

# PVC AND STEEL ACCESS TUBE DEBONDING DURING SONIC LOGGING TESTING FOR THE SC 170 BRIDGE REPLACEMENT PROJECT

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During sonic logging quality control testing of the drilled shaft foundations for the replacement bridges crossing the Broad and Chechessee Rivers for SC 170 in Beaufort County, South Carolina, irregular signals were observed on a consistent basis near the shaft top elevations. These irregular sonic signals were attributed to access tube “debonding”, which is the separation of the access tubing from the surrounding concrete. A total of 160 drilled shafts were installed for this project, of which 41 were evaluated using sonic logging testing. Both PVC and steel access tubes were used during the project to allow for sonic logging testing.

This paper details the investigation of access tube debonding with time, discusses the solutions used to minimize access tube “debonding”, and presents the results of the sonic logging testing for the entire project. The solution selected, installation of PVC along the pile length and steel access tubing within 40 feet from the top of shaft, allowed for reliable sonic logging to effectively evaluate the upper portions of the drilled shafts.

## INTRODUCTION

As part of a 20.1 kilometer (12.5 mile) widening project for South Carolina Highway 170 (SC170) in Beaufort County, SC, replacement bridges were constructed over the Broad and Chechessee Rivers. The new Broad River Bridge (BRB) has a total span of 2.74 km (1.7 miles), while the Chechessee River Bridge (CRB) has a total span of 0.57 km (0.35 miles). A total of 126 and 34 drilled shafts were installed on the Broad and Chechessee Rivers, respectively. Figure 1 shows the location of the project.

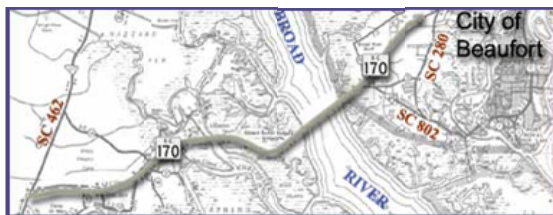


Figure 1. Site Location.

The contractor for this project was Balfour Beatty Construction International (BBCI). As part of the contractor’s quality control program for these bridges, a minimum of 25% of the drilled shafts for each bridge were randomly

selected for sonic logging testing using both Crosshole Sonic Logging (CSL) and Singlehole Sonic Logging (SSL). CSL and SSL testing consists of placing sonic transmitters and receivers down access tubes installed along the length of the drilled shaft. These access tubes are placed within the reinforcing steel cage prior to concrete placement. A detailed explanation of CSL and SSL testing is presented by Chernauskas and Paikowsky (1999).

During CSL testing of the drilled shafts, irregular ultrasonic signals were encountered up to 12.2 meters (40 feet) from the Top Of Shaft (TOS) elevations. These signals were attributed to access tube debonding, which is the separation of the access tubing from the surrounding concrete. An investigation was performed to determine the relationship between time from shaft concrete placement to depth of access tube debonding in order to determine the optimum time for sonic logging testing. The following paper describes the time vs. debonding depth investigation, presents the solution selected to minimize the effects of tube debonding of shaft integrity evaluation, and presents the results of the sonic logging testing for the entire project.

### **DRILLED SHAFT INFORMATION**

The drilled shafts for this project consisted of two separate sizes for both bridges: those placed over open water and marsh areas and those installed at the bridge abutments. The drilled shafts over water consisted of 2.62m (103in) outside diameter (O.D.) by 12.7mm (0.5in) wall thickness steel casing that was driven through the overburden soils into an underlying cohesive deposit, known as the Marks Head Formation. Underlying this cohesive deposit is a soft, fractured limestone layer (i.e. the Santee Formation), in which the drilled shafts were founded. The drilled shaft diameter within the limestone was 2.44m (8ft). The total drilled shaft length varied between 29.6m to 40.1m (97.1ft to 131.6 ft), with actual length dependent on the required bridge loads, current depth to the mudline, design scour calculations, and elevation of the top of the limestone layer. At the bridge abutment locations, the drilled shafts consisted of 0.97m (38in) O.D. by 12.7mm (0.5in) wall thickness steel casings that were driven through the overburden soils into the Marks Head Formation. The drilled shaft diameter for the abutment shafts within the limestone was 0.91m (3ft). All the drilled shafts were installed using polymer slurry and tremie pipe installation methods. A typical cross-section for the large drilled shafts for this project is presented in Figure 2.

