

CHAPTER 9

LONG TERM MONITORING AT THE ROUTE 351 BRIDGE

9.1 INTRODUCTION

An important reason that composite piles have not gained wide acceptance in the civil engineering practice is the lack of a long track record of performance. To help fill this void, a long term monitoring program was implemented at the Route 351 bridge project. The initial plan was to compare the performance of three adjacent bridge piers each supported by different pile types. The three pile types initially considered for this study were: Lancaster composite piles, Hardcore composite piles, and VDOT standard prestressed concrete piles. Unfortunately, the scope of the monitoring program was reduced due to withdrawal from the project by Lancaster Composites Inc., and a request from Hardcore Composites Inc. to reduce the quantity of their piles installed in the pier from seven piles, i.e., full pier support, to just one pile installed at the pier centerline. Hardcore's request was partly due to their concern of lack of precedent for using FRP piles to support bridge piers. Therefore, the long term monitoring program was modified to a reduced version consisting of monitoring two instrumented piles installed at the center of two adjacent piers. The instrumented production piles will be monitored for several years. This reduced program is not the most ideal, particularly because the bent with the FRP composite pile will have two types of piles with stiffness differences that may affect load distribution among the piles in the pier. In addition, the pile arrangements in the two piers are not the same. The pier with the FRP pile has the five central piles installed vertically, and the two outer piles installed with 4 to 1 batter in the direction perpendicular to the bridge axis. The pier with the instrumented prestressed concrete pile has the three central piles installed vertically and the two outer piles on each end of the pier installed at 4 to 1 batter oriented in the direction of the bridge axis. Nevertheless this program is expected to provide some insight on the long term durability

and performance of the FRP composite pile. This chapter describes the instrumented production piles, the instrumentation used, the soil conditions at the locations of the instrumented piles, the installation information including driving records, PDA, CAPWAP, and PIT tests, and the monitoring data gathered to date.

9.2 INSTRUMENTED PRODUCTION PILES

Long term instrumentation was installed in a Hardcore FRP composite pile and a prestressed concrete pile, which were installed as the center piles of Piers 11 and 10, respectively. The location of the instrumented production piles are shown in Figure 9.1.

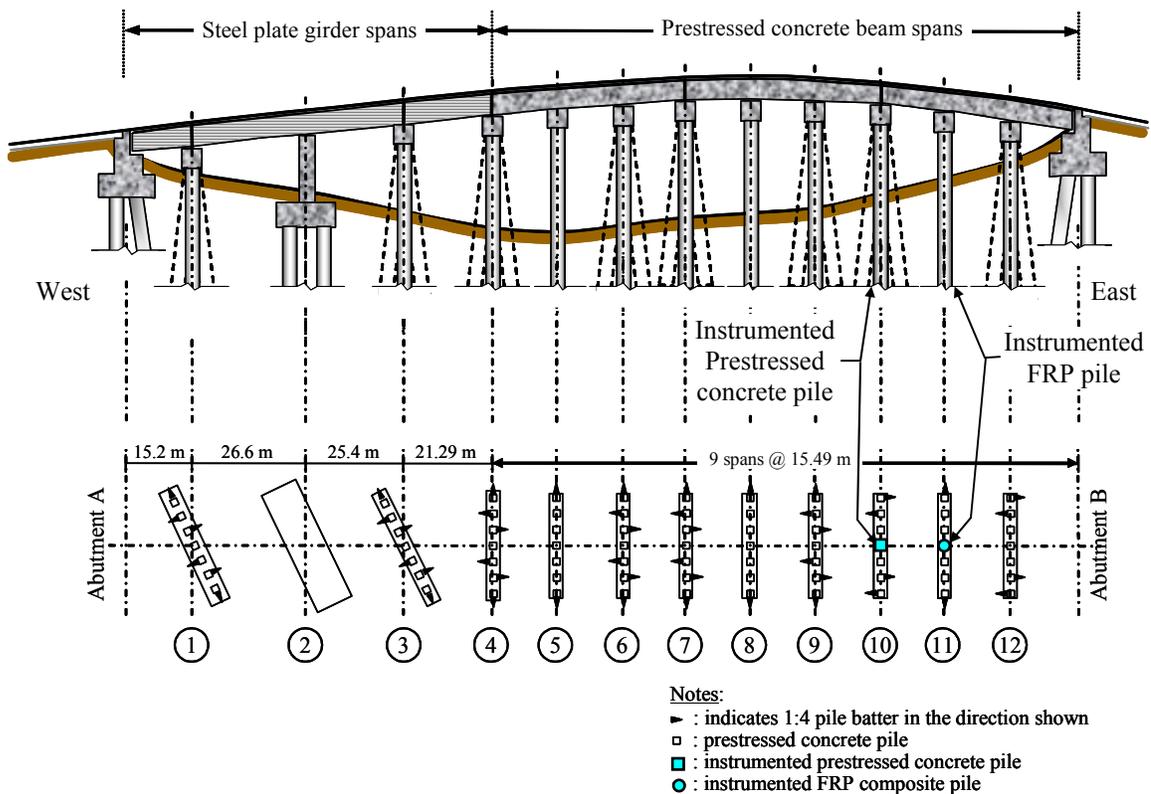


Figure 9.1 Location of instrumented production piles at the Route 351 Bridge

9.2.1 Prestressed Concrete Production Pile

The instrumented prestressed concrete production pile has characteristics similar to the test pile described in Chapter 6. However, the production pile is longer, with a length of 22 m (72.2 ft). The 28-day strength of the concrete used in this pile is 61 MPa (8,870 psi).

The prestressed concrete pile was instrumented with eighteen vibrating wire “sister bar” strain gages located at seven levels, as shown in Figure 9.2. These gages will be used to assess the load transfer from pile to soil.

As shown in Figure 9.2, a pair of gages was located at each level to provide gages on opposite sides of the pile. Two extra gages were installed at the uppermost and lowermost levels for redundancy. The gages are Geokon Model 4911 rebar strain meter gages manufactured and calibrated by Geokon Inc. These gages consist of two lengths of No. 12M, grade 420 steel bar (No. 4 steel bar, grade 60) welded onto each end of a miniature vibrating wire strain gage element. The entire assemblage is 1.3 m long. The instrumentation for the prestressed concrete production pile was installed on November 6, 2001. The pile was cast on November 7, 2001. The vibrating wire sister bar strain gage survival rate, after pile manufacturing, driving, and restrike, was 100%.

