Successful Testing Methods for Unknown Bridge Foundations

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ABSTRACT

The United States Federal Highway Administration has estimated that there are approximately 80,000 bridges with unknown foundations that may be susceptible to damage due to scour at abutments and piers in high water flow events. In partial response, the North Carolina Department of Transportation (NCDOT) identified 6000 bridges across the state where the type or depth to the bottom of the foundation was unknown. This paper discusses the strategy and methods developed to assist the NCDOT in deciding which NDE testing methods would be most appropriate for bridges identified as having unknown foundations. Case histories in which the lengths of in-service H-Piles were determined using an induction method are also presented.

INTRODUCTION

The United States Federal Highway Administration has estimated that there are more than 80,000 bridges with unknown foundations (Richardson and Davis, 2001). Some of these may be susceptible to damage due to scour at abutments and piers in high water flow events. In partial response, the North Carolina Department of Transportation (NCDOT) identified 6000 bridges across the state where the type of foundation or depth to the bottom of the foundation was unknown. Due to the large number of bridges, the NCDOT began a program to determine the bridge foundation types, the depths to the bottom of the foundations and soil conditions at the bridge locations. GRL was one of four consultants selected to assist the NCDOT in determining this information.

A brief description of all of the testing methods that GRL employed for determination of the unknown foundations at various bridge locations is provided below. Other methods were used by the other selected engineering firms. However, the primary purpose of this paper is to present a less-used testing method for determining the lengths of steel piles. GRL has performed this testing at several bridge projects and we have found it to be very successful in determining the lengths of steel piles.

NCDOT PROGRAM

The NCDOT unknown foundations program consisted of five distinct phases. The first phase was completed by NCDOT personnel and consisted of identifying all bridges where the bridge foundations were unknown. This was generally accomplished by reviewing the existing bridge maintenance files or as-built drawings. In Phase 2 the selected consultant conducted a second review of the bridge maintenance files for bridges that had been identified as having unknown foundations. In this way a thorough review of the existing documents would be performed prior to any field testing.

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In Phase 3 of the program the consultant recommended Non-Destructive Evaluation (NDE) methods for evaluating each bridge identified as having an unknown foundation based upon the expected bridge foundation type and local geology. Once the NDE methods to be employed were determined, Phase 4, performing the testing, was carried out. Finally, a report for each bridge structure was prepared to be included in the bridge maintenance files to document the results of the NDE testing.

AVAILABLE METHODS

Driving Rods

The most common testing method performed by all of the consultants was a driven rod test, which was conducted to assess the likelihood of deep foundation or shallow foundation, the latter if the drive rod test indicated intermediated geomaterial or rock near the surface at the bridge site. The driven rod tests consisted of driving a 0.5-inch diameter steel rod into the subsurface near the bridge foundation units. The 0.5-inch rod was driven with a 15 pound hammer dropped from a height of 2 feet. Blow counts per foot of driving were documented from the ground surface to the final rod penetration, which was usually at the point where refusal of the driven rod occurred. This evaluation of the subsurface conditions is crude, but often supplied important information concerning the depth to weathered rock, dense sand layers or soft soil layers. Typically, rods could be driven up to 30 feet below grade although most of the driven rod testing GRL performed resulted in refusal at depths of between 5 and 10 feet.

Low Strain Integrity Testing

Low strain pulse echo testing was employed for most bridge locations where driven concrete, timber or steel piles were encountered. In almost all cases this required mounting of one or two low strain accelerometers along the side of the pile, striking either the pile top, grade beam or an impact block also mounted on the side of the pile and reading the ensuing velocity traces in the PIT equipment. Typically, this method worked well for the concrete and timber piles as can be seen from the results obtained for two bridge foundations shown in Figure 1 and
Figure **2**. Whenever exposed pile lengths allowed, two velocity pulse echo tests were performed to aid in evaluation of the pile wave speed as shown in Figure 1 which shows low strain velocity signals in a time (horizontal) length (vertical) plot for locations near the pile top and 5 ft below it. Results for steel piles were less conclusive as the collected records were much more difficult to interpret, often because the steel H-piles were concrete encased at, and below, the water line. A successful low strain test record, i.e. pile top velocity vs. time, is shown for a steel pile in
Figure **3**. An advantage of testing steel piles by the low strain method is given by the accurately known wave speed while typically a 10% uncertainty exists for the wave speed in concrete. The indicated pile length is only as accurate as the assumed or known wave speed.

