CROSSHOLE SONIC LOGGING: INSIGHTS ON TESTING NEVADA INFRASTRUCTURE

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ABSTRACT

For over three years, Terracon Consultants, Inc. (Terracon) has been performing nondestructive testing (NDT), including Crosshole Sonic Logging (CSL) and Sonic Echo (SE) testing, of Nevada infrastructure, particularly highway bridge structures. CSL testing is highly recommended, particularly in certain conditions, including deep shafts, shafts drilled in loose sands, or shafts drilled below the groundwater table. These conditions can adversely affect the construction and subsequent quality of a drilled shaft. NDT testing can determine shaft integrity in areas that may not be evident to field inspectors. In some cases, subsurface issues such as sloughing and other conditions may affect the shaft. These issues may not be apparent to field inspectors.

It should be noted that NDT testing, such as CSL and SE, is not a substitute for onsite field inspection and laboratory testing. However, it provides complementary quality assurance that the drilled shaft integrity is acceptable.

CSL and SE testing should be performed concurrently. In our experience, SE testing performed at the time of CSL testing is convenient, easy to perform, and provides a second method of quality assurance. Certain situations, such as debonding of the concrete away from the PVC or steel CSL access tubes, may cause signal reduction or a loss of signal. The shaft may be sound, yet CSL testing may be inconclusive or indicate anomalies due to debonding. SE testing can be used to evaluate that portion of the shaft affected by debonding and can detect potential anomalies that are 25 percent or larger of the cross-sectional area of the shaft. Additionally, SE testing can generally be used to help verify anomalies that are detected during CSL testing and can provide added assurance that an anomaly is present before more costly methods, such as coring, are conducted.

INTRODUCTION

For nearly three years, Terracon has been performing nondestructive testing (NDT), including Crosshole Sonic Logging (CSL) and Sonic Echo (SE) testing, of Nevada infrastructure, particularly highway bridge structures. This paper is intended to document the test results of over 17,000 feet from nearly 400 drilled shafts tested in Nevada.

CSL testing is an important quality assurance tool in construction and is highly recommended, particularly in certain conditions, including deep shafts, shafts drilled in loose sands, or shafts drilled below the groundwater table. These conditions can adversely affect the construction and subsequent quality of the drilled shaft. NDT testing can determine shaft integrity, particularly in areas of sloughing that may not be evident to field inspectors. *Crosshole Sonic Logging (CSL) transmits ultrasonic pulse waves between probes in parallel tubes that are embedded in drilled shafts. Due to ease of use, CSL has become the standard method to evaluate the integrity of drilled shafts* (Likins, et al. 2004).

CSL testing has confirmed the presence of voids or soft bottoms in numerous drilled shafts throughout the state. However, CSL testing has drawbacks, with the most evident being debonding of the access tubes with the concrete. This is an important notable drawback, as debonding of the access tubes may cause such significant signal loss that CSL testing is inconclusive.

Debonding can be caused by a number of factors, including the type of access tubes used, age of the shaft, and ambient air temperature. In some cases, significant signal loss due to debonding does occur. Under these circumstances, Sonic Echo/Impulse Response (SE/IR), also known as Pile Integrity Testing

(PIT), is a technique used to complement CSL testing. This test does not require access tubes and can be performed on shafts with exposed tops. Terracon has been performing SE/IR testing in conjunction with CSL testing over the past year as a way to differentiate signal loss due to debonding or defects.

CROSSHOLE SONIC LOGGING AND DEBONDING

Terracon has performed non-destructive testing in Nevada on approximately 400 shafts, with a combined length of over 17,000 feet. The data discussed in this paper are from a variety of Nevada projects, including bridge structures on U.S. 95 in Las Vegas, the Henderson Spaghetti Bowl, and Interstate I – 580, which includes the Galena Creek Bridge, the longest concrete thin arch span in the United States.

