

Pile Integrity Testing To Determine Storm-Induced Damage

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Hurricane Hugo made landfall in 1989 near Charleston, South Carolina, causing extensive damage. A pleasure boat marina was exposed to the full force of the storm. The marina consisted of concrete floating docks held in place by 14-in.-square prestressed concrete piles. The 42-ft-long piles had been driven 2 years before, and installation records were not available at the time of the testing (1990). The water depth was between 2 and 10 ft, and the soil conditions consisted of approximately 10 ft of soft mud overlying the Cooper Marl. During the storm, the surge floated the docks to nearly the pile tops and the extraordinary winds and waves pushed the large pleasure boats against the piles. After the storm, it was observed that some piles could be moved several inches laterally simply by pushing on them while standing on the docks, thereby causing the pile integrity to be questioned. Short on time for the new season, the owner was faced with a serious problem with potentially expensive remedies. Low-strain integrity testing performed on each of the 78 piles provided a timely and cost-effective solution for pile structural integrity assessment. Testing was performed in 2 days at an average cost of less than \$100 per pile. Testing indicated that none of the piles were structurally damaged, although some records showed evidence of tensile cracking and an absence of soil resistance. The pile testing program is discussed, and the theoretical background and field testing procedures are discussed.

In September 1989, Hurricane Hugo made landfall near Charleston, South Carolina, causing extensive damage. Many of the structures in the Charleston area were exposed to conditions that met or exceeded their expected design conditions. Most of the damage caused by the storm was obvious. However, for various reasons, the integrity of many seemingly sound structural members was questioned. Such was the case for the dock piles at a pleasure boat marina near the Charleston Harbor. The work performed to assess the poststorm integrity of the piles at this marina is summarized.

PROJECT DETAILS

Marina

The marina contains five concrete floating docks. Each dock consists of linear and perpendicular arrangements of 4-ft-wide concrete-covered foam sections. Pinned or hinged connections are used to connect the individual sections, and driven piles are used to anchor the docks in place. The piles provide lateral support while allowing the docks to rise and fall with the roughly 6-ft tidal cycles.

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Soils and Foundations

A total of seventy-eight 14-in.-square (area = 196 in.²) prestressed concrete piles were used in the construction of the marina docks. The piles had been installed approximately 2 years before the storm. The driving records and the soil boring logs were not available at the time of testing. However, on the basis of conversations with several individuals involved with the original construction and a knowledge of local geology, the profile shown in Figure 1 was assumed to be a reasonable representation of the subsurface conditions. In general, the piles were located in 2 to 12 ft of water and penetrated roughly 10 ft of soft bottom sediments and approximately 10 to 12 ft into a stiff sandy calcareous clay (known locally as the Cooper Marl). Depending on the tides, the pile tops were 8 to 14 ft above the water surface.

During the hurricane, the storm surge caused the docks to rise to nearly the tops of the piles, creating moment arms that probable approached 35 ft. The high wind and wave forces acting on the docks as well as the loads applied by the remaining large pleasure boats must have generated extremely large bending moments in the concrete piles. Although the majority of the piles appeared to be undamaged after the storm, several deflected 2 to 4 in. when pushed laterally. In addition, some piles were left slightly out of plumb after the storm.

TEST DETAILS

All 78 piles were tested over a period of 2 days using the Pile Integrity Tester[®] (PIT)—PC version system. The purpose of the tests was to evaluate the pile structural integrity. PIT tests are performed by using an accelerometer and a special power/amplifier-receiver, a small impact device (i.e., a 6-lb hammer), a personal computer with graphics capabilities, and a dedicated software package. The accelerometer is attached to the pile top and a hammer blow is applied. The measured pile top acceleration is recorded and integrated to yield velocity. The curve is displayed on the computer screen over both a time and a pile length scale. The velocity records may be amplified with exponentially increasing intensity over time to compensate for internal pile damping. Usually, a number of these traces are averaged, amplified, and plotted for each pile.