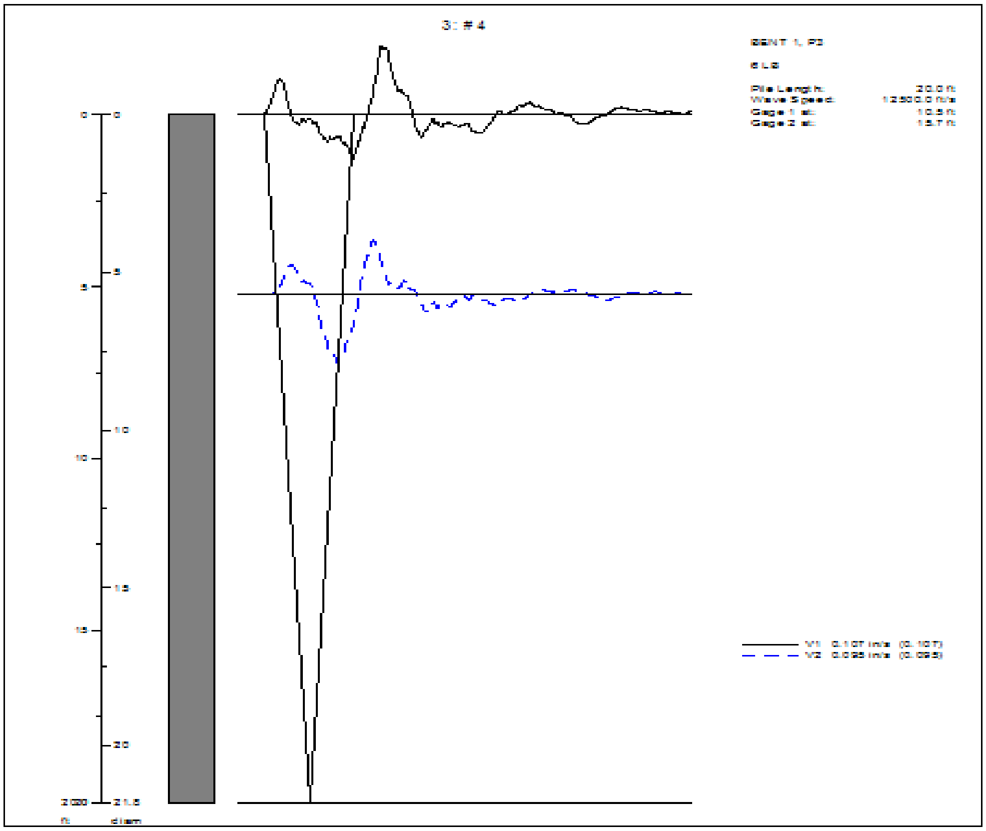


Figure 1. Two Velocity Signals in a Length-Time Plot from Pulse Echo Test on Concrete Pile