For the drilled shafts over water, the project specifications called for a minimum of eight (8) access tubes, equidistantly spaced, to be installed along the entire shaft length for sonic logging testing. For the bridge abutment drilled shafts, three (3) equidistantly spaced access tubes were installed along the entire shaft length. The project specifications also stated that either 5cm (2in) nominal diameter Schedule 40 Polyvinyl Chloride (PVC) or Schedule 40 steel pipe could be used as the access tubing for the sonic logging testing. The contractor selected PVC access tubing based on cost and ease of construction considerations.

### **SONIC LOGGING TESTING**

Sonic logging for the drilled shafts was conducted using the Pile Integrity Sonic Analyzer (PISA), manufactured by Piletest.com. The PISA is a lightweight, portable, pen touch computer that operates in a Windows based environment (Chernauskas and Paikowsky, 2000). The PISA has consistently detected

anomalies that have been verified to be defects during inspection coring (Chernauskas and Paikowsky, 2000; Haramy and Mekic-Stall, 2000; and Amir, 2002).

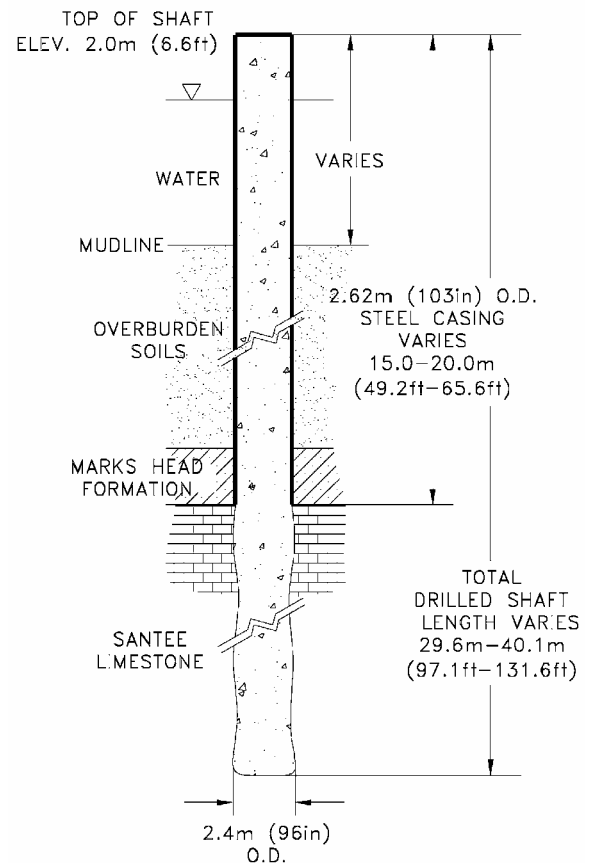


Figure 2. Typical Drilled Shaft Cross-Section.

The project specifications did not specifically state the crosshole and/or singlehole combinations to be tested during sonic logging. Therefore, sonic logging was conducted on all possible access tube combinations to allow for a complete evaluation of shaft integrity. After CSL testing was performed on the initial six (6) drilled shafts and access tube debonding signals were noticed at the shaft top for each of these shafts, singlehole sonic logging (SSL) testing was also conducted on the drilled shafts. For the water shafts, a total of twenty-eight (28) crosshole and eight (8) singlehole combinations were tested. For the abutment shafts, a total of three (3) crosshole and three (3) singlehole combinations were tested.

During the initial sonic logging testing of the first few shafts, erratic sonic signals were observed

at various distances from the shaft top. These distances extended up to 12.2 meters (40 feet) from the shaft top, which was approximately 40% of the shaft length for the tested shafts. The erratic sonic signals consisted of increased First Arrival Times (FAT) and decreased relative energies (RE) within the CSL results. Typically, although not always, major principal diameter and near major principal diameter combinations during CSL testing experienced a complete loss of signal within these zones. Figure 3 shows a typical major principal diameter CSL signal along the shaft, while Figure 4 presents a typical CSL signal near the top of the shaft.

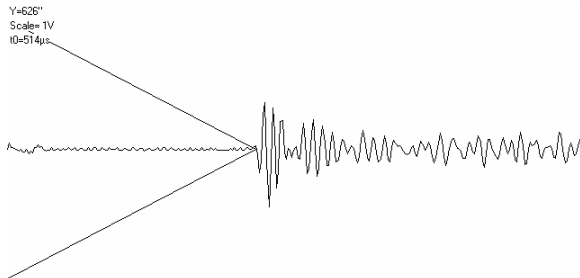


Figure 3. Typical CSL signal across shaft.