In approximately 70 percent of the 383 shafts included in this paper, anomalous zones were not detected for the portions tested with CSL. These anomalous zones include signal reduction due to voids, soft bottom conditions, or debonding. Debonding is a condition that occurs when the access tube separates from the concrete. Concrete heats as it cures, and since the access tube material has different thermal expansion properties than the surrounding concrete, separation of the access tubes and the concrete of the drilled shaft may result.

Approximately 30 percent or 114 drilled shafts tested in Nevada contain detected anomalous zones, of which 90 cases could be attributed to debonding of the access tubes with the concrete. The remaining 24 shafts were recommended for additional testing, using Sonic Echo (SE) testing, and, in more extreme cases, coring. SE testing was typically not performed at the same time as CSL testing prior to 2006.

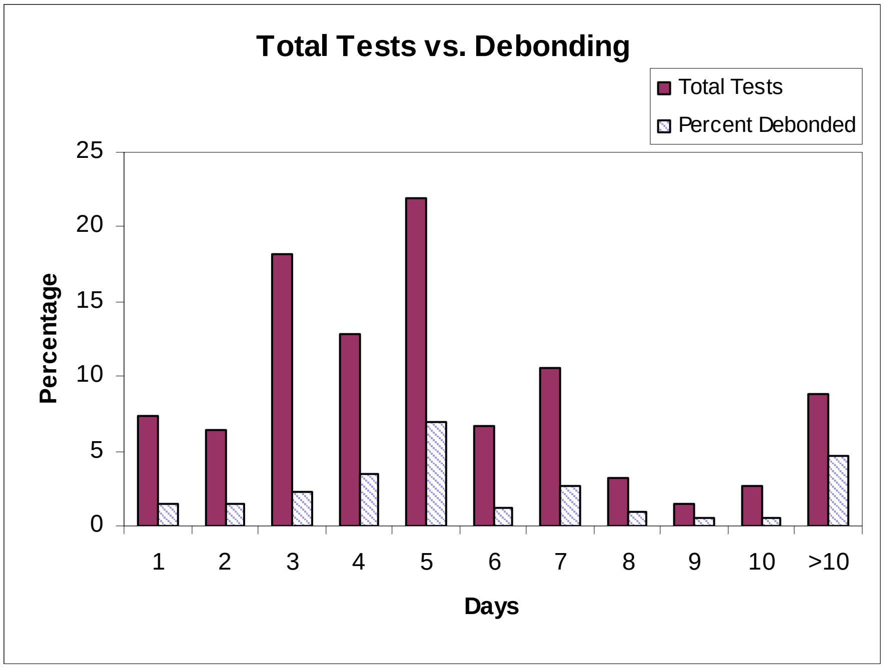
CSL testing is an important component of quality assurance testing for drilled shaft construction; however, it cannot take the place of a qualified field inspector. What CSL can provide is additional integrity information on a shaft that should be used in conjunction with on-site field inspections. However, due to the relatively low cost of CSL and SE testing, each shaft should be tested. These conditions can adversely affect the construction and subsequent quality of the drilled shaft.

Factors Affecting Debonding – Age

ASTM Standard D6760 states that *tests shall be performed no sooner than 3 to 7 days after casting depending on concrete strength and shaft diameter* (ASTM, 2002). We have found that the percentage of debonding increases greatly three days after casting. Table 1 and Figure 1 show the total number of tests performed on Nevada infrastructure projects and the associated incidence of debonding over time. Figure 2 illustrates the percentage of debonding for all shafts tested in Nevada as a function of age. According to our data set, 20% of shafts have debonded by Day 1, 23% by Day 2, and 13% by Day 3. The logarithmic best fit line shown on Figure 2 represents the increase in debonding over time for all shafts tested. The data become skewed over time, as fewer tests are generally performed after approximately 8 days. Despite ASTM recommendations, we have generally found that in most cases, CSL testing should not be performed after three days. After three days, debonding becomes a more significant issue.