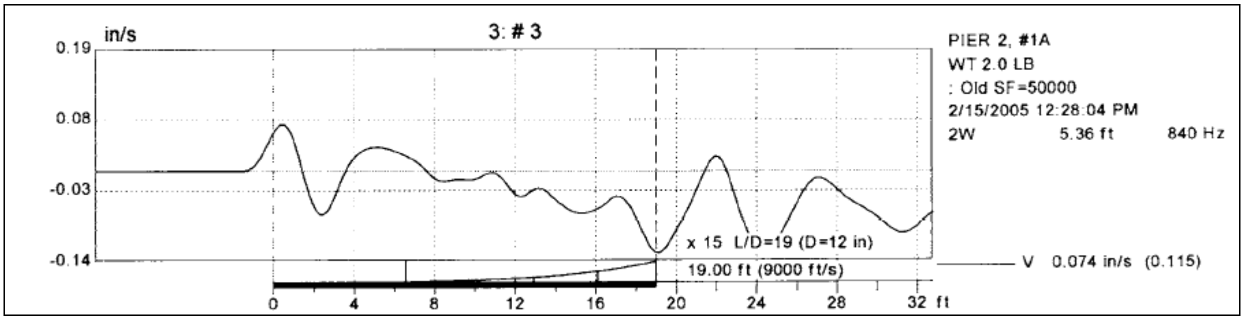


Figure 2. Pile Top Velocity from Pulse Echo Test on Timber Pile

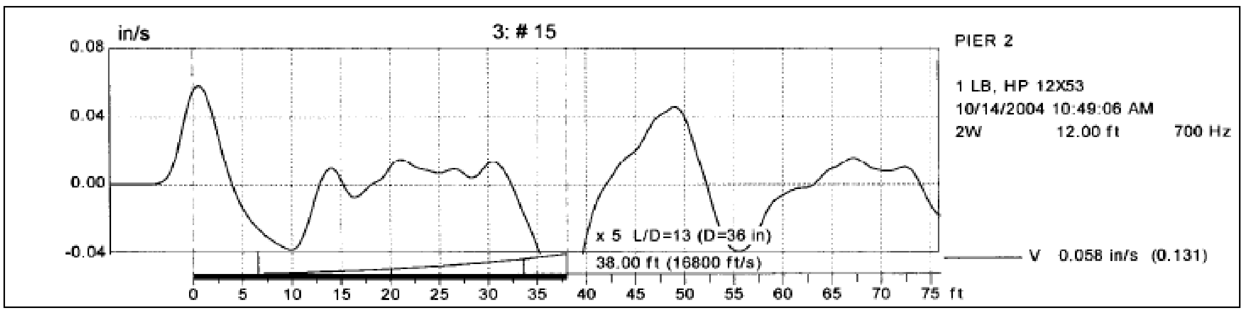


Figure 3. Pulse Echo Test on Steel Pile

Parallel Seismic

Parallel seismic (PS) testing was performed at one bridge structure where a determination of the depth to the bottom of its spread footing foundations was considered critical. The bridge structure in question was a relatively large structure (approximately 1600 feet long) and was known to have been constructed using spread footing foundations placed upon competent rock. However, bridge inspection records indicated that scour of the existing foundations had been noted over the past years. Therefore, it was considered critical that the elevation of the bottom of the spread footings be determined at those piers where scour was evident.

Pulse echo and parallel seismic testing was performed at four of the twenty-six substructure units. In order to complete the PS testing, it was necessary to drill borings next to the pier, lower a hydrophone in those bore holes and impacting against the foundation with a hand held hammer to generate and measure stress wave arrival in the bore hole by means of the hydrophone. The depth of the foundation is found as the point where the stress wave arrival is noticeably delayed by transmission through soil rather than structure. The boreholes consisted of drilling a rock core to a depth of approximately 15 feet and grouting a PVC pipe in the completed borehole. The PVC pipe was generally 30 to 35 feet long to extend from the bottom of the borehole to approximately 5 feet above the river water level. PS testing was then conducted in order to determine the depth to the bottom of the footing elevation. Compiled results are shown in Table 1.

Table 1. Low Strain and Parallel Seismic Test Results for 1600 ft Long Bridge

Bent	Water Depth During Test (ft)	Pulse Echo Length Below Water (ft)	Parallel Seismic Length Below Water (ft)
14	16.8	19	17
15	16.9	18	19
16	16.7	20	19
20	8.5	10	10

Induction Method

Induction testing is performed by lowering an induction sensor through a PVC pipe placed in a borehole. The induction sensor acts in a similar manner to a metal detector, creating a magnetic field which is disrupted be any metal object. The disruption results in the metal object creating its own magnetic field which is then detected by the induction sensor. This results in a received voltage which is recorded by the Length Inductive Test Equipment (LITE). Readings are recorded every foot as a minimum, but may be recorded every 3 or 6 inches to further refine the measurement. The induction sensor is simply lowered into the PVC pipe and voltage readings are taken to the full depth of the PVC pipe. The length of the pile in question is determined by the depth at which LITE no longer indicates a received voltage.

CASE HISTORIES

North Carolina

A bridge located in central North Carolina was identified as having an unknown foundation by the NCDOT. Upon first review of the bridge maintenance documents it was clear that the single span bridge was supported by steel H-piles at the abutments. Upon site review of the bridge it was determined that pulse echo testing of the H-piles would be difficult due to the limited amount of pile extending above grade. To further complicate the situation, the piles were also concrete encased at the ground surface. Because of these conditions it was determined that the best means to estimate the length of these piles would be to perform an induction test using the LITE equipment.

The induction test was performed through a PVC-cased borehole near one of the piles in Abutment A (second pile in from the east). The borehole was extended to a depth of 21.5 feet below the ground surface and was located seven inches from the flange of the H-pile. This was important because the maximum horizontal distance for a successful induction test is approximately 18 inches. The PVC pipe was grouted in place and continued to the top of the pile. The induction testing was performed from the pile top to the bottom of the PVC pipe which was approximately 24 feet long. The results of the induction test are provided in Figure 4 and the soil boring information is provided in
Figure 5. Based upon these results it was determined that the pile penetrates approximately one foot into to the weathered rock indicated in the soil boring.