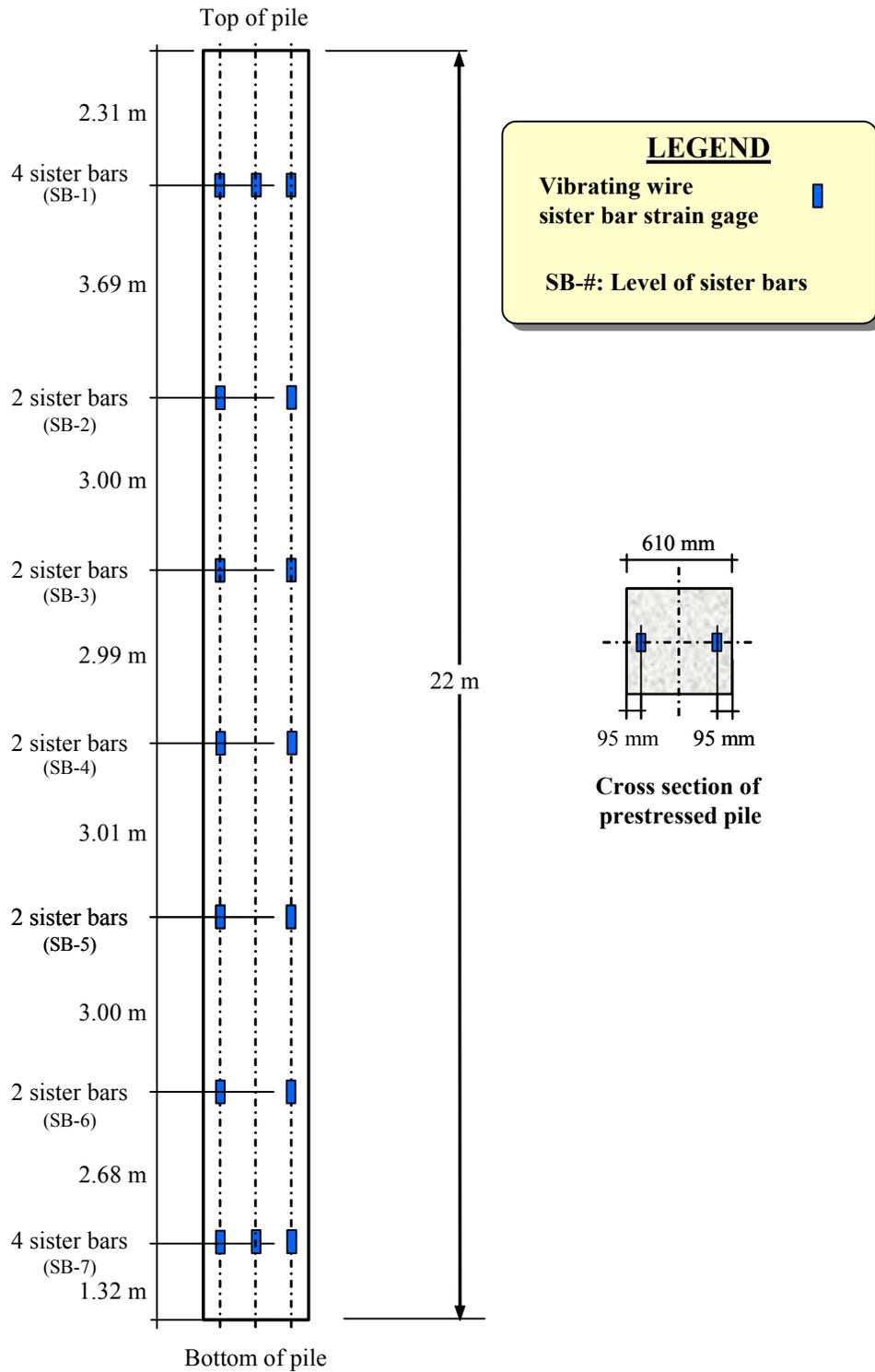


Figure 9.2 Load transfer instrumentation layout for prestressed concrete production pile

9.2.2 FRP Composite Production Pile

The instrumented FRP composite production pile has the same characteristics as the FRP composite test pile described in Chapter 6, but the length of this pile is 21.2 m (69.6 ft).

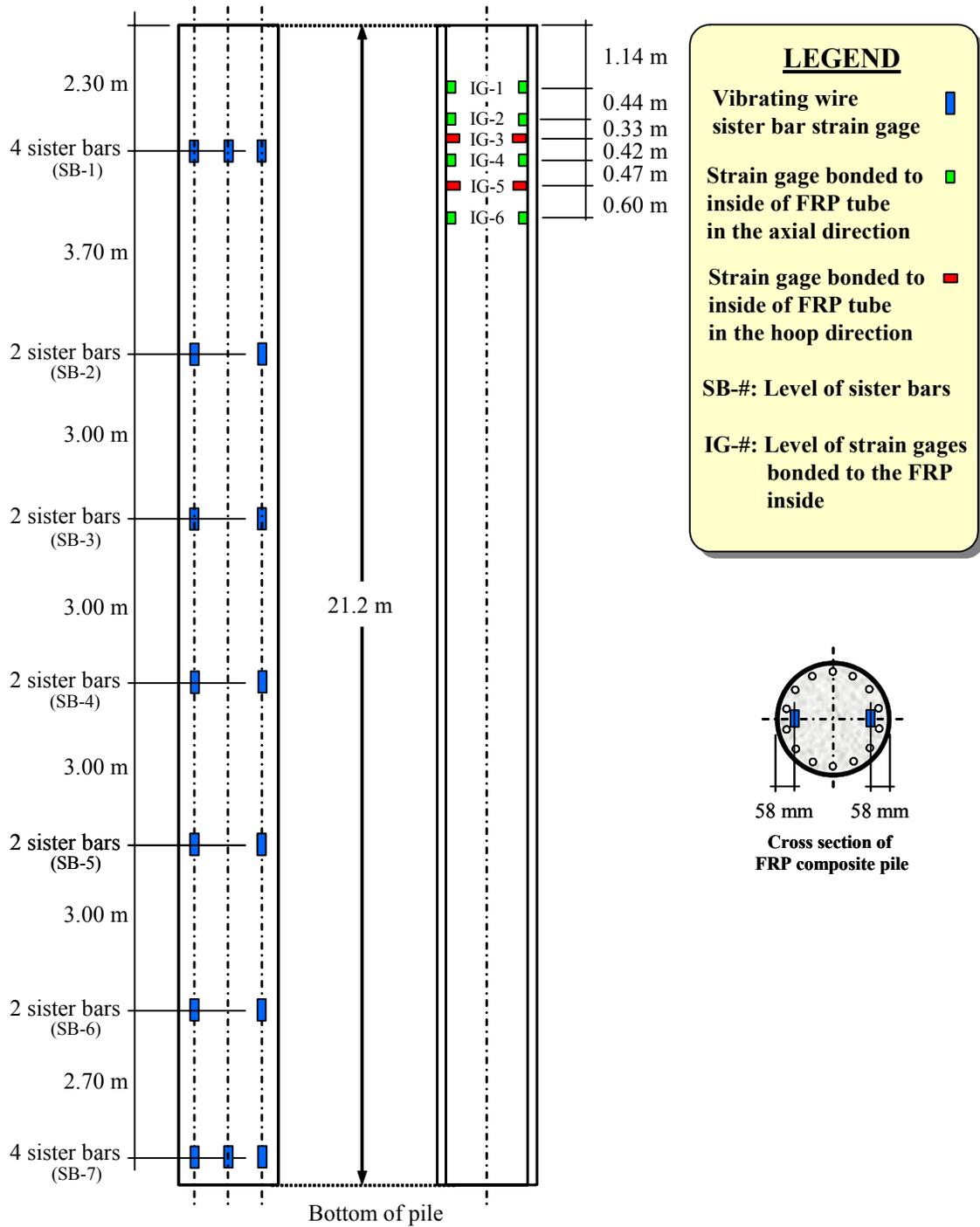
Similar to the prestressed concrete pile, the FRP composite production pile was instrumented with eighteen vibrating wire “sister bar” strain gages located at seven levels, as shown in Figure 9.3. These gages will be used to assess the load transfer from pile to soil.

The FRP pile was also instrumented with gages installed to study the performance and durability of the FRP tube. The following durability instrumentation was installed to monitor strains in the FRP tube:

- Two foil gages at each of six levels, labeled IG-1 through IG-6, as shown in Figure 9.3, for a total of twelve gages bonded to the internal wall of the FRP tube. The foil gages are type CEA-13-500UW-350, temperature compensating, underwater, resistance strain gages manufactured by the Micro-Measurements Division of Vishay Measurements Group, Inc. The gages are configured in a one-quarter active bridge. A protective coating system was used to cover these gages to protect them from possible moisture and chemical attack during filling of the tubes with concrete. The protective coating consisted of a Teflon film, overlain by a layer of polymer compound, overlain by aluminum foil, overlain by another layer of polymer compound, overlain by aluminum foil with the edges sealed with a rubber coating.
- Four vibrating wire strain gages were installed on the outside surface of the FRP pile at the locations shown in Figure 9.4. These gages are Geokon Model VK-4100 vibrating wire strain gages manufactured and calibrated by Geokon Inc. These gages have a 50 mm (2 in.) gage length. The gages were installed by epoxy bonding their mounting tabs to the pile exterior. In addition to providing strain,

these gages can measure temperature since they come with a thermistor incorporated.

