Non-Destructive Testing and Evaluation of Timber and Steel H-Piles

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ABSTRACT

Timber and steel H-piles have been used in the construction of many aging locks, dams, levees, and other structures in the United States. Failure of these piles may adversely affect the structural integrity, and potentially cause damage and/or catastrophic structural failure. This study aims at utilizing state-of-the-art non-destructive testing (NDT) techniques to assess the condition of steel and timber piles. Two pairs of timber piles and steel H-piles were prepared and nondestructively tested in the laboratory. The test parameters were the two types of piles and pre-planned defect sizes/locations. Four NDT methods were investigated including bending wave (BW), dispersive wave (DW), combinations of dispersive-bending wave (DW/BW), and parallel seismic (PS). Wavelet transform, an advanced signal processing method, was used to post-process the NDT data. The method known as "peak identification (PI)" was used to detect the pile tip in both BW and DW/BW tests. The results reveal that the DW/BW accurately detected the pre-planned defects for timber piles. For steel piles, the PI method could only detect deeper defects in the DW/BW tests. The reflected signals from shallower defects had a relatively high signal-to-noise ratio and were hard to interpret. The wavelet transform approach was successfully used to detect both the shallow and deep defects in all the piles. The PS tests were proved to accurately and effectively capture all the pre-planned defects in both the timber and steel H-piles.

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INTRODUCTION

In the United States of America (USA), many bridges are built over waterways to facilitate navigation along the river systems. Wooden and steel piles are commonly used as foundation of these bridges and many other civil and military infrastructures to provide support to such infrastructures, thereby protecting lives from floods, environment, and property. Much of the pilings throughout the U.S. water resource infrastructures are over 50 years old. There exists little to no documented evidence of the pilings'structural health. This is because (a) It is challenging to inspect the pile foundations that are embedded in the soil and (b) Condition assessment of the pilings throughout the U.S. water resource infrastructure is costly. The consequences of their unknown conditions could pose significant risks throughout infrastructure inventories across the U.S.

Foundation pilings are generally expected to have a long life, but the failure of the piles would result in major structural and catastrophic failure. The failure may be caused by defects along the piles. An effective inspection or nondestructive testing (NDT) technique would yield better maintenance management of the pilings and would help engineers accurately predict current conditions of the pilings. Though wooden pilings are generally the oldest foundation components and may represent a significant risk, inspection methods are necessary for both wooden and steel piles.

NONDESTRUCTIVE TESTING OF PILE FOUNDATION

Non-destructive testing methods can be categorized based on stress waves (a.k.a. acoustic or mechanical waves), electromagnetic waves, electrical/magnetic fields, and others. For deep foundations, the following NDT techniques are commonly used [1,2]:

- *Surface-based NDT methods*: Sonic echo/impulse response (SE/IR); Flexural (bending) wave (BW); Ultra-seismic (US); Spectral analysis of surface waves (SASW); Ground-penetrating radar (GPR); Dynamic foundation response; Electrical resistivity imaging/induced polarization.
- *Subsurface-based (a.k.a. borehole-based) NDT methods*: Parallel seismic (PS); Borehole sonic; Borehole radar; Cross-hole sonic logging; Induction field; Borehole magnetic.

Impulse response/sonic echo (IR/SE) methods [2-4] have been used extensively to check lengths, continuity, and integrity of both newly installed and in-service deep foundations, e.g., concrete or timber drilled shafts driven piles. They can be used to detect defects (e.g., cracks and breaks), pile necking and lengths, bulbs (i.e., diameter increases), and soil inclusions (Figure 1a). The IR/SE method is a surface reflection technique that relies on the identification of compressive wave reflections.

The bending wave (BW) method [2,4] uses flexural waves instead of compressional waves, which are used to determine the unknown depth and integrity of deep foundations in the IR/SE methods. The BW method is limited to applications on "rodlike" deep foundations such as timber/concrete piles and drilled shafts that extend above the ground or water surface (Figure 1b).

