APPENDIX A – DUAL CROSSHOLE SONIC LOGGING (CSL) AND GAMMA-GAMMA DENSITY LOGGING (GDL) - CASE HISTORIES

As stated by Jerry DiMaggio (2004), FHWA Principal Geotechnical Engineer, "*unfortunately* (NDT) *tests, due to their qualitative nature, sometimes raise more questions than provide exact answers, and the quality of all testing firms and test results appear to be somewhat variable and inconsistent."*

In this appendix, seven (7) case histories are presented to outline the benefits of **dual** logging for accurate interpretation of anomalies in drilled shafts both inside and outside the rebar cage (including rebar exposure to soil). Dual logging is performed using both crosshole sonic logging (CSL) and gamma-gamma density logging (GDL) methods. Dual logging provides with independent verification of anomalies and provides a better picture for the possible causes for the observed anomalies. It also helps eliminate false positives or false negatives in the data that results in costly construction delays. The seven (7) case histories are all from the Arizona Department of Transportation (ADOT) project sites where dual logging was performed:

Case History 1 (CSL False Negative):

Field Testing: GDL indicates an anomaly with no indication on the CSL record.
Interpretation: Density anomalies were located outside the rebar cage.

Case History 2 (GDL False Negative):

Field Testing: CSL indicates an anomaly in all tubes with no indication on the GDL.
Interpretation: Velocity anomalies were located in the interior portion of the shaft.

Case History 3:

Field Testing: GDL indicates an anomaly with only low amplitudes indicated in CSL.
Interpretation: Density anomalies were located outside the rebar cage and intruding in and just touching the tubes.

Case History 4 (CSL False Positive):

Field Testing: CSL indicates low amplitude anomalies with no anomalies on the GDL.
Interpretation: Tube instillation problem.

Case History 5 (Anomaly Confirmation):

Field Testing: GDL indicates 3 anomaly zones. CSL indicates 1 low amplitude zone and 1 low amplitude/velocity zone.
Interpretation: First anomaly located outside the cage, second anomaly located outside the cage just touching the tube, the third anomaly intrudes inside the cage.

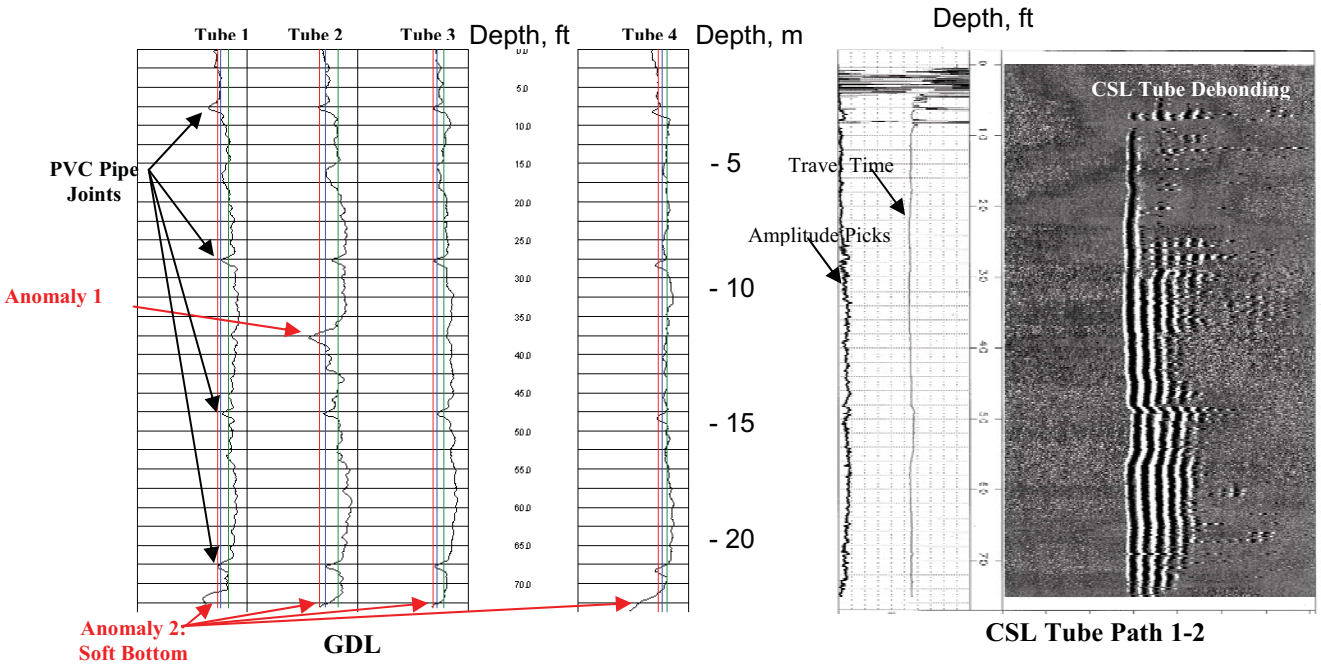
Case History 6 (Anomaly Confirmation):