The vibrating wire sister bars and the internal foil resistance strain gages for the FRP composite production pile were installed between January 24 and February 1, 2002. The concrete was poured for this pile on February 6, 2002. The vibrating wire sister bar strain gage survival rate, after pile manufacturing, driving, and restrike, was 100%. The survival rate of the internal foil gages was 30%. The majority of the internal foil gages started to drift after the concrete was poured. This could be due to moisture from the concrete. The external vibrating wire strain gages were installed after pile installation on November 7, 2002. As of December 30, 2002, all external gages are functioning.



Note: Layout of external durability instrumentation shown in Figure 9.4.

Figure 9.3 Instrumentation layout for FRP composite production pile

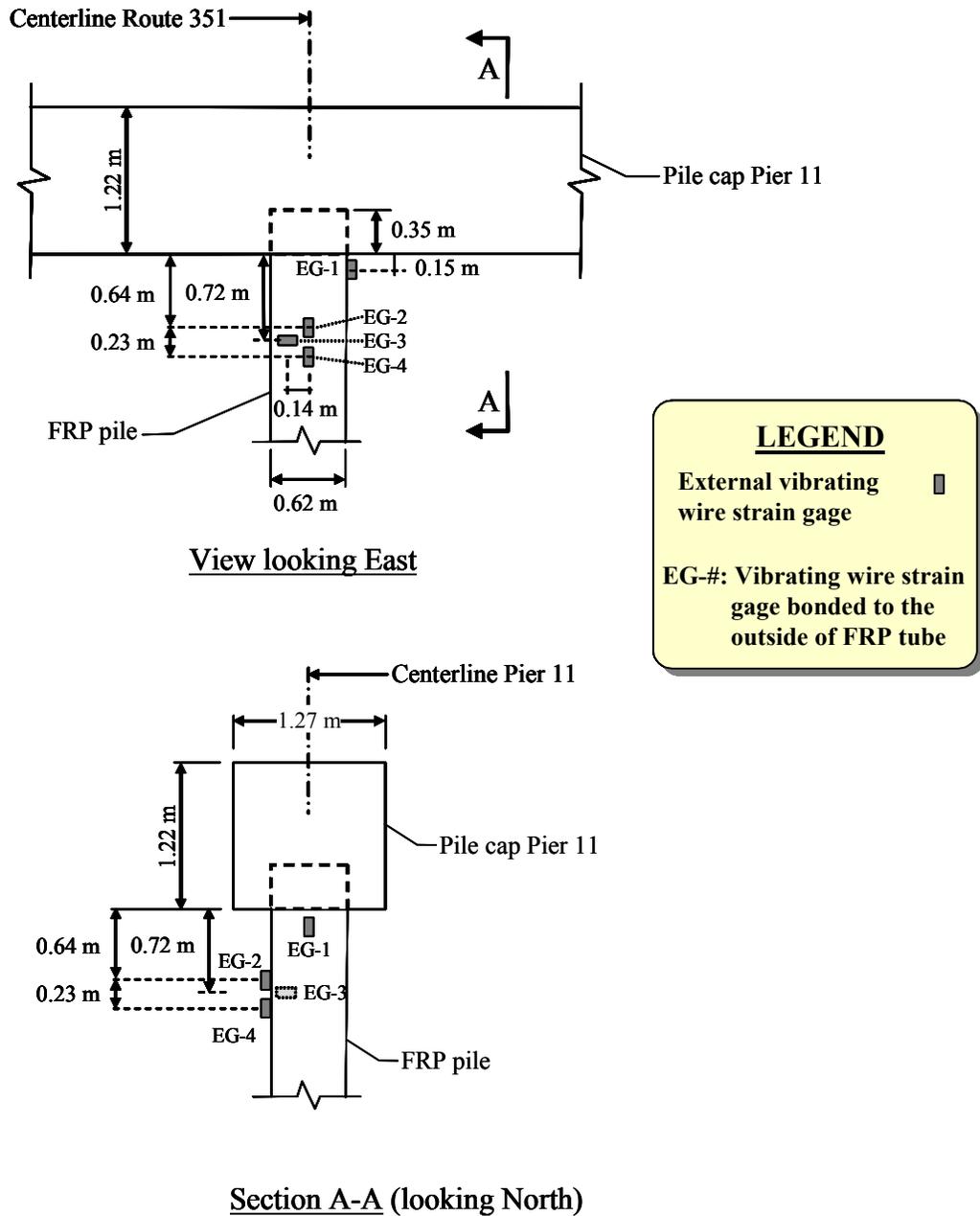


Figure 9.4 Layout of external durability instrumentation used in the FRP composite production pile

9.3 SOIL CONDITIONS AT THE INSTRUMENTED PRODUCTION PILES

VDOT investigated the soil conditions along the bridge alignment. The general soil stratigraphy found along the Route 351 bridge alignment is shown in Figure 9.5. The uppermost layer of river sediments consist of very soft to soft silty clay of varying thicknesses, as shown in Figure 9.5. The soft river sediments are underlain by loose to medium dense silty fine sand extending to variable depths depending on the location along the alignment. In general, the silty fine sand was found to increases in density with increasing depth, becoming dense to very dense at a depth of about 30 m.

The specific soil conditions found at the Piers 10 and 11 are shown in Figures 9.6 and 9.7, respectively. As shown, a sandy, silty, clay interbed was found at Piers 10 and 11, between elevations -18.7 and -20 m, and -11.6 to -20 m, respectively. For reference, the elevations of the installed piles are also shown in these figures.