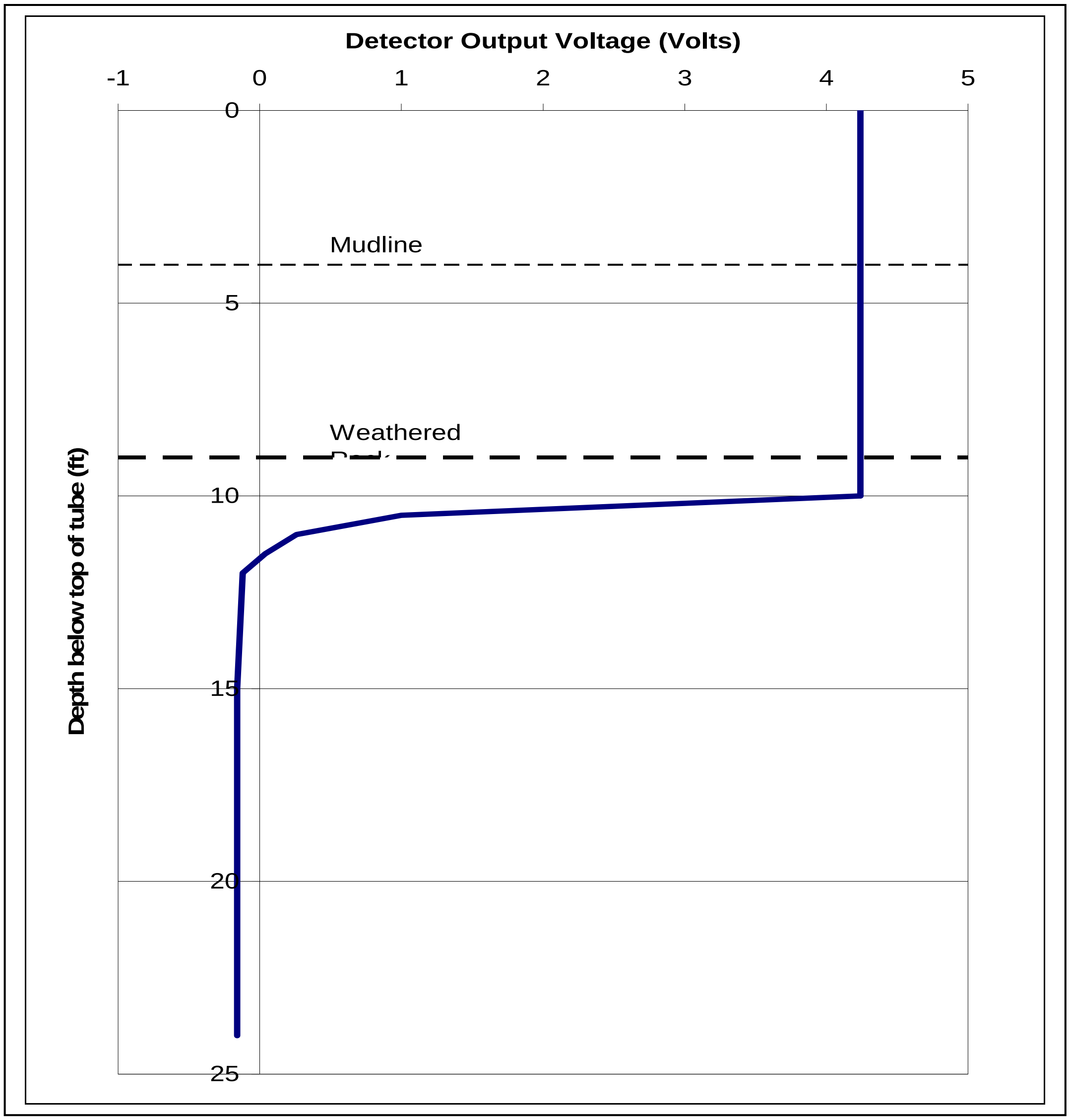
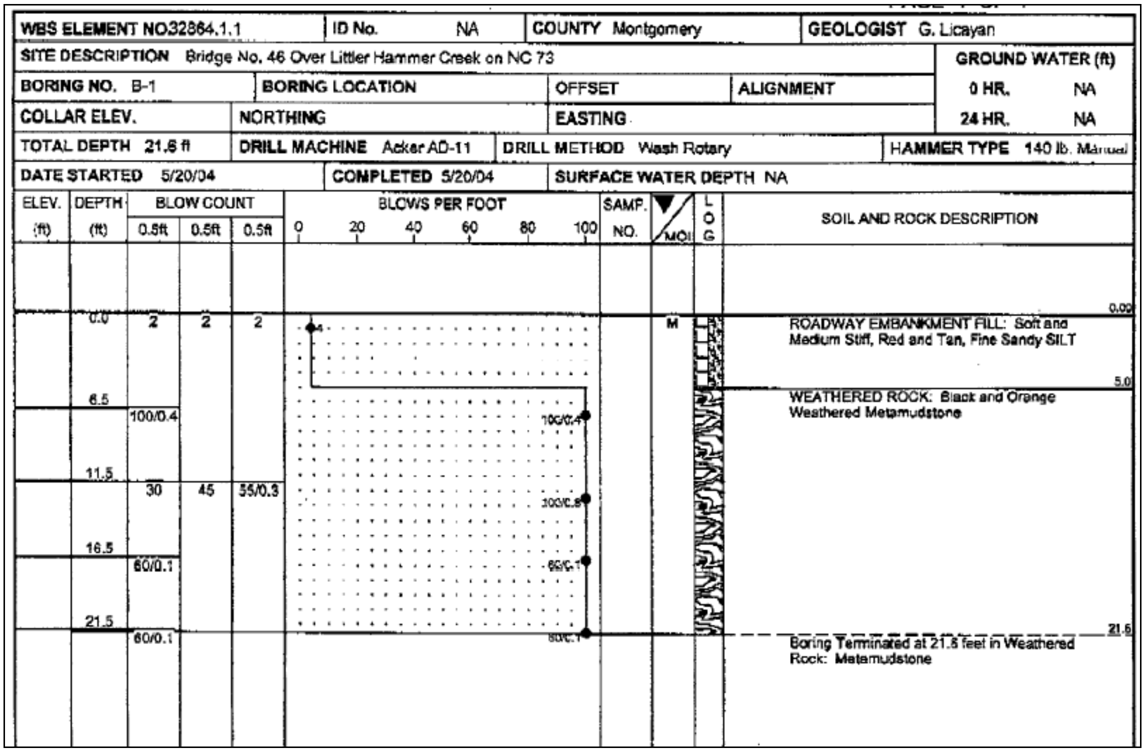