Age (Days)	Total Tests	Number of Debonded Tubes	Percentage of Debonding per day
1	25	5	20
2	22	5	23
3	62	8	13
4	44	12	27
5	75	24	32
6	23	4	17
7	36	9	25
8	11	3	27
9	5	2	40
10	9	2	22
11	6	0	0
12	2	1	50
13	2	1	50
14	4	4	100
15	3	2	67
16	1	0	0
17	2	1	50
18	0	0	0
19	0	0	0
20	3	3	100
21	0	0	0
22	2	2	100
23	0	0	0
24	1	1	100
25	0	0	0
26	1	1	100
27	3	0	0
Unknown	41	0	0
Total	383	90	---

Table 1 – CSL tests and associated debonding in relation to days since casting.



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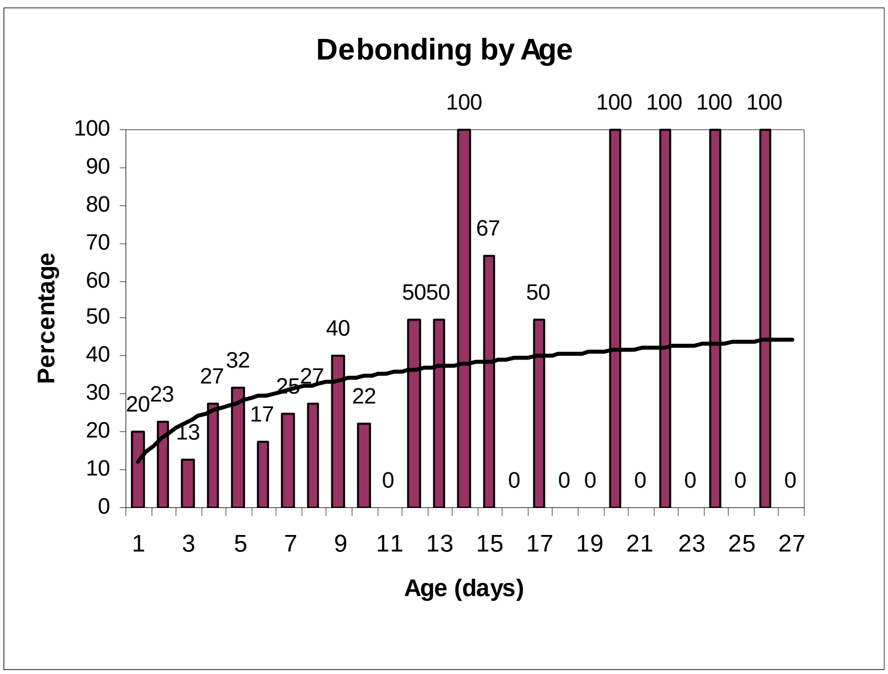

Figure 2 – Percentage of debonding in shafts as a function of days since casting.

Factors Affecting Debonding – Ambient Temperature

Figure 3 illustrates the average daily high temperature by month for Reno and Las Vegas, Nevada between 1937 and 2004. The data were provided by the Desert Research Institute (DRI, 2006). Generally, average Las Vegas temperatures are greater than 10°F warmer than average Reno temperatures.

The data presented here represent nearly three years of testing in Reno and Las Vegas, Nevada. The nine CSL tests performed on the Beowawe Bridge in Elko County, Nevada have been removed from the following data sets since Elko, Nevada is several hundred miles away from both Reno and Las Vegas and the Elko County data set was too small to use. Figures 4 and 5 illustrate the prevalence of debonding by month in each of these locations. Generally, it has been our experience that debonding is of greater concern in warmer weather or during rapid temperature fluctuations. The spikes during February shown on Figure 4 are likely due to diurnal temperature fluctuations, though further study is necessary. In addition, fewer tests are performed during the winter months, so the prevalence of debonding as a function of cold temperature is not known at this time due to the limited data set.