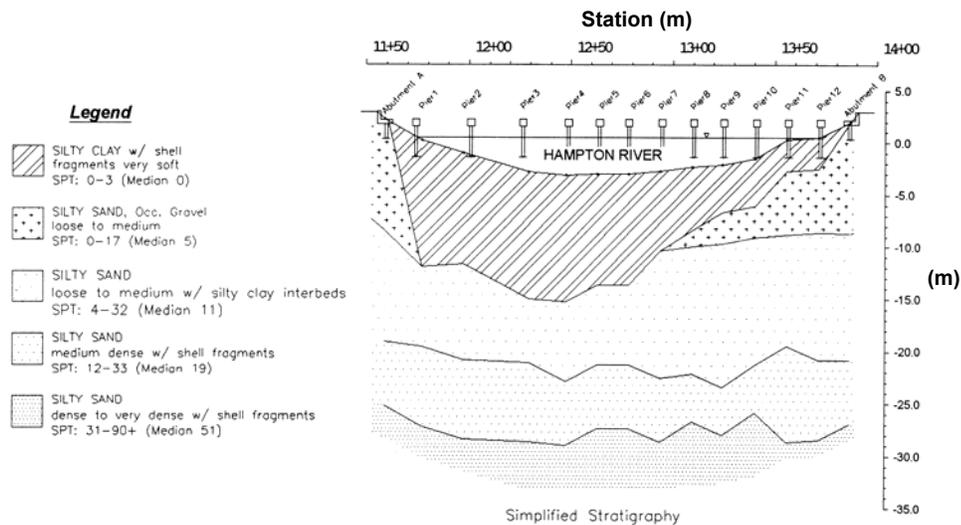


Figure 9.5 Simplified stratigraphy along the Route 351 bridge alignment

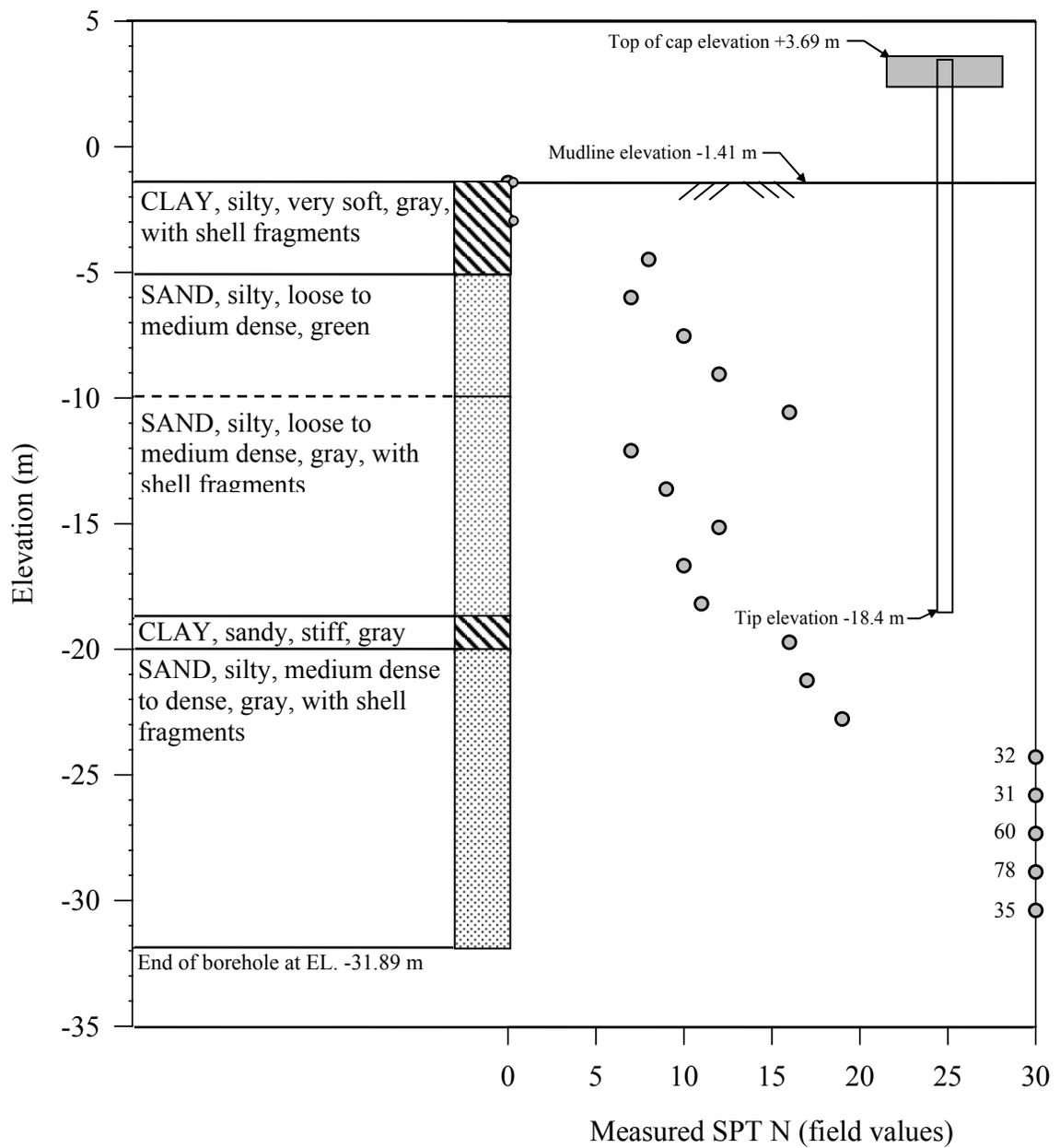


Figure 9.6 Simplified stratigraphy in the vicinity of the instrumented prestressed concrete pile installed at Pier 10

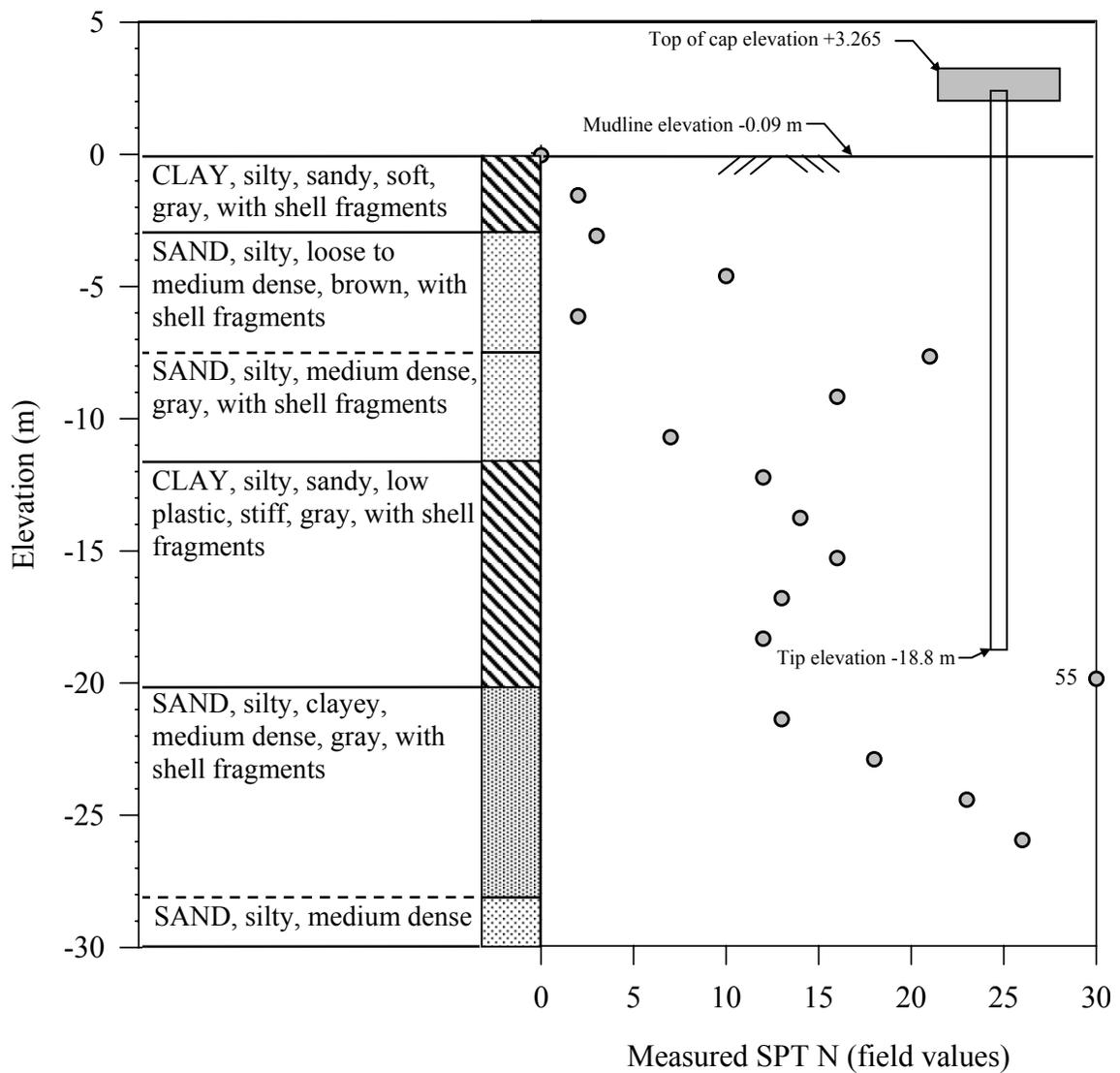


Figure 9.7 Simplified stratigraphy in the vicinity of the instrumented FRP composite pile installed at Pier 11

9.4 PILE INSTALLATION AND DYNAMIC TESTING

9.4.1 Pile Driving

The instrumented production piles were driven with an ICE model 80S single-acting diesel hammer. The maximum rated energy of the hammer is 108.6 kN-m (80,000 ft-lbs). Both instrumented production piles were driven with 230 mm (9 in.) thick plywood pile cushions. The pile driving records are shown in Figure 9.8. The prestressed concrete pile and FRP pile were driven on June 13, 2002 and June 14, 2002, respectively.