Field Testing: Three methods: CSL, GDL, and neutron moisture logging (NML) all indicate the same anomaly. CSLT was used to image the defect.
Interpretation: Low velocity/density zone with high moisture that extend inside the cage.

Case History 7 (Anomaly Confirmation):

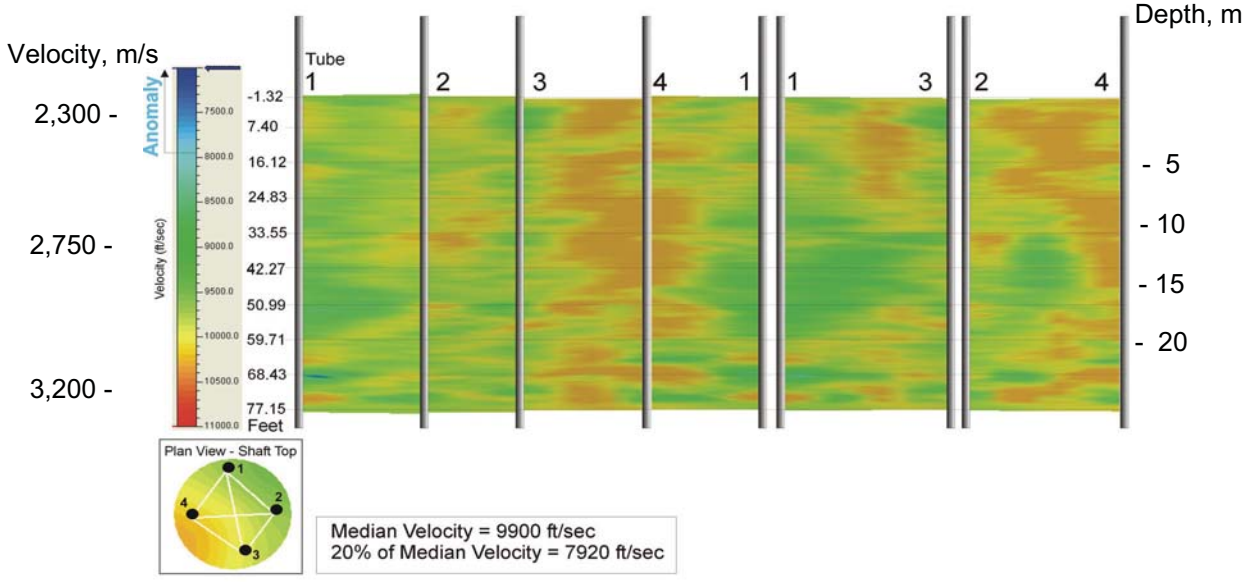
Field Testing: Both CSL and GDL indicate an anomaly.
Interpretation: Anomaly extends inside the cage. CSLT was used to image the defect in three-dimension for coring confirmation followed by remediation.