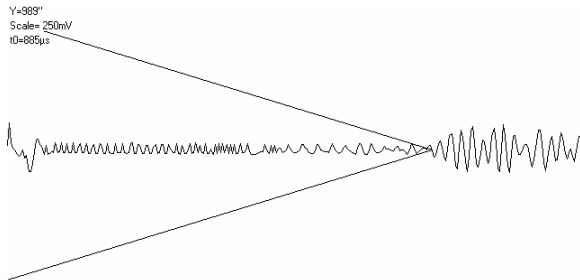


Figure 4. Typical CSL signal within the upper portion of the same combination for the same shaft.

Based on previous CSL testing experience, it was believed that these erratic signals were due to access tube debonding. Access tube debonding is the separation of the access tube from the surrounding concrete and/or weakening of the interface between the two materials. Typically, access tube debonding occurs when polyvinyl chloride (PVC) pipe is used in place of steel, although debonding can occur when steel tubing is used. As the concrete cures, the heat of hydration causes increased temperatures with the drilled shafts. This increased temperature causes the access tubing to expand. As the concrete cools, the access tubes contract, cause

separation between the two materials and/or weakening of the interface bond. If the material thermal expansion properties between the concrete and access tubing are substantially different, the potential for the interface (i.e. bond) between the two materials to be affected is greater. Disturbance of the interface or a separation between the two materials can cause increased FAT times, reduced relative energy of the signal, or both. A summary of typical coefficients of thermal expansion for concrete, steel, and PVC is presented in Table 1.

Table 1. Comparison of Typical Coefficients of Thermal Expansion (CTE).

Material	CTE ( $\mu\epsilon/\text{°C}$ )	Source
Concrete	8-12	FHWA Website (2003)
Steel	12	PPI (2001)
PVC	63	PPI (2001)

As shown in Table 1, the coefficients of thermal expansion for concrete and steel are similar, while PVC is approximately 5-6 times greater than these two materials. This is most likely the reason why debonding occurs more frequently when PVC access tubes are used.

Although the time for concrete hydration to be completed varies with amount and type of Portland cement and concrete admixtures used in the mix design, hydration usually continues to occur in concrete for up to 28 days. This corresponds to the authors' experience with sonic logging testing, which has shown that the likelihood and/or severity of debonding increases with the passage of time from the date of concrete placement for both PVC and steel access tubes.

While thermal expansion is the major contributor to access tube debonding, other factors are involved with this phenomena. These factors include surface texture of the access tubing, the presence of contaminants on and within the access tubing, and handling of the access tubing during and after concrete placement.

In order to minimize access tube debonding, the authors recommended the following to the contractor at the start of the project:

- The access tubes should be cleaned prior to installation within the drilled shafts.
- If possible, the exteriors of the access tubes should be sandblasted or otherwise scoured prior to installation within the drilled shafts.
- The access tubes should be filled with water immediately after concrete placement within the shaft.

Although past sonic logging testing experience indicated these erratic ultrasonic signals were due to debonding, the potential existed that the CSL signals classified as debonding could be actual anomalies within the drilled shaft. Therefore, the following steps were taken to verify that these erratic CSL signals were due to tube debonding:

- Pulse Echo Testing (PET), also known as low strain or sonic echo testing, was performed on the shafts that had the greatest depths of debonding to verify shaft integrity. A detailed explanation of PET testing is presented by Chernauskas and Paikowsky (1999). Although PET has limitations in determining small anomalies within large drilled shafts, the extent of the CSL data, if not attributable to debonding, indicated anomalies across the entire shaft area. Refer to Likins and Rausche (2001) for further discussion of PET limitations. The PET did not detect any anomalies within the tested drilled shafts.
- A review of the drilled shaft installation records, to include shaft excavation logs and concrete placement logs, was conducted by the senior quality control engineer and the CSL testing engineer. This review did not detect any significant irregularities or deficiencies during the various drilled shaft installations.
- Interviews with the drilled shaft inspectors and construction personnel present during reinforcing steel and concrete placement. No significant irregularities or deficiencies during drilled shaft installation were recalled

by the various construction and quality control personnel.

- Visual examination of the top of the drilled shaft during CSL testing. These examinations did not detect any significant irregularities on the shaft surface that might indicate problems within the drilled shaft.

Based on the data compiled above, it was concluded that the erratic ultrasonic signals were due to access tube debonding with the surrounding concrete and were not indicative of anomalies within the drilled shafts.