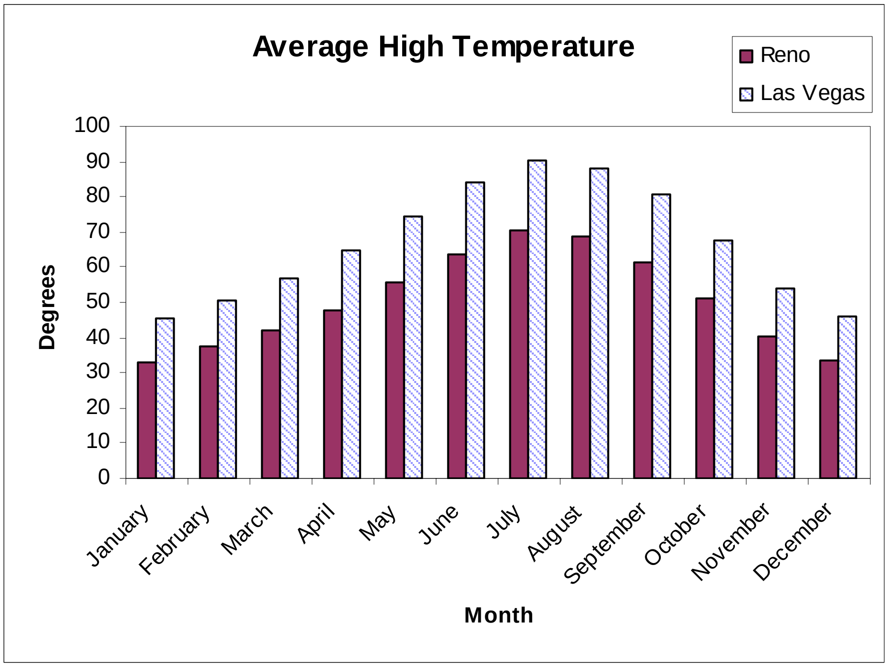

Figure 3 – Average Monthly High Temperature for Las Vegas and Reno, Nevada.

This data can be further analyzed to include the age of the shaft in relation to debonding. Figures 6, 7, 8, and 9 illustrate the prevalence of debonding in Reno and Las Vegas for shafts that are up to three days in age and for shafts that are greater than three days in age.

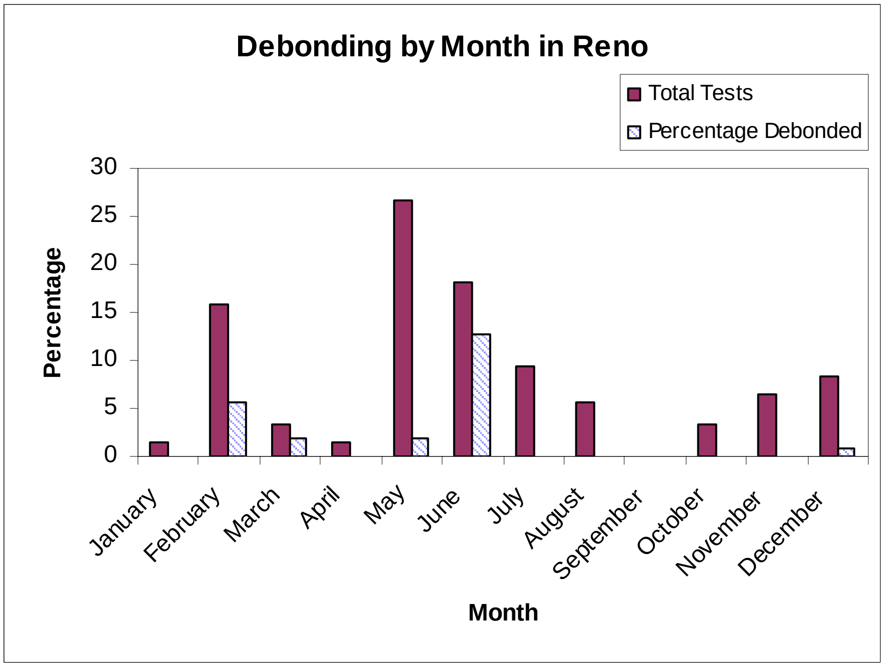

Figure 4 – Percentage of Debonding in shafts for Reno, Nevada.