This type of test is often referred to as a low-strain test because the stress wave, generated by only a small hand-held hammer, produces correspondingly small strains. The background and specifics of the method and equipment used and

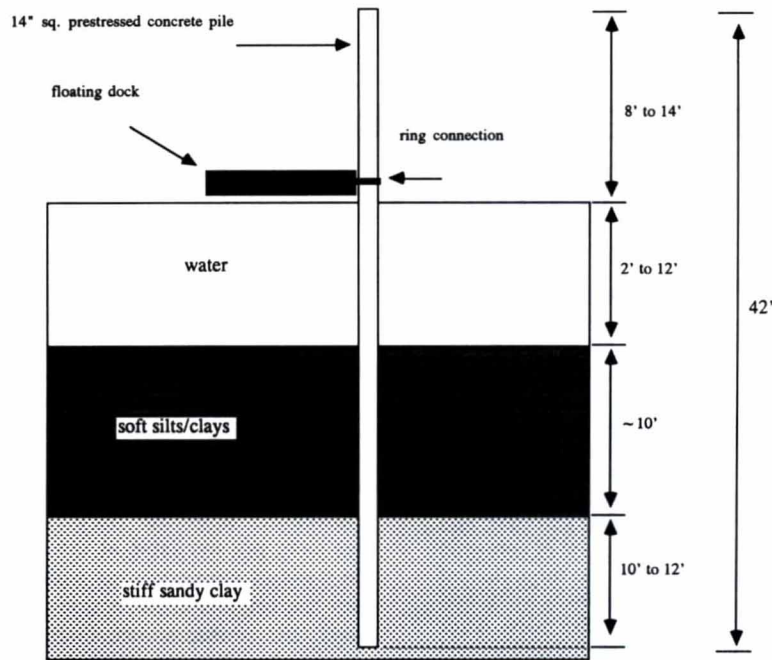


FIGURE 1 Assumed cross section.

an explanation of data interpretation may be found elsewhere (1,2).

DISCUSSION OF RESULTS

Typically, each test consisted of three or more hammer blows. Data from the blows were averaged, amplified, and plotted in the form of pile top velocity and acceleration as a function of pile length. A material stress wave speed of 14.6 ft/msec was used to convert from a time scale to a length scale. A typical result is shown in Figure 2; averaged and amplified pile top velocity and acceleration records are plotted on a length scale and superimposed pile length graphically depicting the applied data magnification.

Assessments of structural pile integrity were based on the obtained records and their interpretation assuming a stress wave speed of 14.6 ft/msec. Typical data from apparently problem-free piles are shown in Figure 3. In general, the test records indicated that the piles were structurally sound. However, approximately half of the 78 piles had indications of possible minor cracks at roughly the pile midpoint. In making such interpretations, previous test results from two extracted piles lying on the ground were considered. One pile had a major crack 27 ft below the pile top. The record from this pile is shown in Figure 4. The pile was essentially broken but held together by the prestressing cables. The other pile had visible hairline cracks but no other apparent damage. Data from this pile were used as a control record. Pile records from the marina project were compared with this control record to aid interpretation. Such a comparison is shown in Figure 5, which includes the control record and typical records from piles with possible minor cracking.

Low-strain pile top records were also indicative of apparent soil resistance. The majority of the pile records exhibited

evidence of soil resistance (a relative decrease in velocity) beginning 7 to 14 ft above the pile toe. However, roughly 25 percent of the piles had very little frictional soil resistance. Figure 6 shows the difference between a pile with no apparent soil resistance and piles with resistance occurring at varying depths.

CONCLUSIONS

The client was informed that from a structural integrity standpoint, all piles were satisfactory. The tensile cracking may have been caused by the storm; however, the location of the cracking generally corresponded to the midpoint of the pile regardless of the depth at which frictional resistance first became apparent. Therefore, it was thought that the cracking had probably occurred during handling or installation of the pile rather than during the storm loading. It was noted that the zone of cracking was frequently above the mudline and in a highly corrosive environment. Consequently, the effect of the cracking on the long term integrity of a pile was unknown. Subsequent integrity testing over the lifetime of the marina could be used to monitor the suspect piles to determine whether significant corrosion was occurring. Because "baseline" records are already available, such an approach should be reliable.