Case History 1	Inspection Tubes	Testing Age (Days)		GDL Anomalies	CSL/T Anomalies	
		CSL	GDL		Travel Time	Amplitude
5' Dia. Shaft	4 PVC	17	7	YES	NO	NO



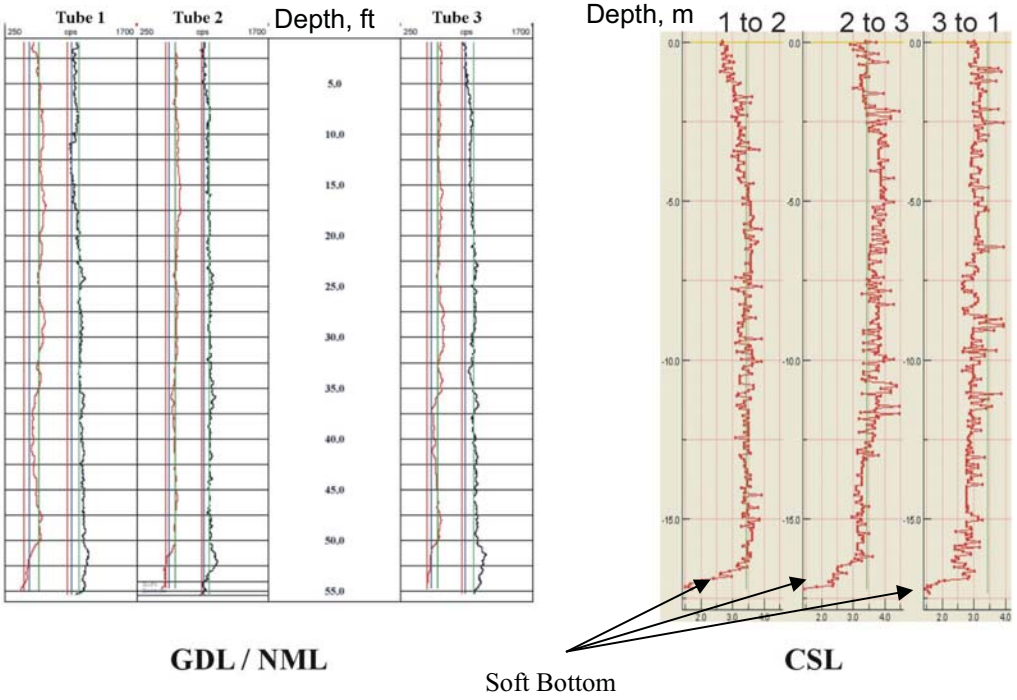
Analysis: GDL test was performed first which indicated a soft bottom condition and a poor quality density zone at Tube 2 between 11.3-11.8 m (37-39 ft). CSL and CSLT did not indicate velocity anomalies (just PVC tube debonding for 17-days old shaft).

Interpretation: Density anomalies were located outside the rebar cage.



3-D Tomography (CSLT)

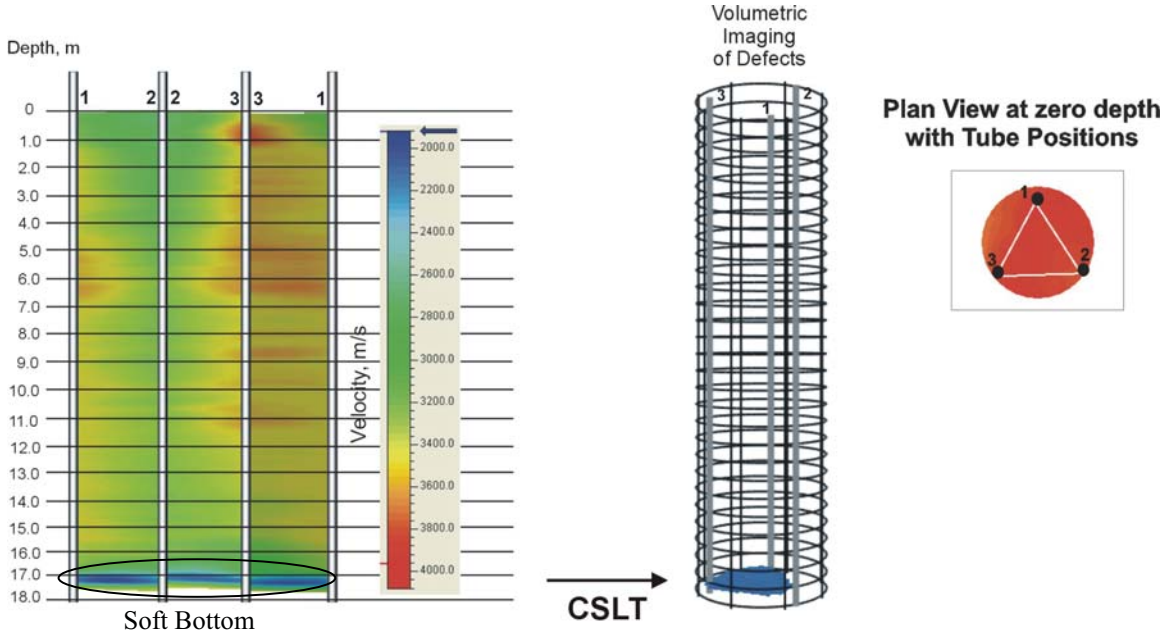
Case History 2	Inspection Tubes	Testing Age (Days)		GDL Anomalies	CSL/T Anomalies	
		CSL	GDL		Travel Time	Amplitude
3' Dia. Shaft	3 STEEL	6	18	NO	YES	YES