Figure 4. Induction Test Results – NCDOT Bridge



WBS ELEMENT NO32864.1.1 | ID No. NA | COUNTY Montgomery | GEOLOGIST G. Licayan

SITE DESCRIPTION Bridge No. 46 Over Littler Hammer Creek on NC 73 | GROUND WATER (ft)

BORING NO. B-1 | BORING LOCATION | OFFSET | ALIGNMENT | 0 HR. NA

COLLAR ELEV. | NORTHING | EASTING | 24 HR. NA

TOTAL DEPTH 21.6 ft | DRILL MACHINE Acker AD-11 | DRILL METHOD Wash Rotary | HAMMER TYPE 140 lb. Manual

DATE STARTED 5/20/04 | COMPLETED 5/20/04 | SURFACE WATER DEPTH NA

ELEV. (ft)	DEPTH (ft)	BLOW COUNT 0.5ft	0.5ft	0.5ft	BLOWS PER FOOT 0 20 40 60 80 100	SAMP. NO.	MOI	LOG	SOIL AND ROCK DESCRIPTION
	0.0	2	2	2			M		0.00 ROADWAY EMBANKMENT FILL: Soft and Medium Stiff, Red and Tan, Fine Sandy SILT
									5.0 WEATHERED ROCK: Black and Orange Weathered Metamudstone
	6.5	100/0.4			100/0.4				
	11.5	30	45	55/0.3	100/0.8				
	16.5	60/0.1			60/0.1				
	21.5	60/0.1			60/0.1				21.6 Boring Terminated at 21.6 feet in Weathered Rock: Metamudstone

Figure 5. Soil Boring Data - NC Site

In addition to the induction test a driven rod test was conducted at Abutment A. The driven rod test consists of driving a 0.5 inch diameter rod to refusal using a 15 lb hammer dropped approximately two feet. Results of the rod tests are provided in Table 2. It is of interest to note that the driven rod test indicated the denser soils of the weathered rock layer at the 5 foot penetration. This is approximately the same depth indicated by the soil boring. However, the driven rod blow counts increased from 3 blows per foot to 27 blows per foot at the 5 foot penetration. The next foot of driving indicated a blow count of 53 blows per foot. These results are somewhat surprising as the blow counts normally associated with these types of soil conditions would have been expected to be much higher.