The apparent lack of soil resistance observed on many of the piles is thought to explain the relatively large lateral deflections that occurred, according to the marina personnel, under small loads. The lack of resistance could be a result of a lateral soil failure caused by excessive loading or erosion. Both possibilities could be related to the hurricane. The lack of resistance could also have been caused by design or construction errors. Regardless of the cause, it was recommended that the lateral capacity of the suspect piles be reevaluated

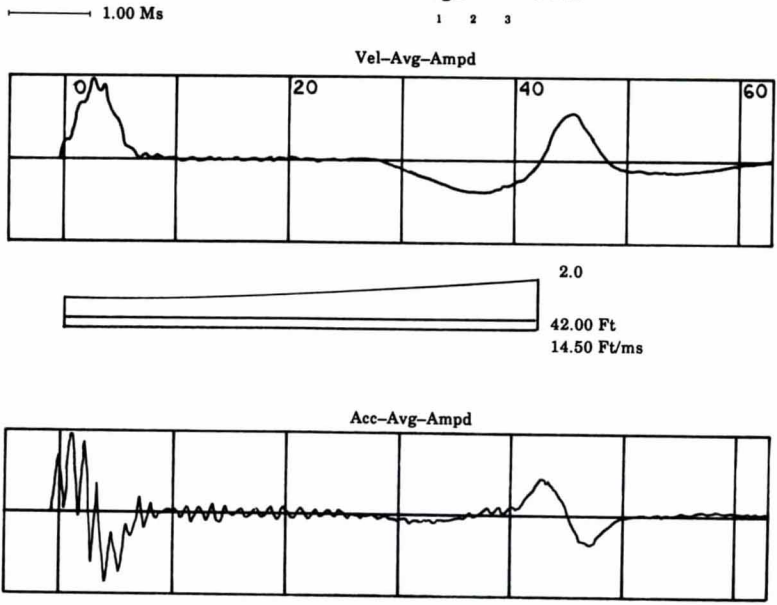


FIGURE 2 Typical PIT results.