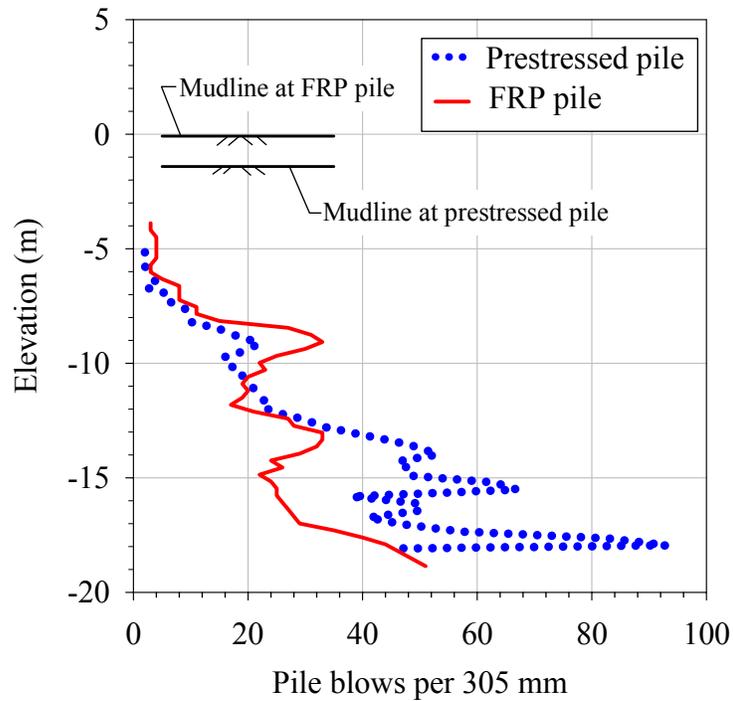
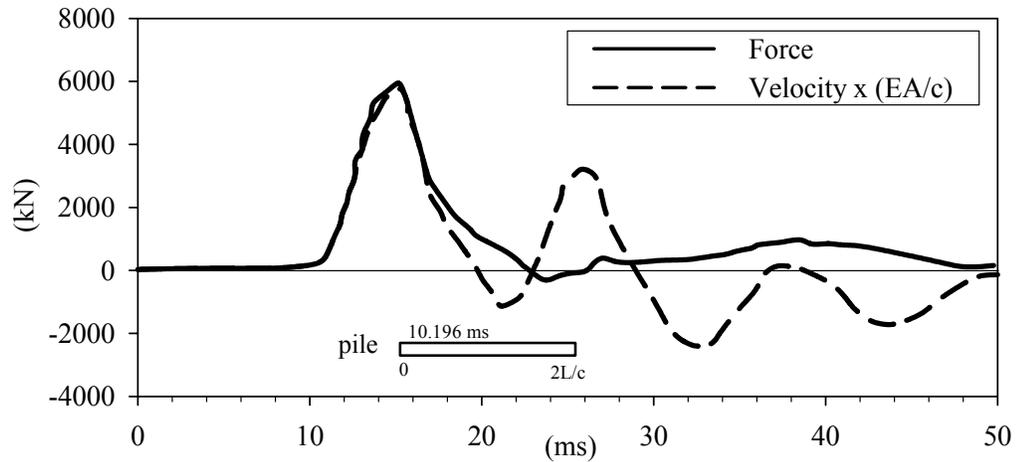


Figure 9.8 Driving records for instrumented production piles

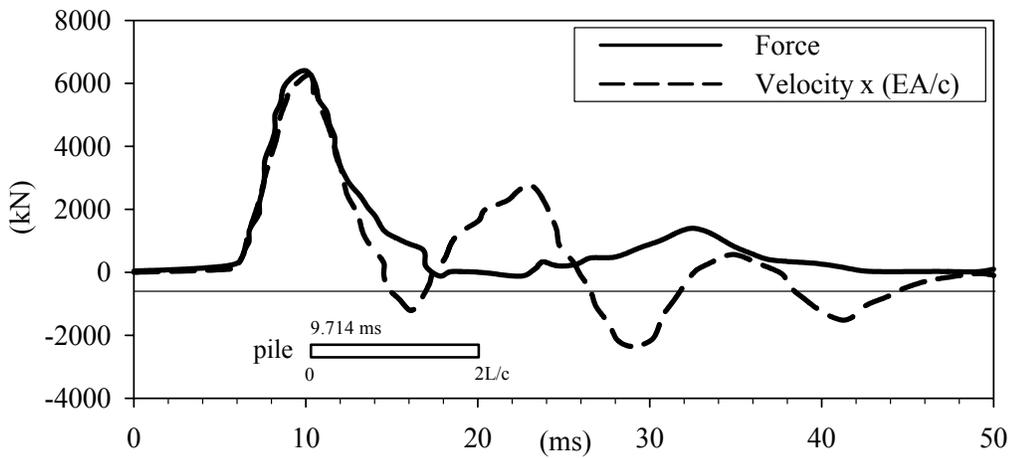
9.4.2 Dynamic Testing

Dynamic monitoring was performed using a Pile Driving Analyzer (PDA) manufactured by Pile Dynamics, Inc. The PDA monitoring and data processing was carried out by GSI, Inc. from Norfolk, Virginia. Monitoring was performed during initial driving and during restrrike. Restrike occurred on June 18, 2002, which represents a setup period of 4 and 5 days after initial driving, for the FRP composite pile and prestressed concrete pile, respectively. PDA records for the two instrumented production piles at restrrike are shown in Figure 9.9. The PDA records show a force peak at about time 0, measured with respect to the horizontal bars that are shown in Figure 9.9 and that represent the wave travel time for two pile lengths for each pile. The prestressed concrete and FRP composite piles show similar dynamic behavior. Both piles show a large increase in the velocity record and a corresponding low force at about $2L/c$ (where L is the pile length, and c is the wave speed). This type of PDA record shape is characteristic of piles with a small toe resistance. Very little separation between the force and velocity traces is noticed between time 0 and about $0.5L/c$. This corresponds to the zone of zero to minimal shaft resistance, i.e., the portion of the pile above the ground surface and the portion through the very soft river sediments where the shaft resistance is small.

Table 9.1 provides some of the measurements obtained during pile driving. It can be seen that the wave speed (c) and impedance values (EA/c) recorded in the FRP composite pile were about 5.3% and 6.1% lower, respectively, than the prestressed pile. The maximum compressive and tensile stresses in the prestressed concrete pile were lower than the allowable stresses recommended for prestressed piles (Hannigan et al. 1996). The highest driving stresses were recorded in the FRP composite pile; however, no standards are currently available for allowable driving stresses of FRP composite piles.



(a) Prestressed concrete pile



(b) FRP composite pile

Figure 9.9 PDA recordings during restrike (Spiro and Pais 2002b)

Table 9.1 Summary of pile driving measurements for the prestressed and FRP production piles (after Spiro and Pais 2002b)

Measurement	Pile Type	
	Prestressed	FRP
Wave speed (c)	4054 m/s	3840 m/s
Impedance (EA/c)	3589 kN/m/s	3370 kN/m/s
Maximum compression stress measured during driving	11.7 MPa	13 MPa
Maximum tensile stress measured during driving	7 MPa	8.8 MPa
Allowable Stresses	Comp. < 24.3 MPa Tension < 7 MPa	No standards available

Estimates of pile capacity from the dynamic strain and acceleration measurements were obtained using the Case Method and CAPWAP analyses (Spiro and Pais 2002b). Both the Case Method and CAPWAP capacities are listed in Table 9.2. The FRP composite production pile showed an increase in the Case Method capacity of about 125% between the end of initial driving and restrike 4 days later. According to the CAPWAP analyses, the prestressed concrete and FRP composite piles have capacities of 1980 and 2046 kN (445 and 460 kips), respectively. These CAPWAP capacities are over two times larger than the design axial design load for the piles in the piers of 890 kN. The CAPWAP analyses also indicate that the shaft capacities, as percentages of the total capacities, are 82%, and 71% for the prestressed concrete, and FRP piles, respectively. These high shaft capacity percentage values agree with the observations made earlier regarding the shape of the PDA records being characteristic of piles with low toe resistance.