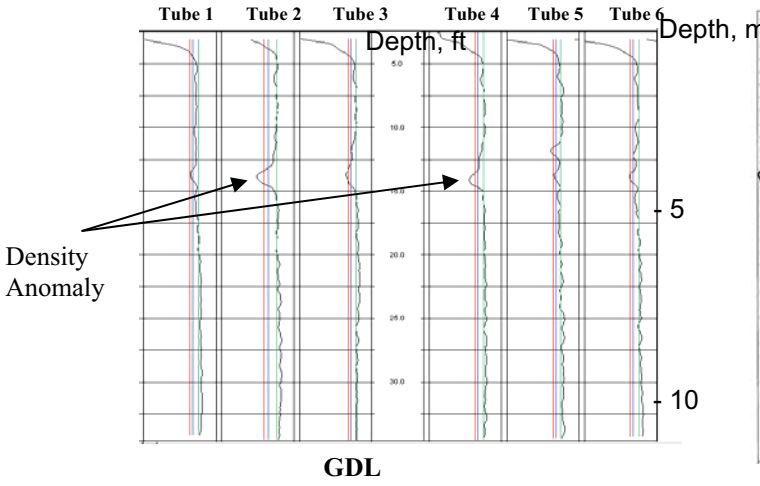
Comprehensive geophysical logging program was performed including: crosshole sonic logging (CSL), 3-D zero-offset tomography (CSLT), gamma-gamma density (GDL), and neutron-moisture logging (NML).

Analysis: ALL three (3) CSL logs indicated a soft bottom. However, GDL, shown in black, indicated no major density anomaly. NML (red), indicated a high moisture zone.

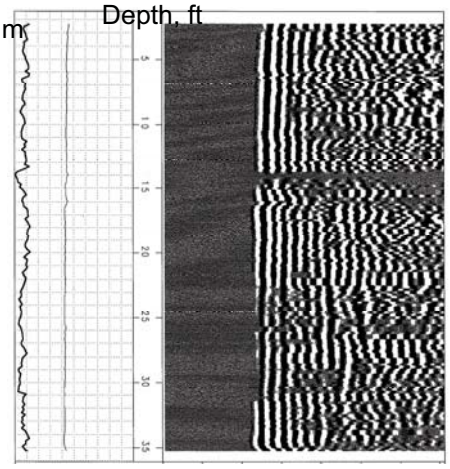
Interpretation: "Soft bottom" condition located in the interior portion of the shaft just missing the tubes.