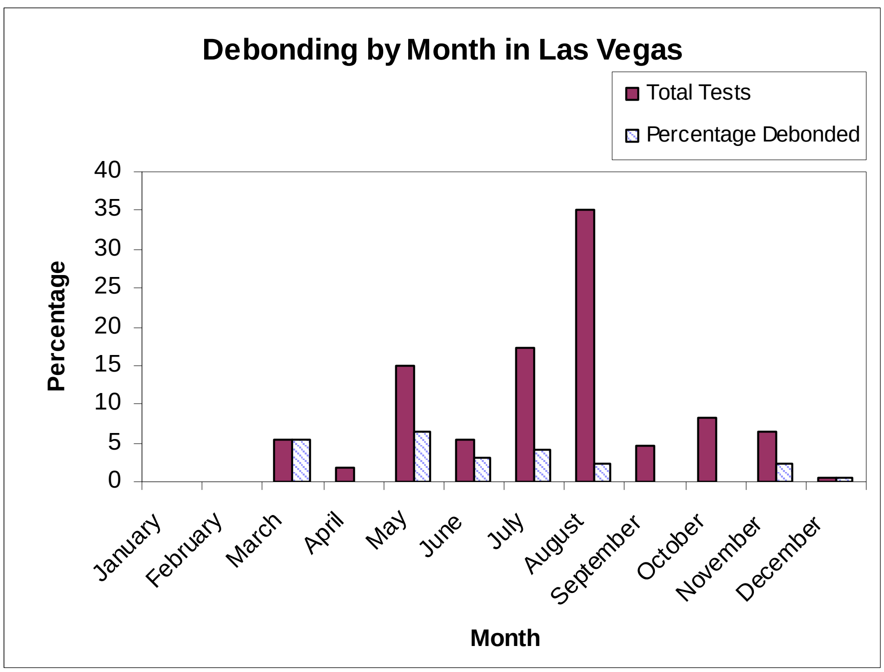

Figure 5 – Percentage of Debonding in shafts for Reno, Nevada.

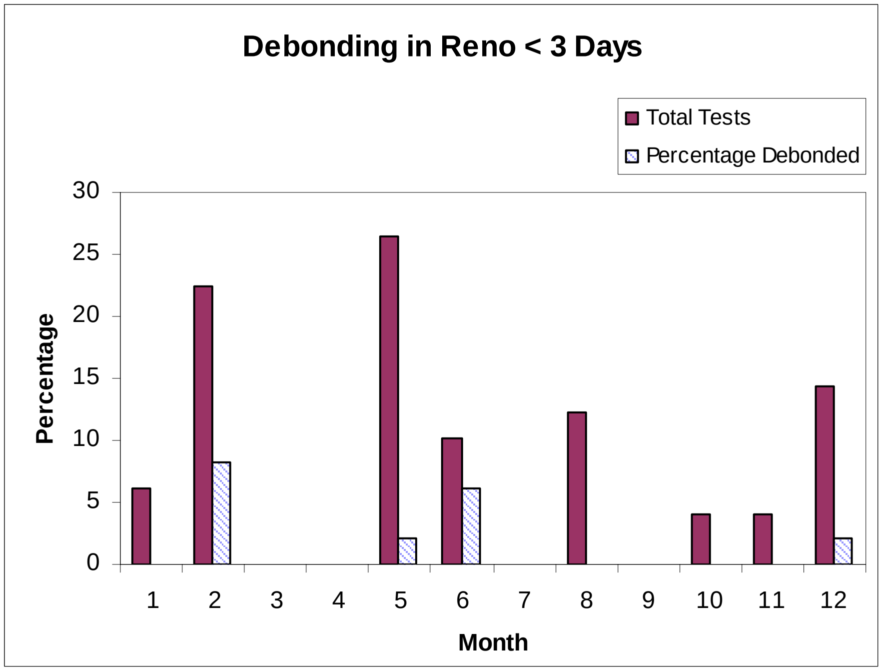

Figure 6 – Percentage of debonding in shafts 3 days or younger in Reno, Nevada.