During the initial four (4) sonic logging tests for this project, fluctuating water levels were observed within the PVC access tubing. A lack of water within the access tubes can also be a cause for erratic ultrasonic signals. For the testing of three of the initial drilled shafts (i.e. BRB 11-1, BRB 21-2, and BRB 22-2), no water was present within the access tubes when the shafts were scheduled for CSL testing and therefore water had to be added prior to testing. The contractor was informed that to reduce the potential for debonding, all access tubes should be filled with clean freshwater before or shortly after concrete placement. After the contractor was notified, the access tubes were filled with water after concrete placement and again prior to the start of CSL testing.

After a total of eleven (11) drilled shafts had been evaluated with sonic logging testing, an analysis was conducted to determine the relationship between average debonding depth and elapsed time from concrete placement. In order to conduct analysis, debonding had to be defined relative to the ultrasonic signal. For purposes of this study, access tube debonding was classified as consistent areas near the shaft top where First Arrival Time (FAT) increases greater than 10% occurred in conjunction with decreases in relative energy. A total of nine (9) drilled shafts had PVC access tubes, while the remaining two (2) drilled shafts had steel access tubes. Steel access tubes were installed instead of PVC within these two drilled shafts in an attempt to eliminate the debonding problem. Sonic logging testing had been conducted for these shafts at dates ranging from 5 to 13 days from the placement of concrete. For each tested shaft, individual CSL combinations were examined and the depth to which debonding results extended was noted. An average

debonding depth for each tested shaft, along with the standard deviation, was then determined based on this data. The results of this analysis with time are presented in Figure 5 and are summarized in Table 2.

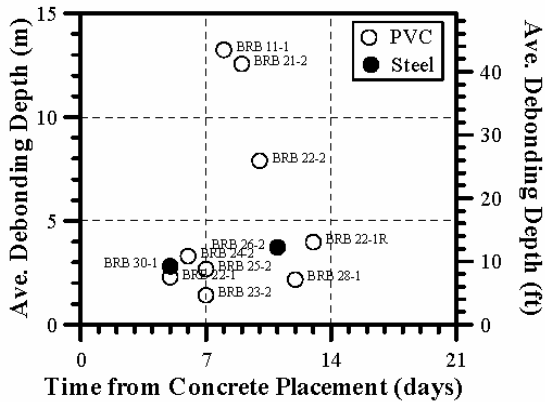


Figure 5. Average Debonding Depth vs. Elapsed Time from Concrete Placement – Initial CSL testing.

As shown in Figure 5, three drilled shafts had average access tube debonding depths greater than 7.56m (25ft). These shafts corresponded to those shafts in which water was not placed in the access tubes immediately after concrete placement.

Based on the analysis of the data from the eleven (11) drilled shafts presented above, the following was concluded:

- Average depth to debonding observed during CSL testing within 7 days of concrete placement does not significantly vary between PVC and steel access tubes for access tubes filled with water after concrete placement. However, it was noted that this was based on a limited number of shafts with steel access tubes.
- After 7 days, average debonding depth varies greatly within PVC access tubes.
- For steel access tubes, debonding does not significantly increase with time up to the time tested.

In addition to the conclusions noted above, obstructions and blockages were observed

within the steel access tubes during the sonic logging testing. Similar problems were not observed within the PVC access tubes. This was most likely due to method of steel reinforcing installation within the drilled shafts.

The steel access tubes also prevented the use of SSL testing to evaluate the shaft integrity. Singlehole sonic logging within steel access tubes is not effective due to the reflection of the ultrasonic signal within the tube. The limitations of steel access tubing and SSL testing are described by Amir (2002). Based on our assessment of the sonic logging testing data and our observations during testing, the following recommendations were provided to the contractor to minimize tube debonding within the shafts:

- PVC access tubes would be adequate for use provided that sonic logging testing is conducted between three to seven (3 to 7) days after concrete placement. Testing within this timeframe should limit debonding to the upper 10 feet. Sonic logging testing should not be conducted prior to three (3) days from concrete placement.
- Hybrid PVC/steel access tubes should be installed within the shafts if debonding depths of 10 feet are not acceptable. A sturdy connection between the PVC and steel capable of withstanding the stresses associated with installation should be used. If this alternative is selected, steel tubing should be used within the upper 40 feet of the shaft followed by PVC tubing to the shaft bottom. CSL testing should be conducted within 3 to 14 days for combination access tubing.
- If hybrid access tubes are not used, then both steel and PVC access tube should be installed within the shaft. The PVC access tubes should extend along the entire length of the shaft, while the steel access tubing should be installed to a depth of 40 feet. All access tubes should be spaced equidistant around the shaft.