Case History 3	Inspection Tubes	Testing Age (Days)		GDL Anomalies	CSL/T Anomalies	
		CSL	GDL		Travel Time	Amplitude
6' Dia. Shaft	6 PVC	6	6	YES	NO	YES



GDL

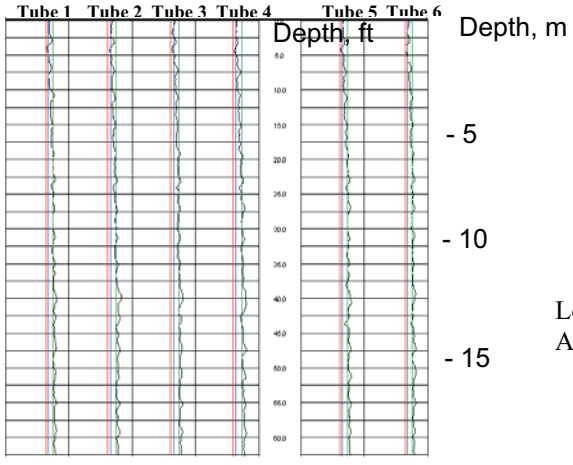


CSL Tube Path 2-3

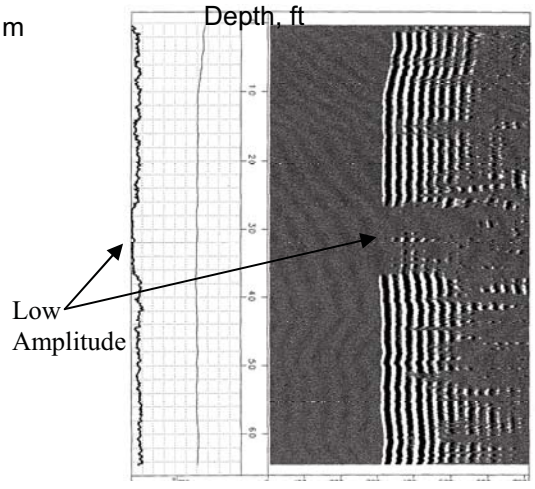
Analysis: CSL and GDL performed at the same time. GDL indicates a density a 4.1-4.4 m (13.5-14.5 ft). CSL indicates low amplitude (reduced signal energy) at the same depth; but no velocity anomaly.

Interpretation: Density anomalies outside rebar cage and is intruding in just touching the tubes. Therefore, the rebar cage is probably exposed to the density anomaly.

Case History 4	Inspection Tubes	Testing Age (Days)		GDL Anomalies	CSL/T Anomalies	
		CSL	GDL		Travel Time	Amplitude
6' Dia. Shaft	6 PVC	4	22	NO	NO	YES