Table 9.2 Summary of CASE and CAPWAP analyses results (Spiro and Pais 2002b)

Method	Capacity component	Prestressed concrete pile	FRP pile
Case ⁽¹⁾ (End-of-Driving)	Total	Not available ⁽²⁾	890 kN
Case ⁽¹⁾ (Restrike ⁽³⁾)	Total	2091 kN	2002 kN
CAPWAP (Restrike ⁽³⁾)	Shaft	1624 kN	1459 kN
	Toe	356 kN	587 kN
	Total	1980 kN	2046 kN

Notes: (1): Case method using a Case damping coefficient of 0.60.

(2): Not available due to signal acquisition problems.

(3): Restrike of piles performed 4 and 5 days after initial driving, for the FRP and prestressed concrete piles.

9.5 PILE INTEGRITY TESTING OF TEST PILES

Pile integrity tests (PIT) were performed on the instrumented production piles before and after pile installation. These tests were carried out using the same procedure used for the test piles described in Chapter 6.

PIT results for the prestressed concrete production pile installed at Pier 10, performed before and after pile driving, are shown in Figures 9.10 and 9.11, respectively. No discernable damage was noted based on comparison of the pre- and post-driving PIT

soundings. The soil resistance in the pile after installation results in a smaller toe reflection, as shown in Figure 9.11.

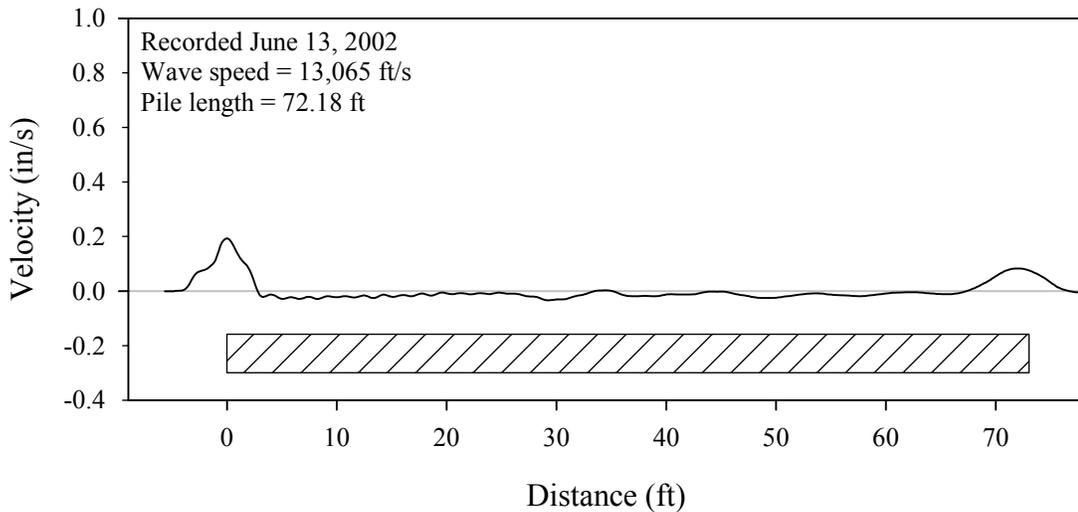


Figure 9.10 PIT sounding on the prestressed concrete production pile before installation

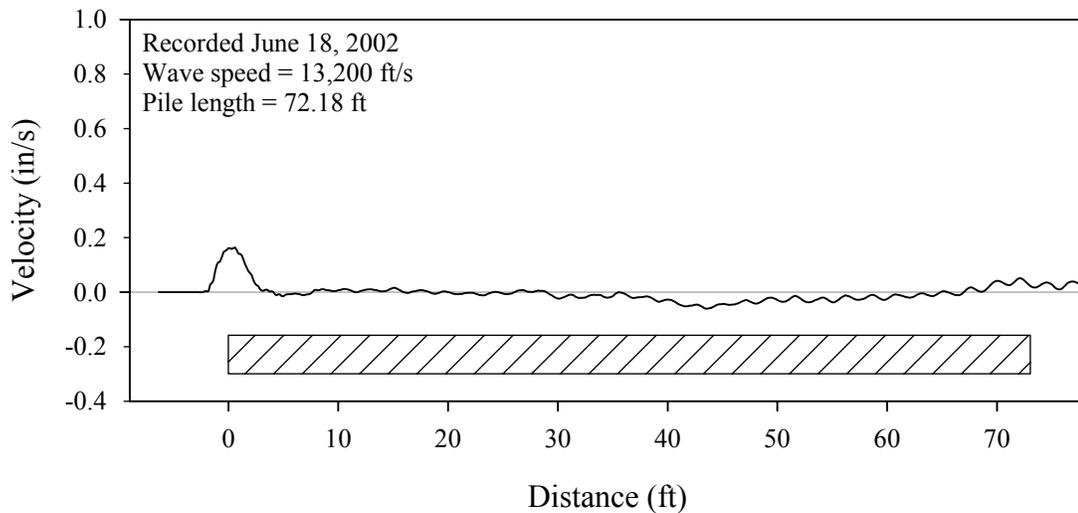


Figure 9.11 PIT sounding on the prestressed concrete production pile after installation and restrike

PIT results for the FRP composite pile installed at Pier 11 are shown in Figures 9.12 and 9.13. No significant difference between the pre- and post-drive PIT traces was observed for the FRP pile. Toe reflection in the post-drive PIT is almost not discernible, probably due to high soil resistance. No discernable damage could be detected based on comparison of the pre- and post-driving PIT soundings.

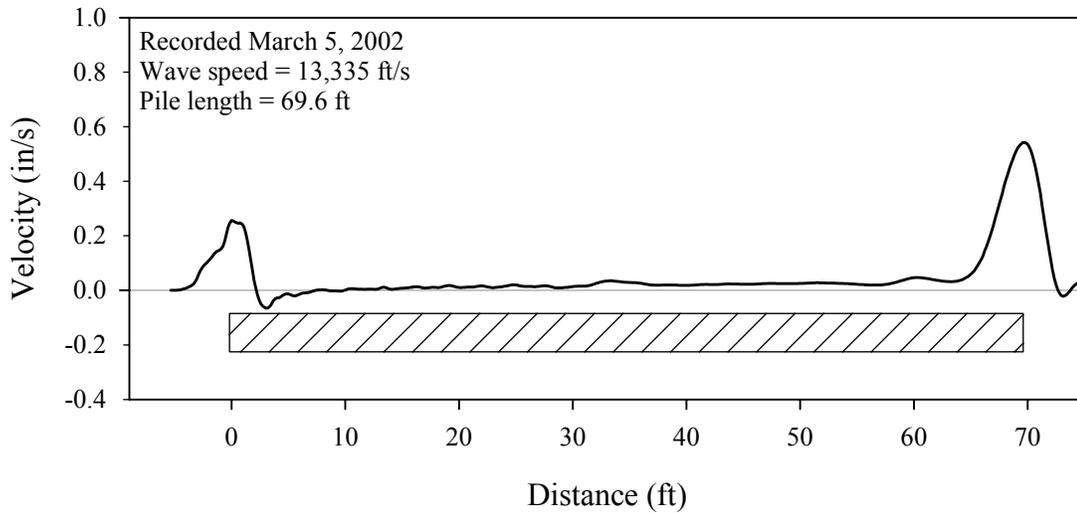


Figure 9.12 PIT sounding on the FRP composite production pile before installation

