Figure 11: Reinforcing Steel Cage Placement.

into a hopper and 10" diameter tremie pipe in 10' sections. Typical concrete placement times took 5-6 hours.

Integrity Testing

The overall inspection and acceptance of drilled shafts was predicated on inspection of completed rock sockets and integrity testing of concrete with Crosshole Sonic Logging (CSL) testing. Rock sockets were inspected upon completion with a downhole camera to inspect the sidewalls and a mini-SID to measure the amount of sediment on the bottom of the shaft.

CSL testing was typically performed 3-5 days after concrete placement and testing was within acceptable guidelines for the first seven shafts from July through the end of September.

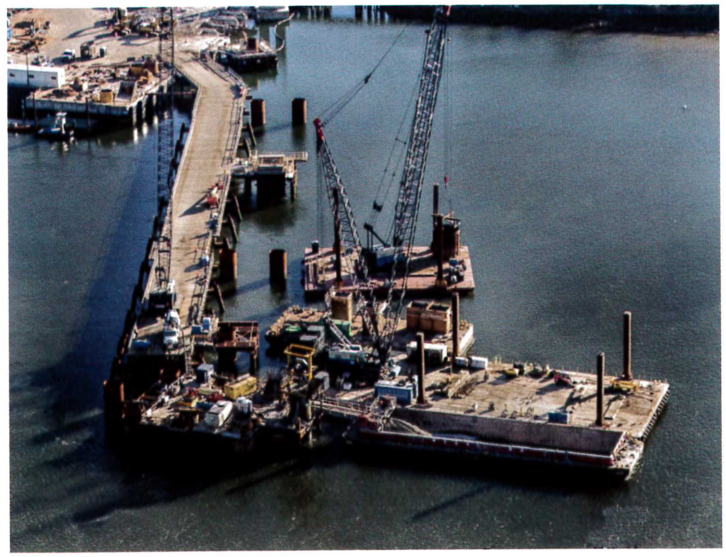


Figure 10: Wirth Set Up (courtesy of Richard Hopley Photography).

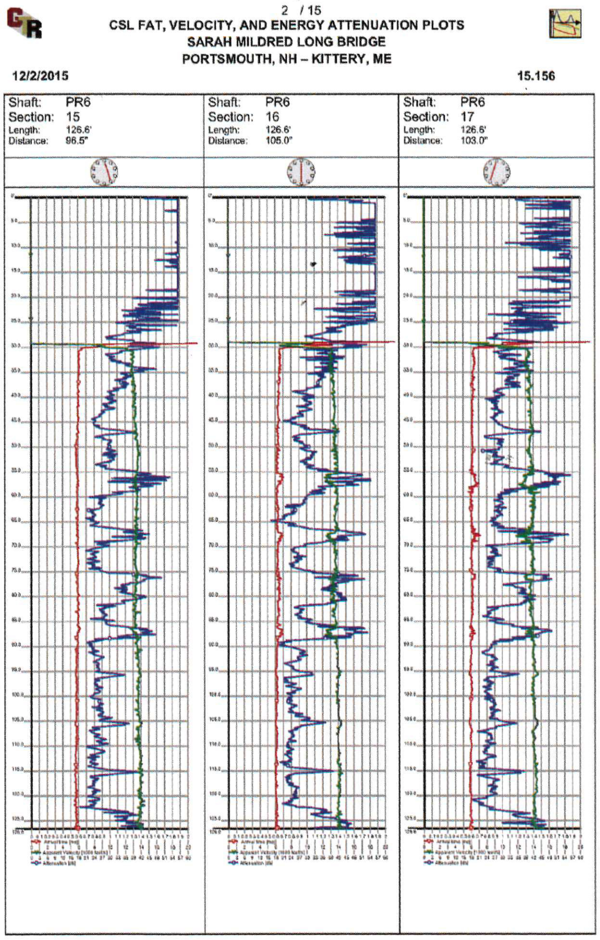
Once the weather started to turn colder in October, CSL testing began to indicate slight velocity reductions and energy attenuations on the longer profiles across the shaft primarily at 10' intervals in the cased portion of the shaft (see Figure 12). These potential anomalies were exaggerated as the air and water temperatures continued to drop. We had not changed our methods and there were no indications of issues with the concrete strength from cylinders so could not identify a conclusive reason for these potential anomalies.

We increased our testing of the concrete mix to confirm that there was not an issue with the concrete and retained several industry experts to review the concrete mix and CSL results to attempt to identify what could be causing the potential anomalies. We proceeded with the standard re-test of shafts in question and results either did not change or were worse than original tests. Tomography was also performed on the data to more clearly show the potential anomalies (see Figure 12). We then engaged a second independent CSL testing firm to rule out the possibility of a calibration issue with the testing equipment and their results confirmed original testing.