GDL

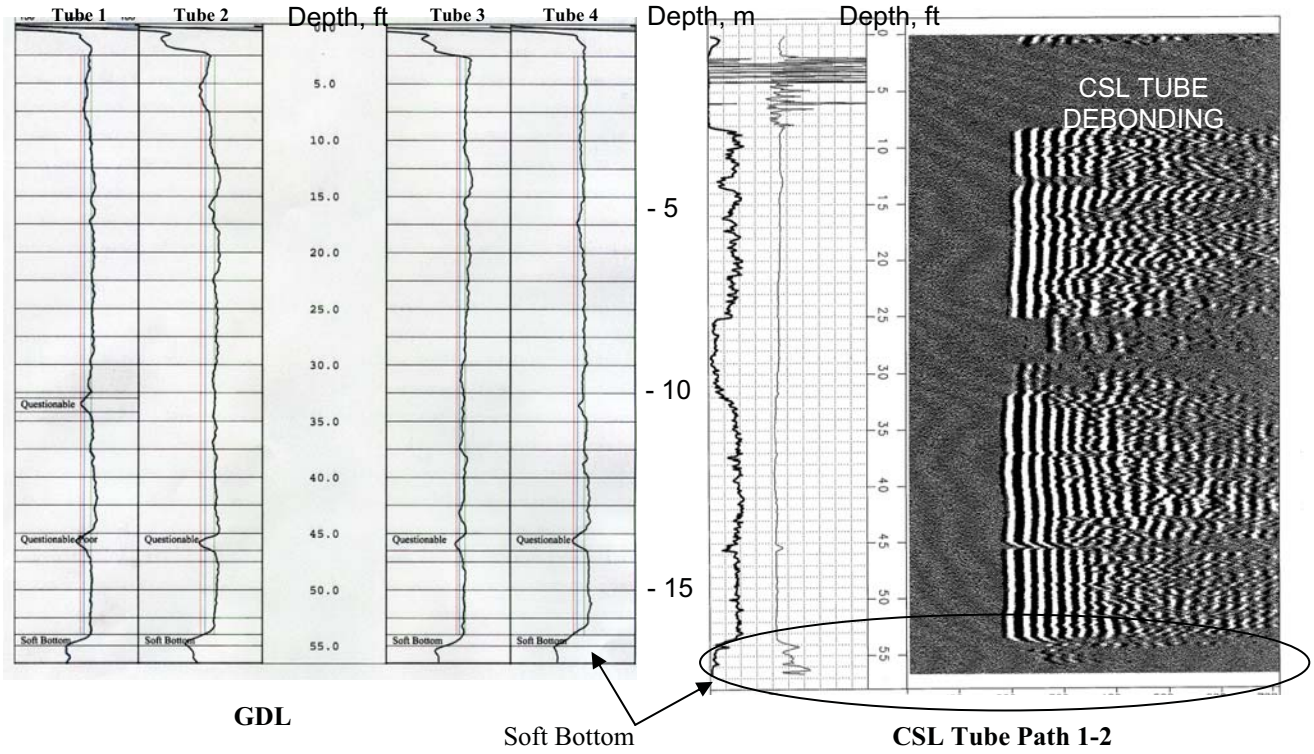


CSL Tube Path 2-5

Analysis: CSL test was performed first which indicated low amplitude (reduced signal energy) near Tubes 2 and 3 between 8.3-11.3 m (27-37 ft); but no velocity anomaly. GDL indicates no density anomalies.

Interpretation: Tube bonding problem, possibly due to excessive vibration during instillation.

Case History 5	Inspection Tubes	Testing Age (Days)		GDL Anomalies	CSL/T Anomalies	
		CSL	GDL		Travel Time	Amplitude
4' Dia. Shaft	4 PVC	43	7	YES	NO/YES	YES



GDL test was performed first which indicated three zones of density anomalies. CSL was performed next with severe PVC tube debonding observed in the 43-days old shaft.

Anomaly 1: GDL indicated a questionable density zones near Tube 1 between 10-10.4 m (33-34.2 ft). CSL testing does not indicate a significant velocity anomaly.

Interpretation: Density anomaly is located outside the rebar cage.

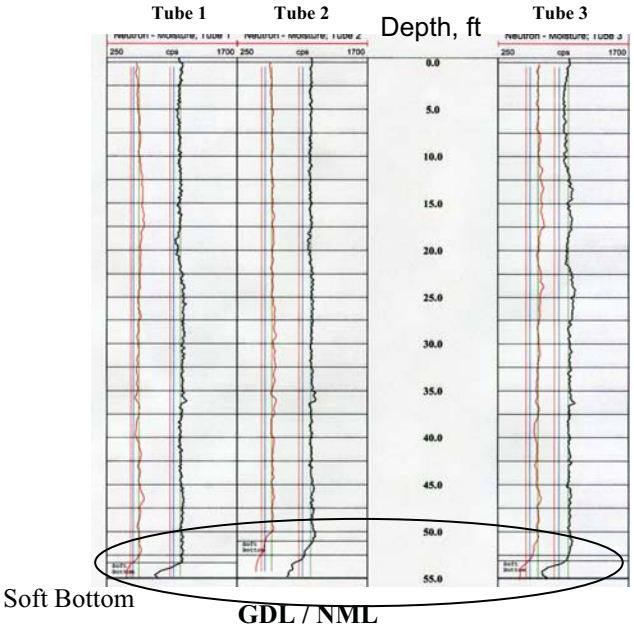
Anomaly 2: GDL indicated a questionable-poor density anomaly in all four tubes between 13.7-14.2 m (45-46.5 ft). CSL data indicate only a drop in signal amplitudes in all four tubes without a significant reduction in velocity (<10%).

