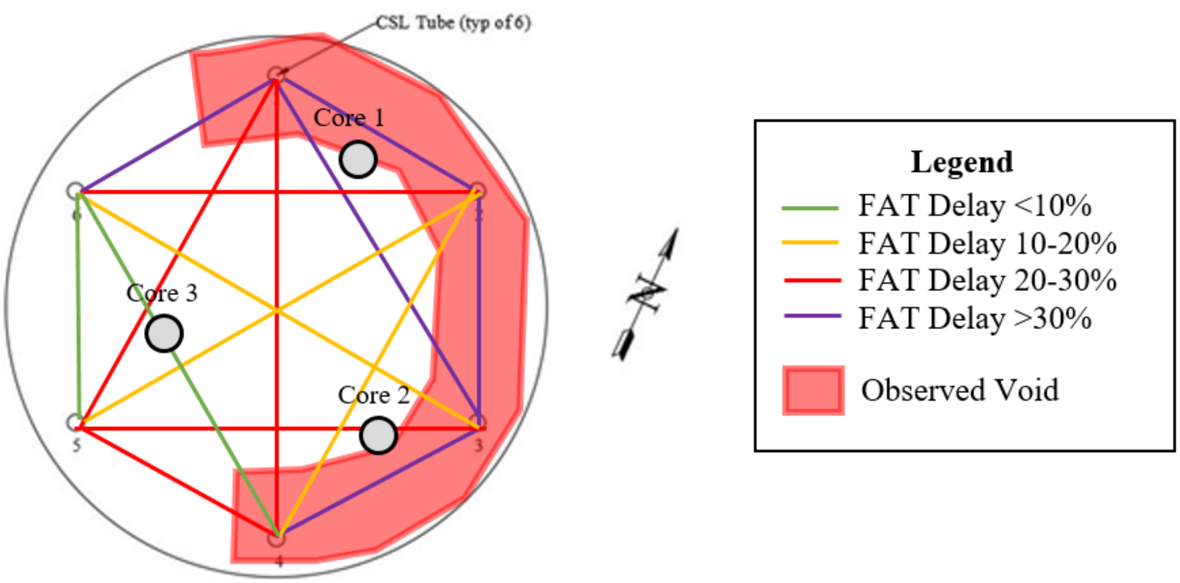

Figure 7. FAT delays with overlay of observed void from Figure 5.

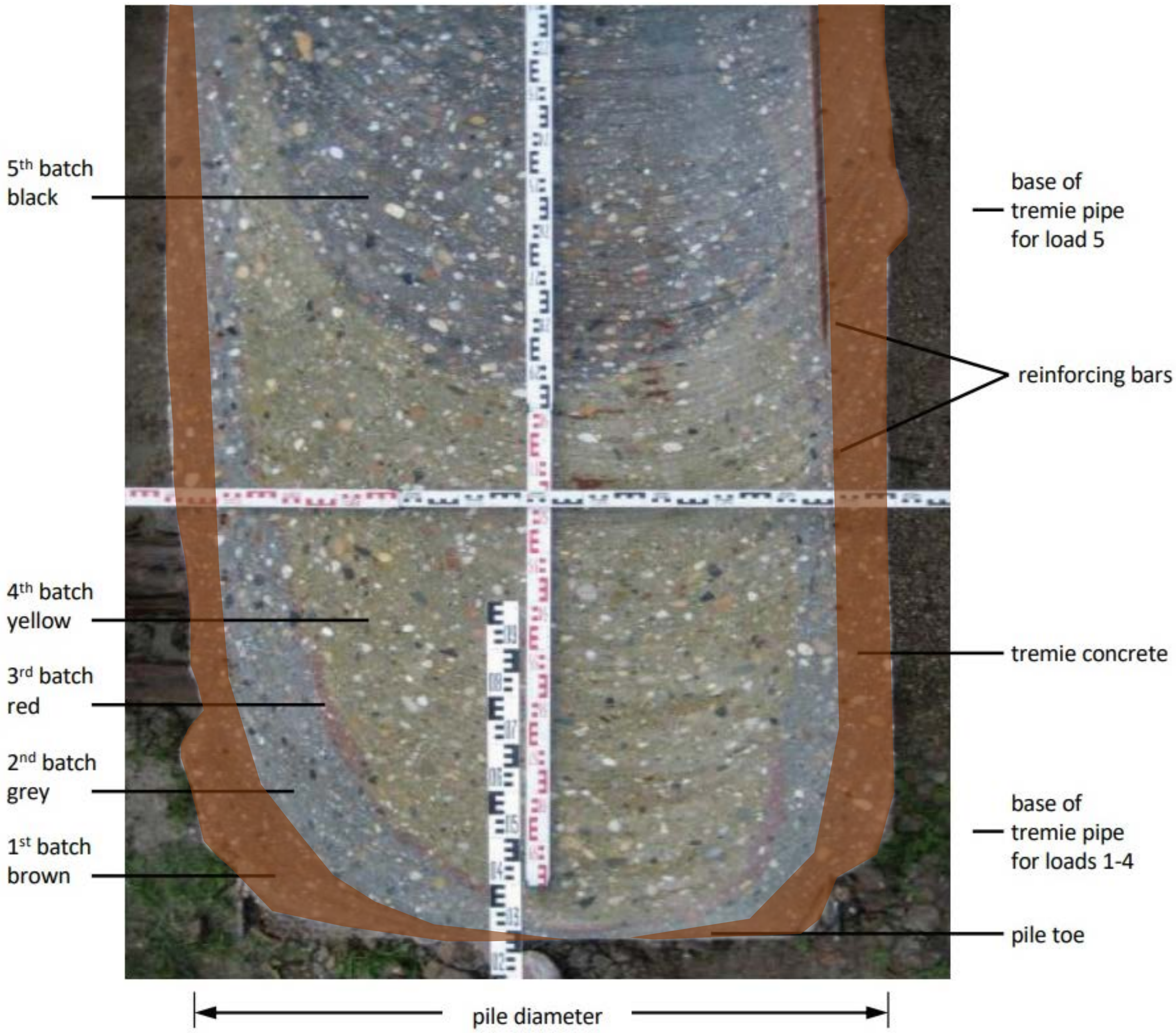

Figure 8. Cross section of a drilled shaft placed with dyed loads of concrete, first batch (highlighted in brown for clarity) approximately corresponded to the location of the defect observed at the case history shaft (Böhle and Pulsfort 2014).

SUMMARY AND CONCLUSIONS

This case history demonstrates that CSL is an effective non-destructive integrity test method for tremie placed concrete in drilled shafts. Based on the current industry understanding of the tremie placed concrete flow, the authors' believe many of the "false anomalies" commonly associated with CSL testing are likely not "false" but rather located around the outside of the shaft where it is difficult to confirm by coring. Additionally, when a poor quality concrete exists directly adjacent to multiple CSL tubes, the CSL results may appear to indicate a defect with a larger cross-sectional area than actually exists, as was the case with the shaft described here.

REFERENCES

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