Table 2. Summary of Initial CSL testing.

Shaft	Matl <sup>1</sup>	Time <sup>2</sup> (days)	NC <sup>3</sup>	Debonding Depths (m)			
				Min	Max	Ave.	$\sigma^4$
BRB 11-1	PVC	8	28	1.83	14.78	13.23	3.11
BRB 21-2	PVC	9	28	5.79	15.24	12.56	1.96
BRB 22-1	PVC	5	28	0.00	6.25	2.28	1.24
BRB 22-1R <sup>5</sup>	PVC	13	28	0.00	10.52	3.98	2.39
BRB 22-2	PVC	10	28	0.00	18.90	8.01	5.26
BRB 23-2	PVC	7	28	0.00	10.36	1.55	2.40
BRB 24-2	PVC	6	28	0.30	8.53	3.36	2.70
BRB 25-2	PVC	7	28	0.00	11.28	3.51	3.93
BRB 28-1	PVC	12	28	0.00	8.84	2.92	2.76
BRB 26-2	Steel	11	28	1.58	5.85	3.73	1.27
BRB 30-1	Steel	5	9	1.60	3.43	2.81	0.51

NOTES:

1. Material
2. CSL/SSL testing time from concrete placement
3. NC = Number of tested combinations
4.  $\sigma$  = Standard Deviation
5. R = CSL Re-test

- All access tubes, both PVC and steel, should be sandblasted prior to placement into the reinforcing cage to improve the concrete/access tube bond. In addition, all access tubes should be completely filled with water prior to or shortly after placement of concrete.

After attempting several hybrid PVC/steel combinations on production shafts, the contractor selected to install both PVC and steel access tubes within the large diameter drilled shaft. Figure 6 shows a typical drilled shaft plan view with the PVC and steel access tubes. This decision was primarily based on construction considerations, such as ease of installation and the ability to maintain access tube integrity. Due to the limited space within the small diameter (i.e. abutment) shafts, PVC remained the access tube material. However, the CSL testing was scheduled within 5 days of concrete placement to limit the depth of tube debonding.

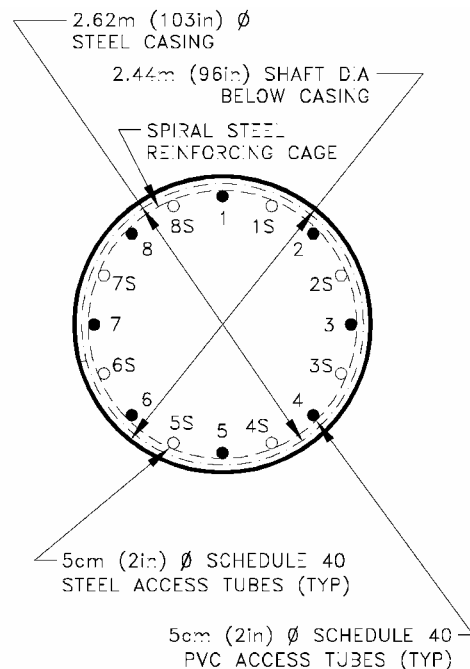


Figure 6. Typical water drilled shaft plan view.

Prior to implementation of the PVC/Steel access tube combination solution, a total of 7 drilled shafts were tested within only PVC access tubes. This was due to the fact that shaft construction did not stop while the debonding phenomenon was being investigated and the solution could be implemented.

**SUBSEQUENT SONIC LOGGING TESTING**

After the PVC/steel access tube combination solution was implemented, sonic logging testing continued on the production drilled shafts. As before, sonic logging consisted of testing all the possible CSL/SSL combinations with the PVC access tubing. For the steel access tubes, only the eight (8) perimeter and four (4) major diameter combinations were tested unless an anomaly area was detected. If an anomaly area was detected with the steel access tubing, then all 28 possible CSL combinations were tested. Testing was typically scheduled for between 3 to 7 days from concrete placement, although several sonic logging tests were conducted past this time frame.

A total of twenty one (21) drilled shafts with both types of access tubes were evaluated with sonic logging testing. The relationship between average debonding depth and elapsed time from concrete placement was determined for these shafts using the same methods as the initial testing.