During the pre-construction meeting for the drilled shafts, the potential for inconclusive CSL test results was discussed. The plan was to default to Sonic Echo testing to confirm the results of the CSL. To test a 10' diameter shaft with Sonic Echo testing requires five test locations, one in the center and one in each quadrant approximately 2' from the center. Sonic Echo testing did not match the CSL results which indicated potential issues with the center of the shaft at 10' intervals within the casing. At this point, we needed to turn to the method of last resort, concrete coring, in order to determine a definitive answer as acceptance of shafts was becoming critical to the project schedule.

Drilled Shaft PR6 was selected to be cored as this was the shaft that endured the most integrity testing with CSL and Sonic Echo. Two cores were taken in the center of the shaft with the deeper core advancing to the lowest level which indicated a potential anomaly. The concrete cores indicated consistent concrete with UCS breaks averaging approximately 8,000 psi or well above the minimum required 4,350 psi.

The results of the cores essentially put to rest the concern with the CSL tests; however, it was still decided to attempt Thermal Integrity Profiling (TIP) at one of the remaining shafts to confirm the results of the concrete coring. Drilled Shaft N3 at the Portsmouth Lift Tower was selected and ther-



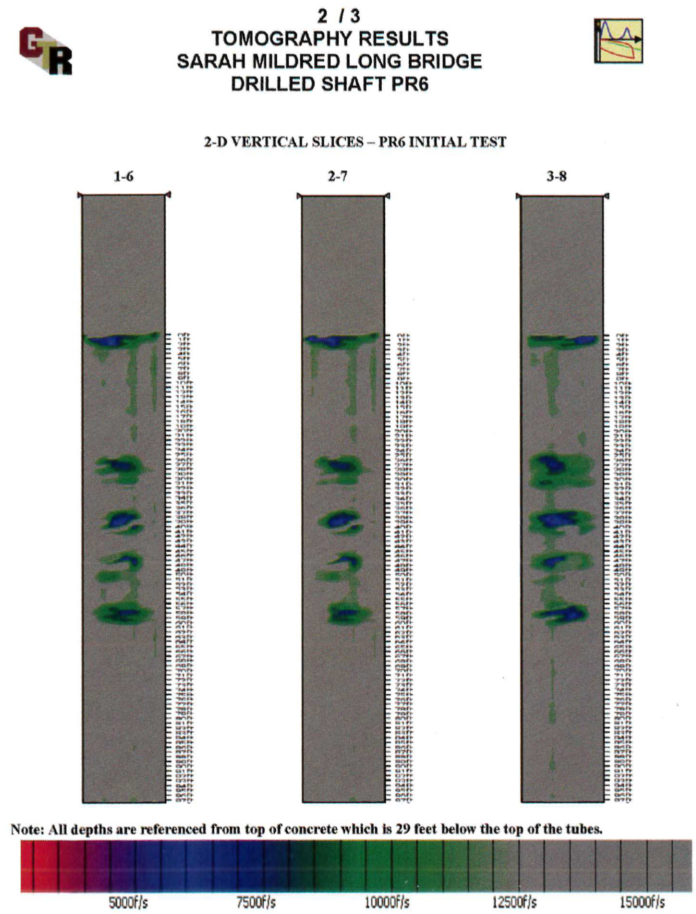


Figure 12: CSL Test Results and Tomography Results (Geosciences Testing and Research, Inc.).

mal wires were installed on the reinforcing steel cage during placement. The results of the TIP showed no evidence of significant anomalies and disproved the persistent anomalous CSL results.

After multiple testing methods consultants were engaged to determine the root cause of the anomalous CSL results. It was determined that the steel bracing rings in the cages were the ultimate cause of the false anomalies. Due to the weight and diameter of the cages, bracing rings were set at 9-10' intervals along the shaft to support the cages during transport and placement. These rings were built into the cages and as such were not removed during placement into the shafts. As the water temperature decreased in the winter months, the temperature differential created by the heavy steel rings was enough to affect the signal in CSL testing on the longer profiles to show an anomaly. The TIP testing also confirmed these moderate temperature variations around the bracing rings. Ultimately, all drilled shafts were accepted as constructed.

Conclusion

In conclusion, proper installation of large diameter shafts in difficult marine conditions requires extensive planning and attention to detail. It is critical when working in a marine environment to understand the conditions and how they will impact the work. It is highly recommended to take as many rock cores prior to the start of the work as possible to accurately map the profile of the rock if the potential for sloping rock exists. Drilling large diameter rock sockets in highly fractured rock layers may require significant embedment of casings to get a seal and carefully selected methods to maintain that seal.

The project was ultimately able to overcome the challenges and achieve a successful completion through planning, aggressive reaction to changing conditions and coordination with all vested parties. The drilled shafts were completed on schedule and without any recordable safety incidents.

**Indicates ADSC Member*

Project Team

Owner:	Maine and New Hampshire DOT's
CM / GC:	Cianbro Corporation
Geotechnical Engineer:	GZA Geoenvironmental*
Geotechnical Contractor:	Case Foundation Company*
Structural Engineer:	Figg Bridge / Hardesty & Hanover

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