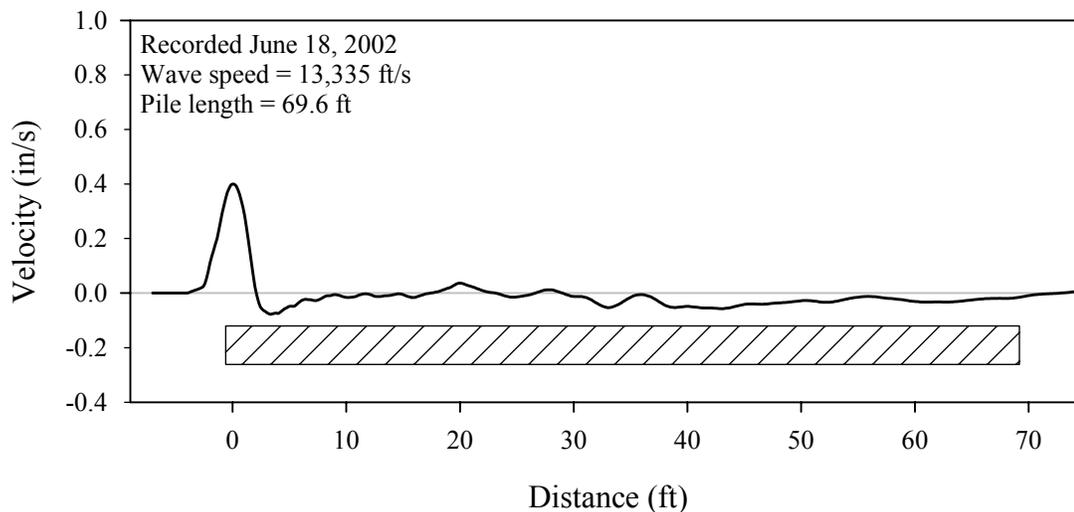


Figure 9.13 PIT sounding on the FRP composite production pile before installation

9.5 MONITORING DATA GATHERED TO DATE

Important date information for these two piles is summarized in Table 9.3.

Table 9.3 Test dates for the instrumented production pile program at the Route 351 bridge project

Pile Type	Cross section	Length (m)	Fabrication date	Driving date	Restrike Date
Prestressed concrete	610 mm square	22	11/7/01	6/13/02	6/18/02
FRP	622 mm circular	21.2	2/6/02	6/14/02	6/18/02

Due to delays in the construction schedule of the bridge, only a few readings have been made on the instrumented production piles. The instrumentation for the prestressed and FRP composite piles have been read on the dates summarized in Tables 9.4 and 9.5, respectively. On December 30, 2002 the estimated loads acting on the prestressed concrete and FRP composite piles were 24.1% and 30.9% of the axial design load, respectively.

Table 9.4 Monitoring dates for prestressed concrete pile at the Route 351 bridge

Date	Description of pile loading condition	Estimated load on pile
6/18/02	After pile installation and restrike.	0 kN
11/7/02	Pile cap and girders from east span installed.	110 kN
12/30/02	Pile cap and girders from adjacent spans installed. Deck slab for east span in place.	227 kN

Table 9.5 Monitoring dates for FRP composite pile at the Route 351 bridge

Date	Description of pile loading condition	Estimated load on pile
6/18/02	After pile installation and restrike.	0 kN
11/7/02	Pile cap and girders from east and west spans installed.	155 kN
12/30/02	Pile cap, girders, and deck slab from adjacent spans in place.	290 kN

The loads acting on each pile were estimated based on the information reported in the bridge design drawings. The weight of the pile cap is based on unit weight for the reinforced concrete of 23.6 kN/m^3 (150 lbf/ft^3) and the pile cap dimensions of $1.22 \times 1.27 \times 12.5 \text{ m}$. The load from the AASHTO Type II girders (7 girders per each span), are based on a span length of 15.5 m and a girder weight per unit length of about 5.6 kN/m (384 lbf/ft) (Nilson 1987). The load due to the reinforced concrete bridge deck is based on a slab thickness of 0.2 m and a deck width of 12.8 m . As a first approximation the loads acting on the pile was estimated by dividing the total pier load by the number of piles in the pier.

A photo of the bridge on December 30, 2002, is shown in Figure 9.14. This photo shows that Piers 7 through 12 have been installed and the bridge deck has been poured up to Pier 10. The photo also shows the formwork for the deck between Piers 9 and 10.

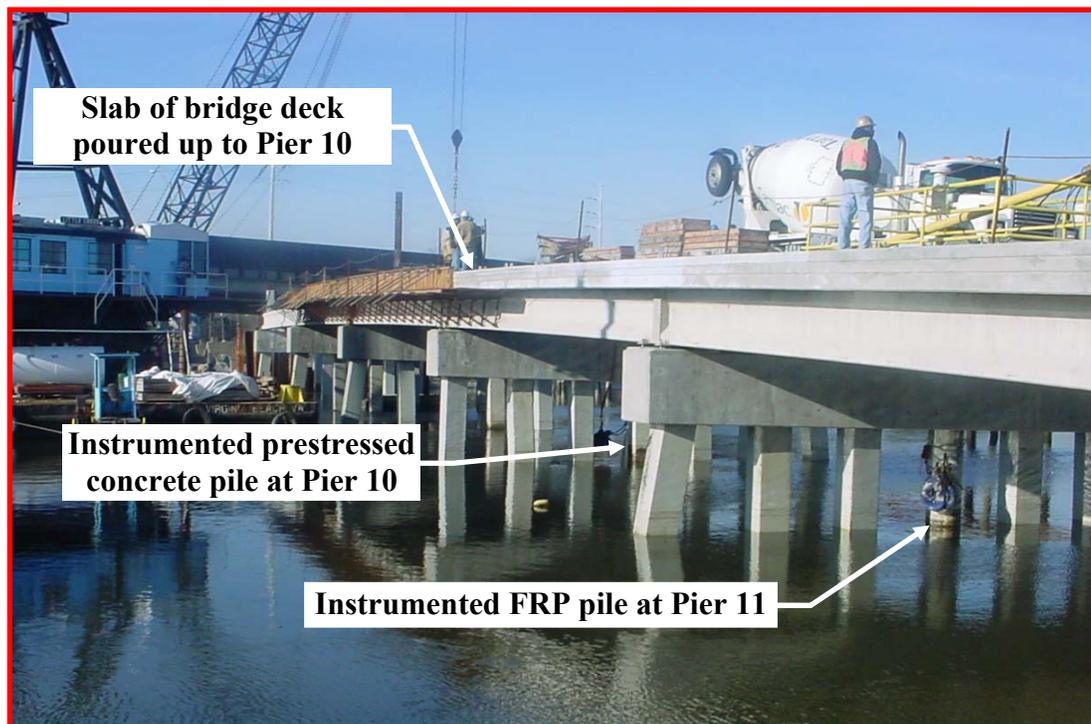


Figure 9.14 Photo of Route 351 bridge under construction on December 30, 2002

The load distributions estimated for the prestressed concrete and FRP composite piles are shown in Figures 9.15 and 9.16, respectively. These load distributions were estimated by multiplying the average strain at each level of vibrating wire sister bars by the values of axial stiffness, EA, of each pile reported in Chapter 6. The load distributions were calculated considering the residual stresses after driving using the procedure described by Fellenius (2002).

Future monitoring of the piles will include readings at the end of bridge construction, which is expected near the end of spring 2003, and periodic readings taken for the next few years with the bridge under normal operation. The long term monitoring and data collection responsibility will be transferred to VTRC/VDOT.