During the subsequent sonic logging testing, an inspection core was conducted on one of the CRB abutment drilled shafts to further evaluate a sonic logging anomaly. Inspection of the upper portions of this inspection core through the debonding zone verified that the concrete within this region was within project specifications. The examination of the inspection core reinforced the previous conclusion that the upper erratic signals were due to debonding and therefore were not indicative of anomalies within the drilled shafts. In addition, the inspection core noted an irregular concrete region within the sonic logging anomaly zone, which confirmed the ability of the PISA sonic logging equipment to detect defects within the drilled shafts.

**SUMMARY OF SONIC LOGGING RESULTS**

The integrity of forty one (41) drilled shafts was evaluated using sonic logging testing. This represents 25% of the total of the drilled shafts installed for this project. Of these drilled shafts,

over half (i.e. 21 out of 41) were evaluated with sonic logging testing with both types of access tubes.

The average debonding depths within the tested PVC access tubing for CSL testing and SSL testing are presented in Figures 7 and 8, respectively. The average debonding depths within the tested steel access tubing is presented in Figure 9. Statistical summaries of the debonding data are presented in Tables 3, 4, and 5 for PVC-CSL testing, PVC-SSL testing, and Steel-CSL testing, respectively.

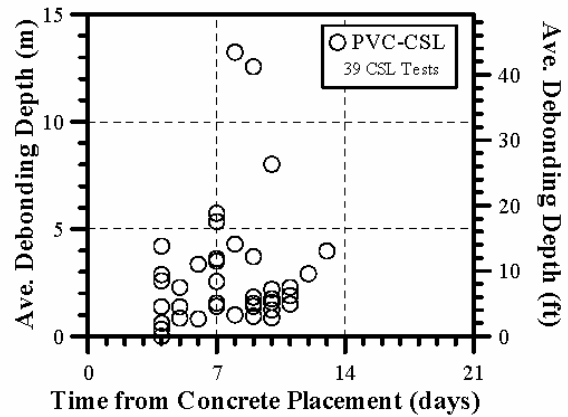


Figure 7. Average Debonding Depth vs. Time (PVC-CSL).

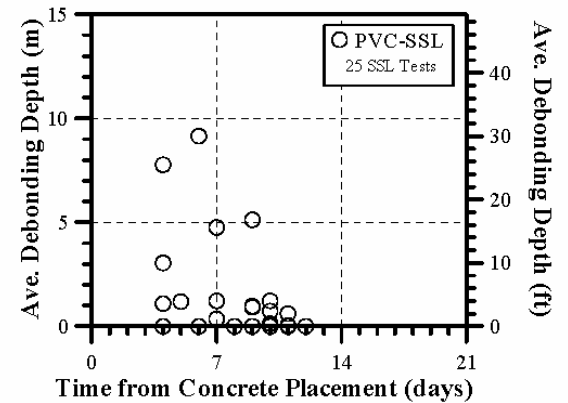


Figure 8. Average Debonding Depth vs. Time (PVC-SSL).

Table 3. Statistical Summary of PVC Access Tubing Debonding Depths – CSL Testing.

Shaft	Time <sup>1</sup> (days)	NC <sup>2</sup>	Debonding Depths (m)			
			Min	Max	Ave.	$\sigma^3$
BRB 11-1	8	28	1.83	14.78	13.23	3.11
BRB 21-2	9	28	5.79	15.24	12.56	1.96
BRB 22-1	5	28	0.00	6.25	2.28	1.24
BRB 22-1R	13	28	0.00	10.52	3.98	2.39
BRB 22-2	10	28	0.00	18.90	8.01	5.26
BRB 23-2	7	28	0.00	10.36	1.55	2.40
BRB 24-2	6	28	0.30	8.53	3.36	2.70
BRB 25-2	7	28	0.00	11.28	3.51	3.93
BRB 28-1	12	28	0.00	8.84	2.92	2.76
BRB 32-1	4	28	1.10	7.19	4.21	2.07
BRB 32-2	7	28	0.00	1.98	1.40	0.61
BRB 33-1	4	28	1.83	4.57	2.87	0.58
BRB 34-1	11	28	0.00	3.35	2.28	0.58
BRB 36-2	7	28	3.10	7.82	5.35	1.55
BRB 43-2	4	28	0.00	2.74	1.38	0.72
BRB 45-2	7	28	1.68	7.77	5.74	1.89
BRB 46-2	7	28	0.91	6.10	3.62	1.84
BRB 47-1	5	28	0.08	2.21	1.37	0.77
BRB 51-2	10	28	0.15	4.27	2.19	0.79
CRB 3-1	5	28	0.00	1.80	0.84	0.87
CRB 3-2	10	28	0.00	1.83	0.86	0.88
CRB 4-1	4	28	0.00	2.04	0.61	0.67
CRB 10-2	4	28	0.00	1.37	0.33	0.37
CRB 11-1	8	28	0.26	10.02	4.30	2.61
CRB B-1	4	3	0.00	7.77	2.59	4.49
CRB B-3	7	3	0.00	5.06	2.56	2.53
CRB B-5	4	3	0.00	0.00	0.00	0.00
BRB 54-1	6	28	0.00	1.94	0.82	0.83
BRB 55-1	9	21	1.16	6.34	3.71	1.85
BRB 56-1	8	28	0.00	2.01	1.00	0.86
BRB 56-2	9	28	0.66	2.03	1.53	0.37
BRB 57-1	10	28	0.91	2.90	1.76	0.45
BRB 57-2	9	28	0.00	1.70	0.94	0.75
BRB 58-1	10	28	0.00	1.96	1.23	0.73
BRB 58-2	11	28	0.80	2.47	1.90	0.41
BRB 59-1	9	28	0.00	3.66	1.83	1.02
BRB 59-2	10	21	0.00	3.48	1.57	0.89
BRB 60-1	11	28	0.00	4.35	1.50	1.13
BRB 60-2	9	28	0.00	2.13	1.40	0.67
BRB 11-1	8	28	1.83	14.78	13.23	3.11