Pennsylvania

A second case history in induction testing involves a bridge located in Western Pennsylvania. This bridge had undergone some apparent settlement and the length of the HP 10x42 steel H-piles needed to be determined. The apparent settlement was primarily located at one bridge pier. Therefore, testing to determine the length of the piles at this pier was undertaken using induction testing. Figure 6 shows a picture of the substructure unit and the installed PVC pipes through which the induction testing was conducted.

Table 2 Driven Rod Test – NC Site

Depth Below Grade (feet)	Rod Results (Blows/ft)
1	Push
2	3
3	11
4	3
5	27
6	53
7	35
8	57
9	63
9.8	100/9"

Figure 6. PVC Tubes for LITE

As shown in Figure 6, two PVC tubes were installed near the edge of the pile cap and approximately 14 inches from the sides of two pile locations. Therefore, the length of two of the piles in this cap could be evaluated. The results of the induction testing are shown in Figure 7. Note that the induction test was performed twice with average reading calculated in the deeper zones. To the right of the recorded received voltage the depths at which reported obstructions were encountered during drilling for the PVC tubes is noted. The obstructions included but may not have been limited to concrete slabs, steel components and voids.

The induction test results at this bridge substructure clearly indicate that the bottom of the piles are located at approximately elevation 694 and 690 or pile lengths of 43 and 47 feet, respectively.

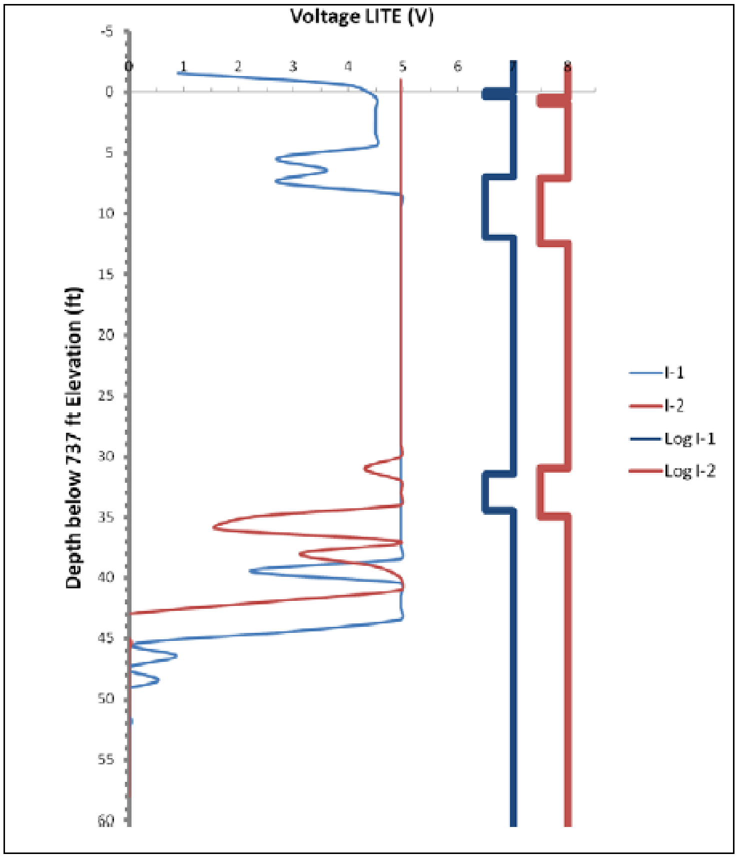


Figure 7. LITE Test Results - PA site

CONCLUSIONS

The examples provided demonstrate reasonable means for estimating the length of unknown pile foundations. Low strain integrity testing, parallel seismic testing and induction methods were described, and relevant examples of data from each test were presented. In addition, use of driven rod testing, while rather crude, does provide some information concerning the subsurface conditions at these bridge structures.

The two case histories where induction testing was performed for steel H-piles indicated that this method of evaluation provides a simple yet definitive method to determine the length of steel piles. This method is limited to projects where a PVC tube can be placed in a boring within approximately 18 inches of the existing pile. In addition, only one pile can reasonably be tested for each PVC tube location. Under these conditions, the system provides definitive information concerning pile lengths with results that can be interpreted with relatively little training.

ACKNOWLEDGEMENTS

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