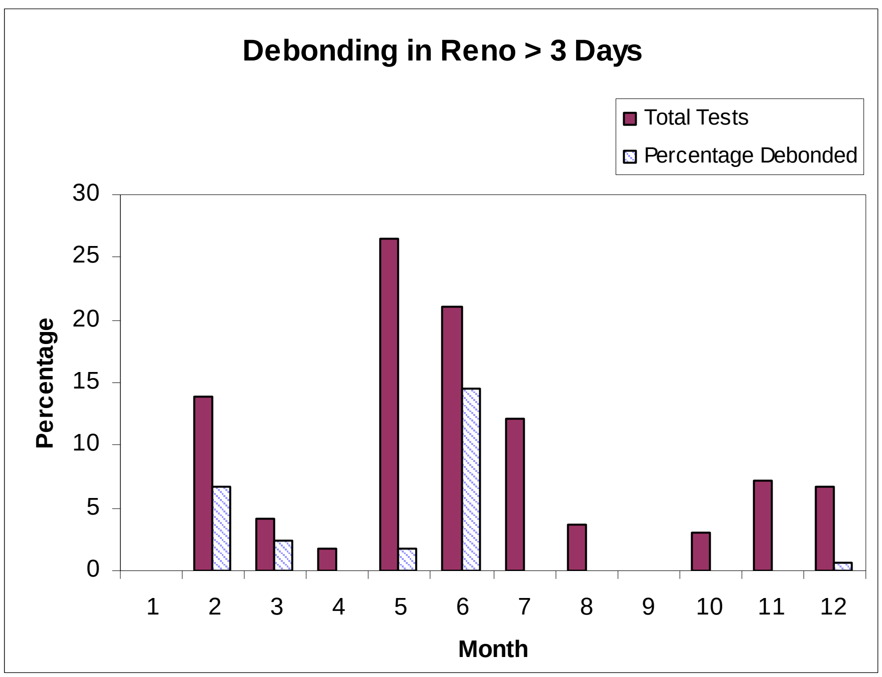

Figure 7 – Percentage of debonding in shafts 3 days or older in Reno, Nevada.

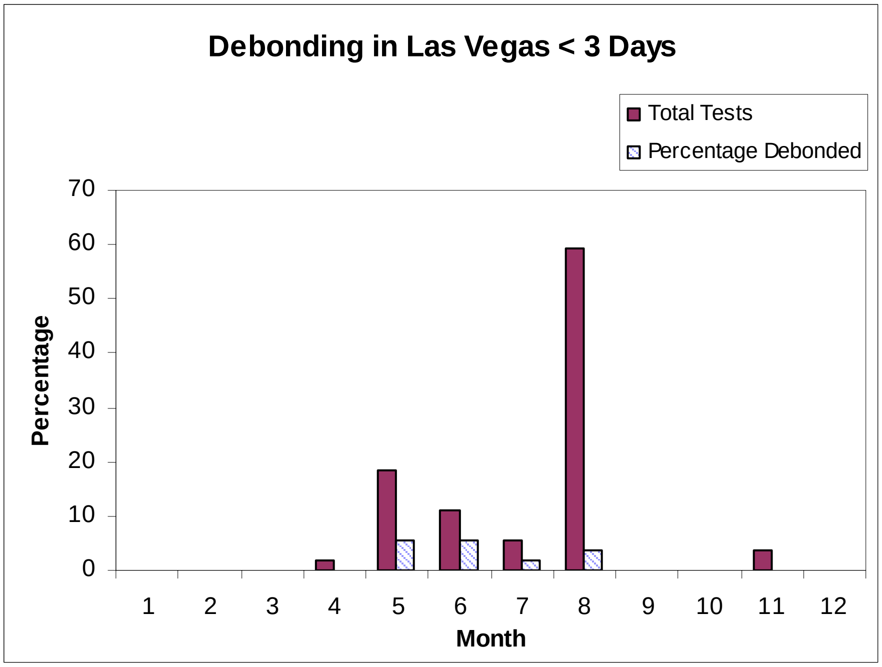

Figure 8 – Percentage of debonding in shafts older than 3 days for Las Vegas, Nevada.