NOTES:

1. CSL/SSL testing time from concrete placement
2. NC = Number of tested combinations
3.  $\sigma$  = Standard Deviation

Table 4. Statistical Summary of PVC Access Tubing Debonding Depths – SSL Testing.

Shaft	Time <sup>1</sup> (days)	NC <sup>2</sup>	Debonding Depths (m)			
			Min.	Max.	Ave.	$\sigma^3$
BRB 24-2	6	8	1.52	9.14	3.60	3.24
BRB 25-2	7	8	0.00	1.22	0.15	0.43
BRB 28-1	12	8	0.00	0.00	0.00	0.00
BRB 32-1	4	8	0.00	1.10	0.50	0.44
BRB 32-2	7	8	0.00	1.22	0.30	0.56
BRB 33-1	4	8	0.00	3.05	0.86	1.12
BRB 34-1	11	7	0.00	0.61	0.09	0.23
BRB 36-2	7	8	0.36	0.36	0.36	0.00
CRB 3-1	5	8	0.00	1.19	0.15	0.42
CRB 3-2	10	8	0.00	1.22	0.15	0.43
CRB B-1	4	3	0.00	7.77	2.95	4.21
CRB B-3	7	3	0.00	4.75	2.46	2.38
CRB B-5	4	3	0.00	0.00	0.00	0.00
BRB 54-1	6	8	0.00	0.00	0.00	0.00
BRB 55-1	9	7	0.09	5.12	2.79	2.18
BRB 56-1	8	8	0.00	0.00	0.00	0.00
BRB 56-2	9	8	0.05	0.97	0.18	0.32
BRB 57-1	10	8	0.00	0.00	0.00	0.00
BRB 57-2	9	8	0.00	0.00	0.00	0.00
BRB 58-1	10	8	0.00	0.13	0.02	0.04
BRB 58-2	11	8	0.04	0.04	0.04	0.00
BRB 59-1	9	8	0.00	0.91	0.23	0.42
BRB 59-2	10	8	0.00	0.74	0.09	0.26
BRB 60-1	11	8	0.00	0.00	0.00	0.00
BRB 60-2	9	8	0.00	0.91	0.15	0.33

NOTES:

1. CSL/SSL testing time from concrete placement
2. NC = Number of tested combinations
3.  $\sigma$  = Standard Deviation

Table 5. Statistical Summary of Steel Access Tubing Debonding Depths – CSL Testing.