Interpretation: Density anomalies outside rebar cage and is intruding in just touching the tubes. Therefore, the rebar cage is probably exposed to the density anomaly.

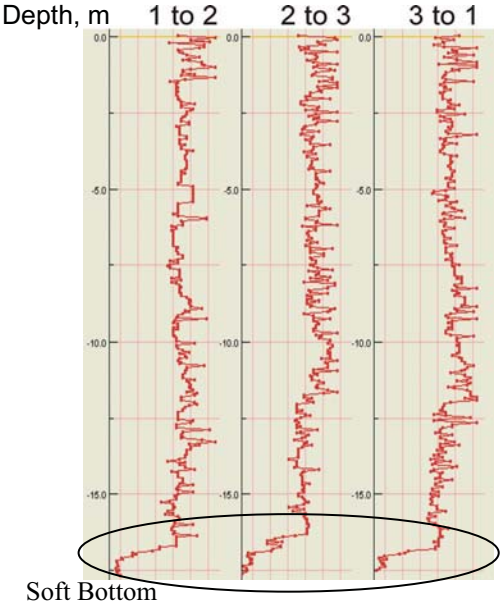
Anomaly 3: GDL indicated a soft bottom condition in all tubes at the bottom 0.76 m (2.5 ft). CSL testing also confirms the soft bottom condition (>20% drop in velocity).

Interpretation: The soft bottom condition is located both inside and outside the rebar cage.

Case History 6	Inspection Tubes	Testing Age (Days)		GDL Anomalies	CSL/T Anomalies	
		CSL	GDL		Travel Time	Amplitude
3' Dia. Shaft	3 STEEL	6	18	YES	YES	YES



GDL / NML

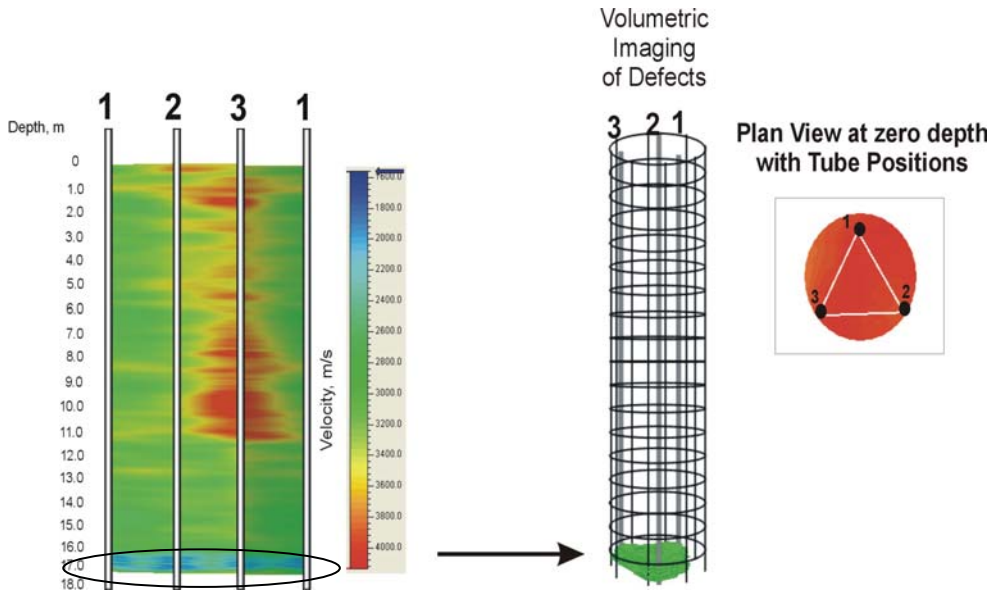


CSL

Comprehensive geophysical logging program was performed including: crosshole sonic logging (CSL), 3-D zero-offset tomography (CSLT), gamma-gamma density (GDL), and neutron-moisture logging (NML).