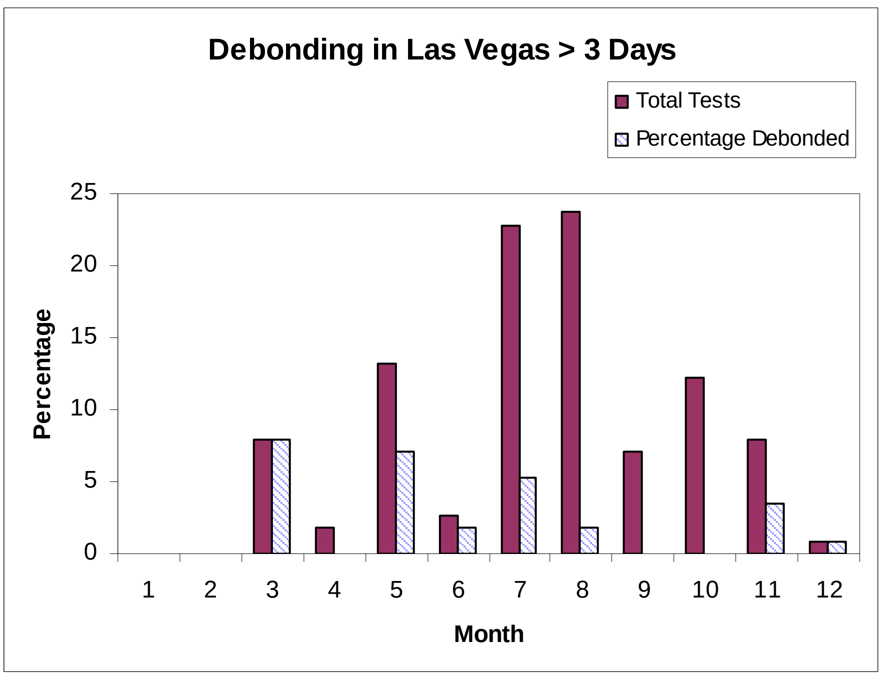

Figure 9 – Percentage of debonding in shafts older than 3 days for Las Vegas, Nevada.

Factors Affecting Debonding – Access Tube Composition

ASTM D6760 states that access tubes shall be composed of *preformed steel or plastic tubes* (ASTM, 2002). All of the 168 tests conducted in the Las Vegas area were in shafts with PVC access tubes, and 110 of 206 tests performed in the Reno area were in shafts with PVC access tubes. Ninety-six tests in the Reno area were in shafts with steel access tubes. Nine shafts associated with the Beowawe Bridge Project were removed from the analysis due to the limited data set in eastern Nevada.

Shafts with access tubes made of PVC account for approximately 74% of all the shafts tested in Nevada. As the results show in Figure 10, PVC access tubes were found to debond in approximately 25% of the shafts tested. Figure 10 does not take into account the age of the shafts being tested.