Shaft	Time <sup>1</sup> (days)	NC <sup>2</sup>	Debonding Depths (m)			
			Min	Max	Ave.	$\sigma^3$
BRB 26-2	11	28	1.58	5.85	3.73	1.27
BRB 30-1	5	9	1.60	3.43	2.81	0.51
BRB 45-2	7	12	0.00	1.75	0.60	0.78
BRB 46-2	7	12	0.00	1.68	0.67	0.78
BRB 47-1	5	12	0.00	1.75	0.97	0.71
BRB 51-2	10	12	0.00	1.98	0.64	0.94
CRB 3-1	5	9	0.00	1.68	1.12	0.64
CRB 3-2	10	12	0.00	2.04	0.72	0.88
CRB 4-1	4	9	0.00	1.98	0.71	0.86
CRB 10-2	4	12	0.00	1.58	0.77	0.65
CRB 11-1	8	12	0.00	1.80	0.82	0.79
BRB 54-1	6	12	0.00	0.35	0.08	0.14
BRB 55-1	9	12	0.02	1.77	0.71	0.86
BRB 56-1	8	12	0.00	1.68	0.58	0.73
BRB 56-2	9	12	0.00	1.80	0.40	0.66
BRB 57-1	12	12	0.00	1.68	0.57	0.82
BRB 57-2	9	12	0.00	1.68	0.57	0.79
BRB 58-1	10	12	0.00	0.41	0.06	0.12
BRB 58-2	11	12	0.00	2.13	0.83	0.86
BRB 59-1	9	12	0.00	1.98	0.66	0.82
BRB 59-2	10	12	0.00	2.02	0.66	0.90
BRB 60-1	11	12	0.00	2.20	1.05	0.85
BRB 60-2	9	8	0.30	1.98	1.10	0.64

NOTES:

1. CSL/SSL testing time from concrete placement.
2. NC = Number of tested combinations.
3.  $\sigma$  = Standard Deviation

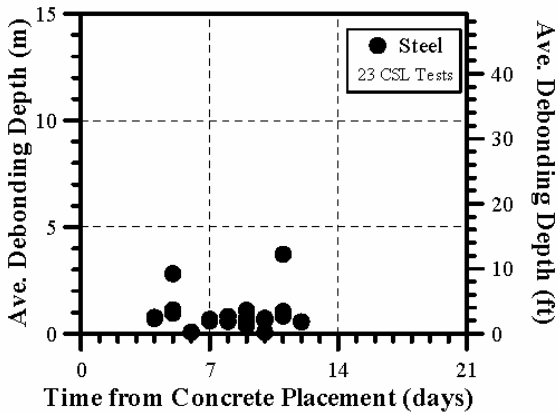


Figure 9. Average Debonding Depth vs. Elapsed Time (Steel-CSL).

As shown in Figure 7, no clear relationship was observed between average debonding depth vs. elapsed time from concrete placement within the PVC access tubing. This was reinforced by the statistical analysis of the debonding data for the PVC access tubing, which showed wide variations between debonding depths within individual combinations for any given shaft.

Analysis of the average tube debonding depth within PVC access tubing using SSL testing for this project showed that average access tube debonding depth did not significantly increase up to 12 days from concrete placement for this project. Further analysis of the statistical data showed little variation between debonding depths within individual access tube tests for any given shaft. It is unknown why the SSL testing did not show indications of access tube debonding to the extent of the CSL testing.

Analysis of the tube debonding within steel access tubing for this project showed that average access tube debonding depth did not significantly increase up to 12 days from concrete placement for this project. Further analysis of the statistical data showed little variation between debonding depths within individual combinations for any given shaft.

Comparison of the CSL data between the PVC and steel access tubing for the twenty one (21) drilled shafts with both access tube types showed no corresponding near Top Of Shaft (TOS) anomalies. The lack of corresponding near TOS anomalies confirmed that the erratic ultrasonic signals near the shaft top within the

PVC access tubing were due to access tube debonding.

### **CONCLUSIONS AND RECOMMENDATIONS**

Based on the analysis of the presented data, the following conclusions were made:

- The average depth of tube debonding within PVC access tubing for this project varied considerably within the sonic logging testing time frame for PVC (i.e. 5 to 13 days from concrete placement).
- Average depth of tube debonding within the steel access tubing for this project did not significantly vary up within the sonic logging testing time frame for steel (i.e. 5 to 12 days from concrete placement).
- Failure to place water within the access tubing after or before concrete placement greatly increased the average depth of access tube debonding within the PVC access tubes.
- The use of both PVC and steel access tubes within the water drilled shafts confirmed that the upper CSL anomalies within the upper portions could be attributed to access tube debonding.

The results of this project clearly show that the use of steel access tubing should be preferred over PVC. The authors note that for future South Carolina Department of Transportation (SCDOT) projects, the use of PVC access tubing is not allowed for sonic logging testing.

Debonding, while acknowledged as a source of potential problems for sonic logging testing, is still a phenomenon that is not fully understood. This is illustrated by the lack of a clear relationship between debonding observed within the CSL and SSL testing for the PVC access tubing. Clearly, future research is needed in this area.

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