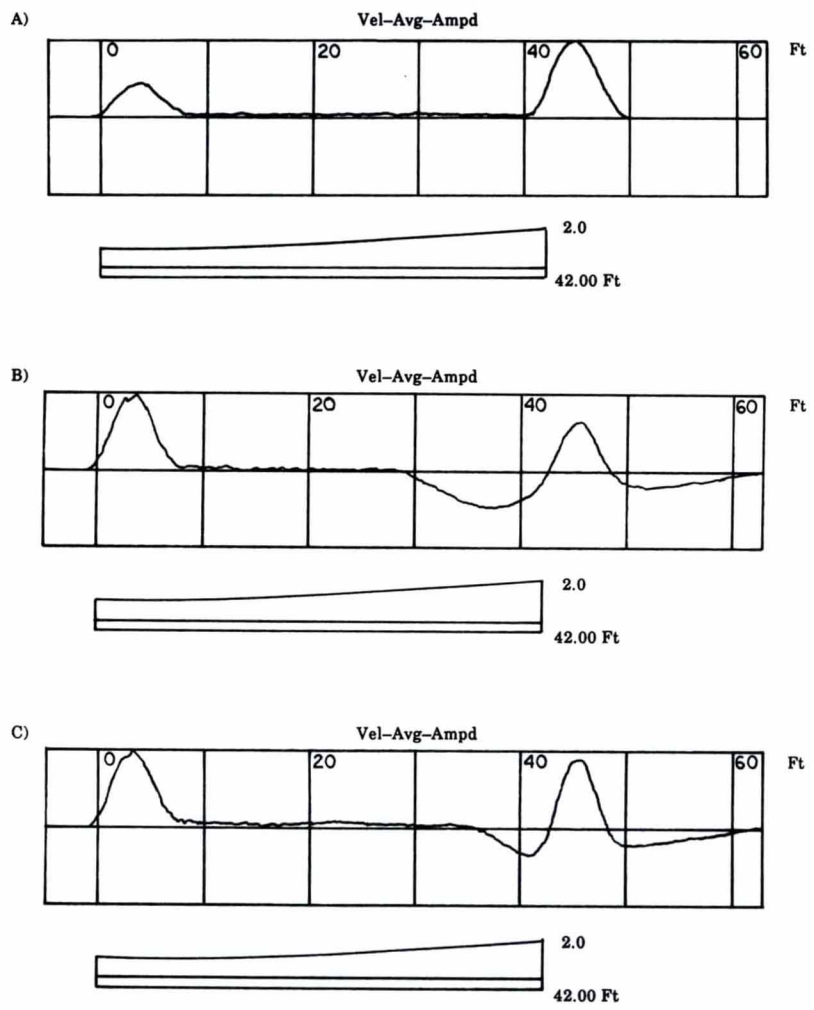


FIGURE 3 Typical results from piles with no integrity problems.

Project:
Loc:
Date: 10/23/89
1.00 Ms

Pile:
Avgd 7 Bls
106 107 108 109 110 111 112

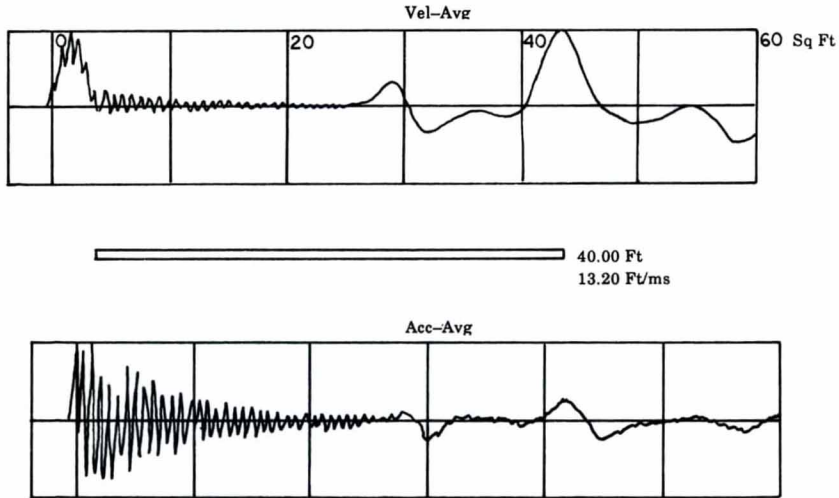


FIGURE 4 Extracted pile with major crack at 27 ft.