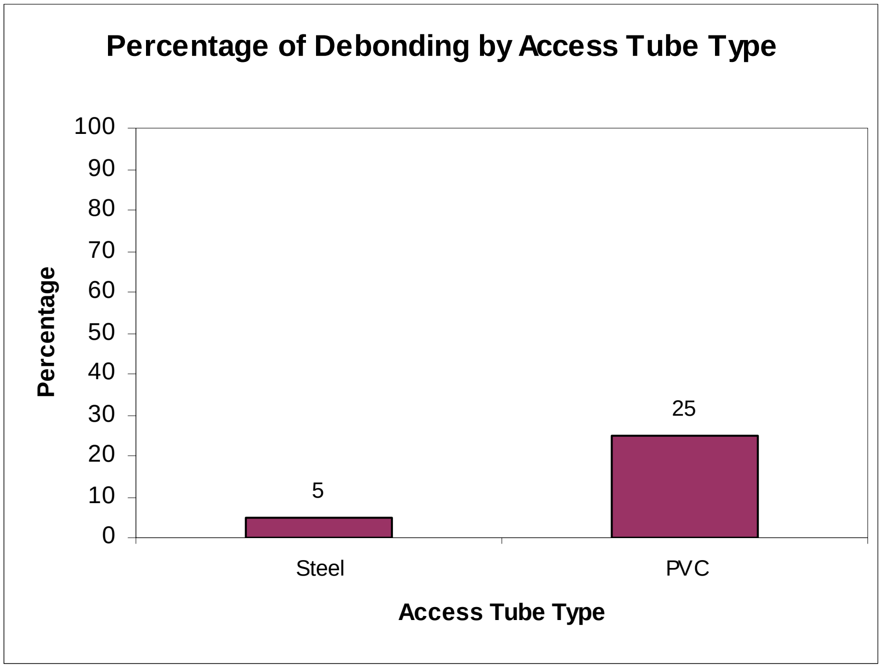

Figure 10 – Percentage of debonding based on access tube composition.

CROSSHOLE SONIC LOGGING AND SONIC ECHO TESTING

Sonic Echo (SE) testing, first utilized in the 1970's (Steinbach, 1975), has since been gaining acceptance and now is standardized under ASTM D5882. The test is generally quick and inexpensive to perform in the field, and little preparation needs to be done on the shafts. Unfortunately, experienced data analysts are required to interpret the data, and occasionally the records are inconclusive due to shaft length or multiple defects (Rausche, 2004).

SE testing can be used to determine shaft length or detect anomalies in the shaft, such as soil inclusions, diameter increases (bulbs), and diameter decreases (necking). Testing is performed by impacting the shaft top with a small hand-held hammer and measuring the response with an accelerometer (Hussein and Likins, 2005) and can be performed as soon as the concrete achieves at least 75 percent of its design strength.

SE testing is not dependent on access tubes and therefore is not affected by access tube debonding. Prior to 2006, Terracon did not perform SE testing at the same time as CSL testing. SE testing became a standard and complimentary method at the beginning of 2006. The SE method was employed when the integrity of the drilled shafts could not be determined due to severe debonding and to perform a second integrity check of the shaft.

To date, SE testing has been performed on 28 of the shafts analyzed here. These shafts contained anomalies detected from prior CSL testing. Of those 28 tests, eight of them contained confirmed defects that could also be correlated to CSL testing. SE testing of the other 20 shafts indicated no detected anomalies, and the anomalous zones were generally attributed to access tube debonding.

It is our opinion that SE testing is an important tool in determining concrete drilled shaft quality. Terracon has recommended coring for eight shafts in which CSL testing has indicated anomalies. Of the eight shafts cored, three of them contained defects and five were shown to have no known defects. Coring of shafts is expensive, time consuming, and generally has a low success rate due to the small core diameter used. Performing SE testing before coring can save time and money and should become a part of the project specifications.

SUMMARY

Terracon has been performing nondestructive testing (NDT), including Crosshole Sonic Logging (CSL) and Sonic Echo (SE) testing, of Nevada infrastructure, particularly highway bridge structures. Our experience has allowed for the improvement of testing techniques and recommendations so that quality data can be collected during CSL testing, minimizing construction delays.

Access Tube debonding has significant impact on the quality of data collected during CSL testing. Anomalous zones in concrete shafts can have a major impact on a project, and anomalies caused by access tube debonding are no exception. Being aware of complications that may arise, and having good communication with the construction personnel are vital. Owner's representatives and others involved in drilled shaft construction management should be aware of issues involved with shaft integrity testing; including scheduling of CSL testing within several days of pouring and using steel access tubes to significantly reduce the occurrence of debonding. In addition, representatives should be aware of higher incidences of access tube debonding during periods of high ambient air temperatures and/or large diurnal temperature fluctuations.

Sonic Echo testing is a viable secondary test that can be performed at the same time as CSL testing. The test is fast, inexpensive to perform, and can generally determine between anomalies in a shaft and debonding. SE testing should always be performed in anomalies are detected during CSL testing.

In conclusion, for the majority of shafts that CSL tests were performed, the results are generally indicative of good quality concrete. By understanding the causes of debonding and testing the shafts sooner and recommending the use of steel access tubes, anomalous zones due to debonding can be minimized.

References

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