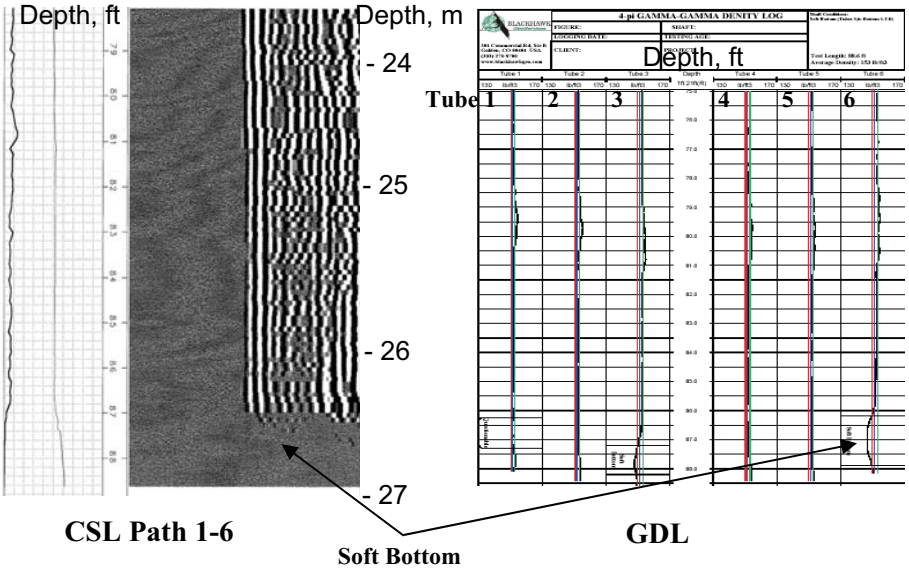
Analysis: ALL three (3) CSL, GDL, and NML logs indicated a soft bottom condition. Therefore, complementary results were indicated; however, note for Tube 3, neutron-moisture (NML) indicates higher extent of high-moisture anomaly.

Interpretation: "Soft bottom" condition which extends to the interior of the shaft.



CSLT

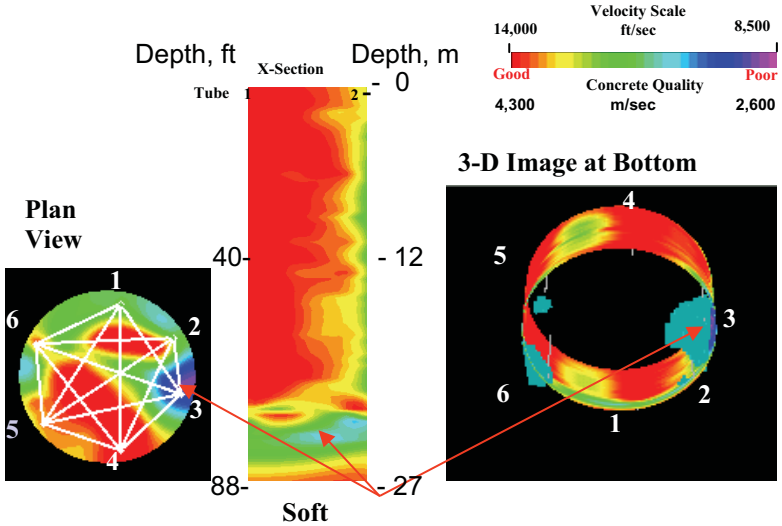
Case History 7	Inspection Tubes	Testing Age (Days)		GDL Anomalies	CSL/T Anomalies	
		CSL	GDL		Travel Time	Amplitude
6' Dia. Shaft	6 STEEL	5	5	YES	YES	YES



Comprehensive Geophysical logging including: crosshole sonic logging (CSL), 3-D multi-offset tomography (CSLT), and gamma-gamma density logging (GDL) was performed from **steel** pipes.

Analysis: CSL and GDL data indicated 0.3-0.6 m (1-2 ft) "soft bottom" condition. Three-dimensional tomographic imaging (CSLT) was performed for coring followed by remediation.

Interpretation: Soft bottom condition which extends to the interior of the shaft. 3-D images defined poor quality concrete zones shown in green, blue, and purple colors. Good quality concrete is shown in red. The defect zones are shown at the bottom of the shaft primarily around Tubes 6, 5, and 3.



CSLT