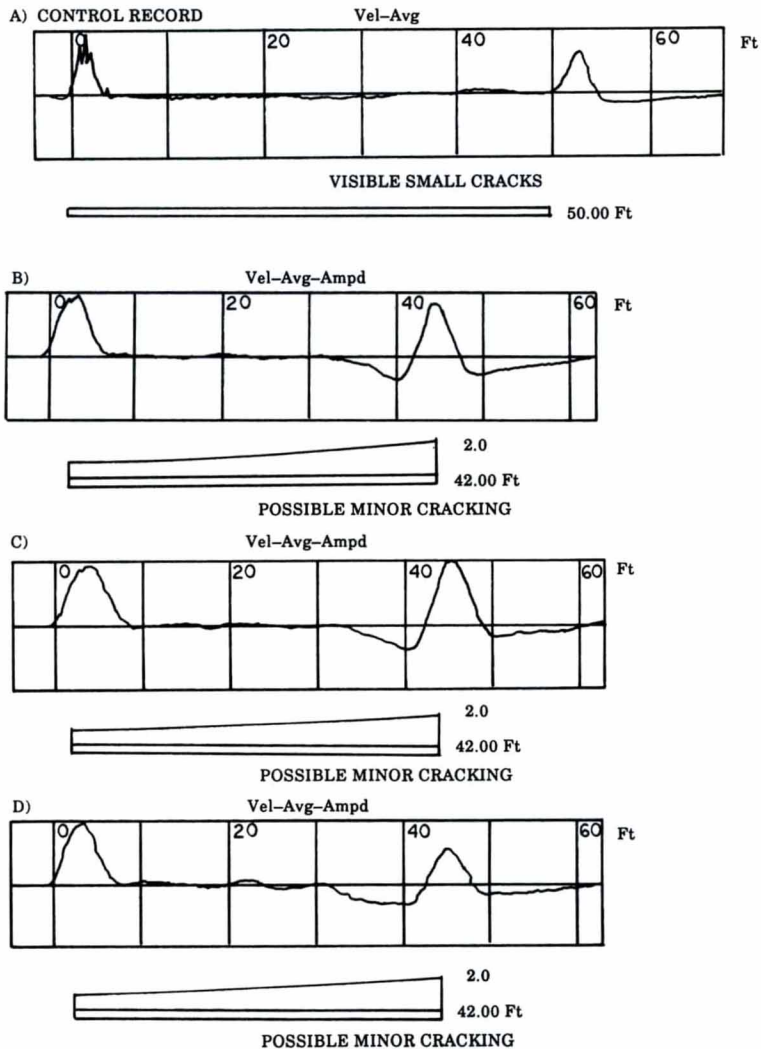


FIGURE 5 Control record and typical records indicating possible minor cracking.

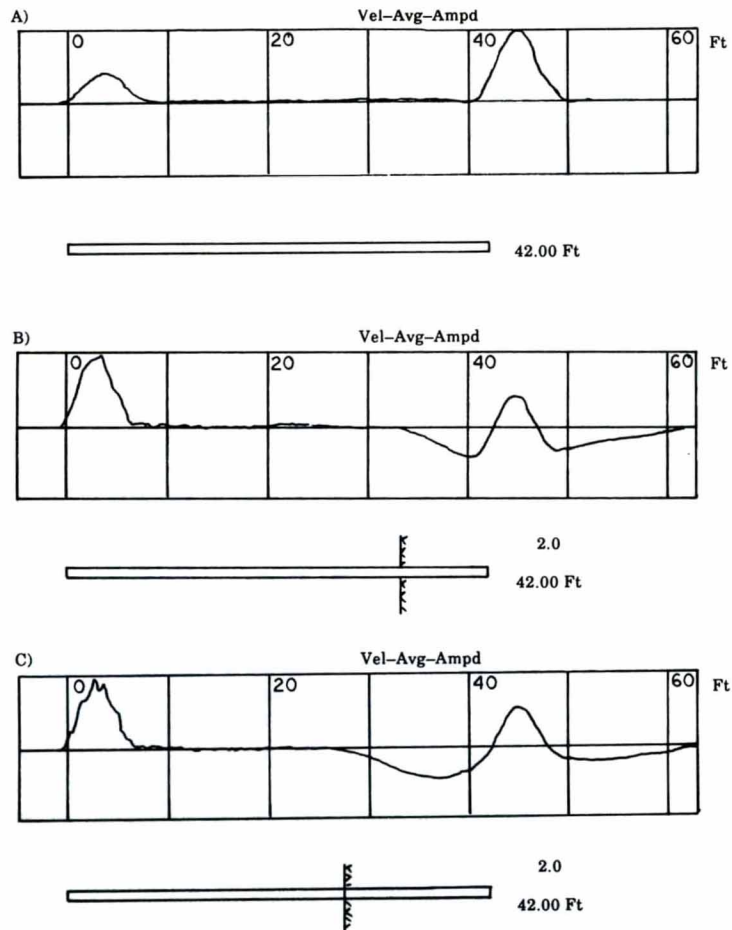


FIGURE 6 Typical records indicating varying amounts of soil resistance: A, no resistance; B, resistance below 34 ft; C, resistance below 28 ft.

through additional exploration and analysis and confirmed via lateral load testing.

For a cost less than \$100 per pile, the testing provided the means to rationally evaluate the serviceability of every pile at the marina. The alternatives would have been to do nothing or replace arbitrarily selected piles. In comparison, the low-strain integrity testing provided the most information at the lowest cost.

REFERENCES

1. *Pile Integrity Tester—PC Version Manual*, Goble Rausche Likins and Associates, Inc., Cleveland, Ohio, 1988.
2. F. Rausche, G. E. Likins, and M. Hussein. *Pile Integrity by Low and High Strain Impacts*. Third International Conference on the Application of Stress Wave Theory to Piles. International Society for Soil Mechanics and Foundation Engineering and the Canadian Geotechnical Society, Ottawa, Ontario, Canada, 1988.