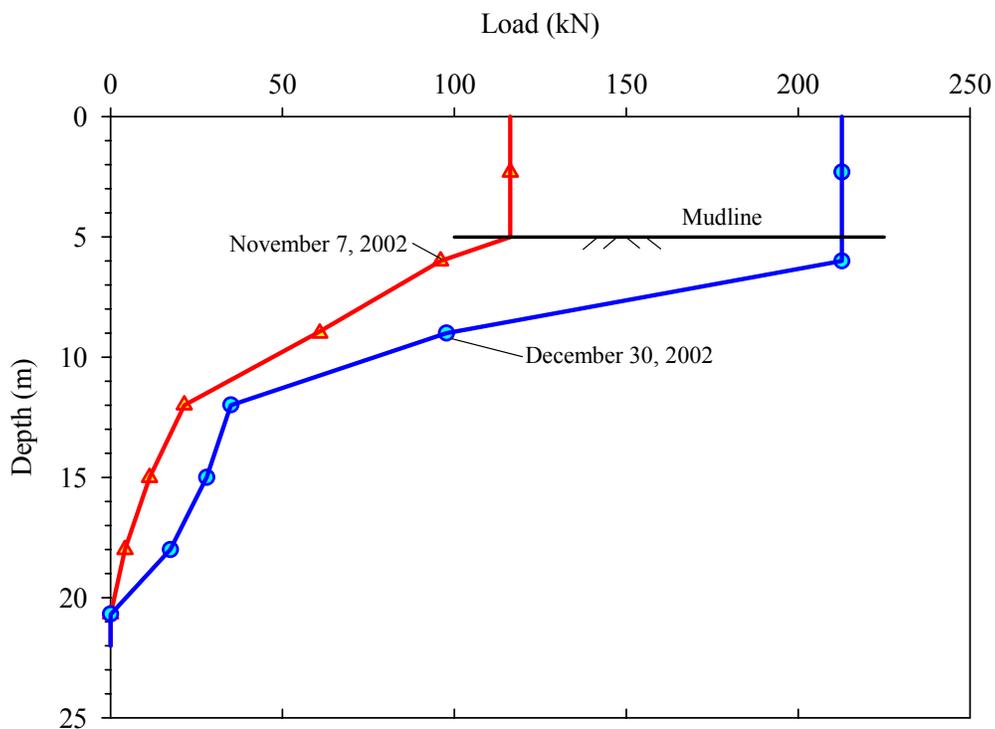


Figure 9.15 Load distributions on November 7, 2002 and December 30, 2002 for the prestressed concrete production pile at Pier 10

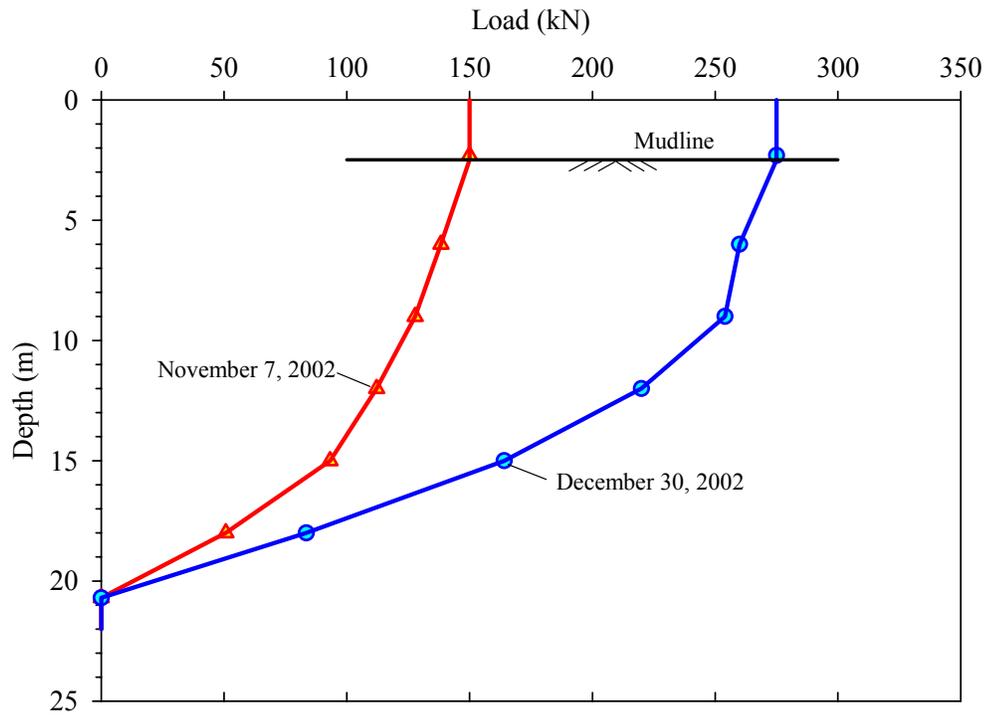


Figure 9.16 Load distributions on November 7, 2002 and December 30, 2002 for the FRP composite production pile at Pier 11

6.8 SUMMARY

A long term monitoring program has been implemented at the Route 351 bridge project to compare the long-term performance, load transfer, and durability characteristics of an FRP composite pile and a standard prestressed concrete pile. The two production piles selected for monitoring were installed at the centers of Piers 10 and 11. The piles consist of: 1) a conventional, 610 mm square, prestressed concrete pile installed at Pier 10, and 2) a 622 mm diameter composite pile formed of an FRP shell and filled with concrete and steel reinforcing bars installed at Pier 11. The instrumented production piles are about 22 m long.

Load transfer instrumentation consisting of 18 vibrating wire sister bars was installed at seven levels in both piles. Durability instrumentation consisting of resistance foil gages and vibrating wire gages was installed on the FRP composite pile to monitor the inside and outside of the FRP tube, respectively.

The soils at the production pile locations were investigated by VDOT, and consisted of very soft to soft silty clay underlain by loose to medium dense silty sand. A sandy, silty, clay interbed was found at Pier 10 between elevations -18.7 and -20 m, and at Pier 11 between elevations -11.6 to -20 m.

The field testing of the instrumented production piles included PDA, CAPWAP, and PIT tests. The following conclusions can be drawn from this test program:

- The FRP composite pile and prestressed concrete pile performed similarly during pile driving, as demonstrated by the driving records, PDA traces, measured wave speed generated by the driving hammer, and measured compressive and tensile stresses.
- Both instrumented production piles showed similar estimated pile capacities using the Case Method on pile restrike blows.

- CAPWAP analyses at pile restrike showed similar estimated pile capacities, and high shaft capacity components. The shaft capacities were estimated as being 82% and 71% of the total capacity, for the prestressed concrete and FRP composite piles, respectively. Based on the CAPWAP analyses the pile capacities were estimated to be more than twice the axial design load of the pier piles of 890 kN.
- No discernable damage was detected in the piles after installation, based on PIT testing performed on the piles before and after pile driving.
- Monitoring data of the piles is limited to date. The bridge is still under construction, and on December 30, 2002, the loads acting on the piles were estimated as 215 kN and 275 kN for the prestressed concrete pile and FRP composite pile, respectively.

Durability instrumentation was installed on the FRP composite pile to monitor the inside and outside strains of the FRP tube. The durability instrumentation had to be installed once the construction activities near Pier 11 were completed. Hence, monitoring data for the durability instrumentation is not yet available at the time of this report. In addition to providing the strain for the FRP shells, the durability strain gages will also provide records of temperature because vibrating wire strain gages incorporate thermocouples to provide information necessary for reducing the strain gage data. The strain and temperature data will be used to interpret the performance of the FRP shells, as follows: Knowledge of the exposure time and temperature can be used to estimate the FRP properties of modulus and strength from the laboratory durability study described in Chapter 4. Knowledge of the strain in the production piles can be combined with the modulus to give the stress in the FRP shell. Comparing the stress with the strength of the FRP shell indicates how close the shell is to failure.