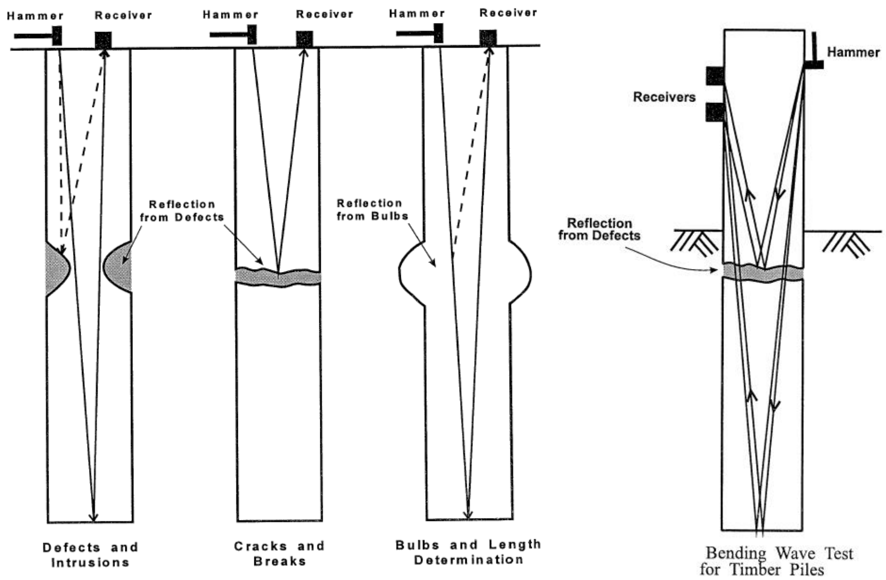

Figure 1. (a) IR/SE and (b) BW test methods [2]

The Parallel Seismic (PS) method [5,6], a borehole test method, is the most common NDT technique that has been researched and developed to determine the length of unknown foundations. The PS method can also detect major discontinuities within a foundation and provide the surrounding soil velocity profile. Cased boreholes (water filled if hydrophones are used) are installed near the foundation being tested. The PS method can be effectively used when the long and slender piles (such as driven piles or H-shaped piles) are unable to be tested by the IR/SE techniques and when the top of foundations are not accessible.

LARGE-SCALE TESTBED

A large-scale testbed has been designed to develop, test, and validate NDT methods for evaluating the conditions of wooden and steel piles. The testbed includes a three-dimensional steel-frame structure filled with sandy soils and pre-installed wood/steel pilings. The steel frame was constructed with H-shaped columns, top/bottom beams, bracing systems, and perimeter steel walls (Figure 2). The overall dimensions of the frame are 9 × 9 × 10 ft (width × length × height).

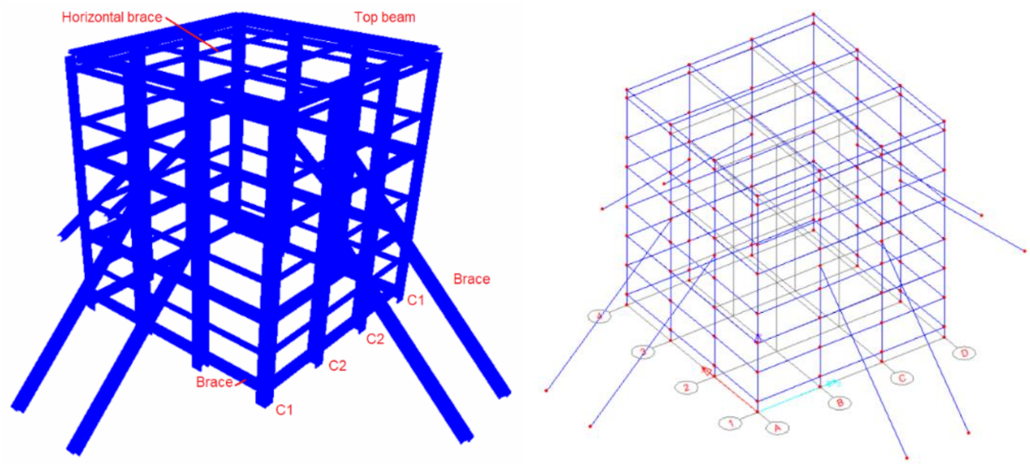

Figure 2. Overview and 3D model of the steel frame

Two pairs of timber piles and H-piles (i.e., one pile as a control specimen without any artificial flaws and another pile with pre-planned defects) are used for the experimental testing. These four piles are located at the corners of the testbed, as shown in Figure 3. A 4-inch polyvinyl chloride (PVC) pipe located in the middle of the testbed is used to accommodate hydrophones for the parallel seismic (PS) NDT method. The elevation view of the testbed with the embedded piles is illustrated in Figure 4. Test parameters include:

(a). Two types of piles (i.e., timber and H-shaped steel piles);
(b). Different employed NDT methods, including bending wave (BW), impulse response (IR), and parallel seismic (PS); and
(c). Sizes and locations of artificial defects on timber and H-shaped steel piles.

The section losses of rectangular shape representing the decays of the timber pile and the wall losses of the semi-ellipse shape of the H-shaped steel pile were created at 12" from the top (upper defects) and 12" from the bottom of the piles (lower defects), as can be visibly seen in Figure 4. Test parameters and details of timber and steel piles are listed in Table 1.

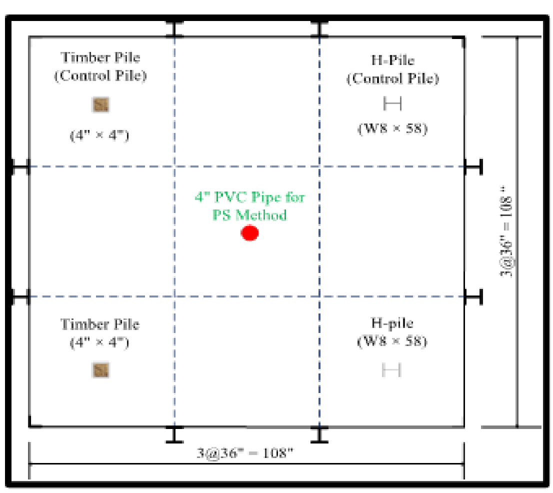

Figure 3. Test layout

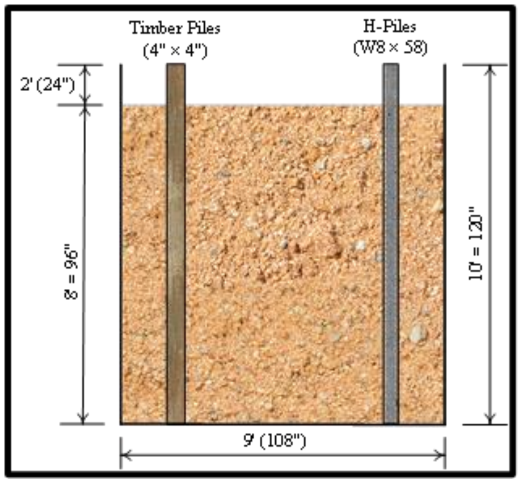

Figure 4. Elevation view of the testbed

The piles were installed inside the steel-box frame (a.k.a. steel cage) and attached to the base plates, which were connected to a strong floor. A PVC pipe with a diameter of 4" was installed in the center of the steel cage. The bottom of the PVC pipe was completely sealed to ensure it could hold the water that was needed to conduct the parallel seismic tests. To mimic the field environment of actual pile foundations, the steel cage was filled with 30 tons of fine-grained construction sand (contained in more than 30 heavy-duty sandbags).

TEST RESULTS

The sonic echo (SE) test method is sensitive to changes in the pile impedance, which causes the reflected wave. A decrease in impedance due to corrosion, decay, and similar defects of the pile generates a reflected wave that combined with the incident wave to form a downward peak (trough) in the signal. The method to evaluate a peak in the signal as a reflection corresponding to a defect is called peak identification (PI). A pile without any defects would typically have only two peak reflections generated from the measured signals, that is, one due to impulse from the impact and another due to reflection at the pile tip. The presence of any intermediate peak reflections in between the pile top and tip would then indicate the existence of the defects. The reflected wave from the small or deep defect is weak and eliminated by the incidence or reflected wave from the pile tip. As a result, the PI method may not detect those defects well. Wavelet transform (WT) is widely used in analyzing periodic, noisy, intermittent, and transient signals [7]. The phase information is more sensitive to damaged locations [7], and WT technique can be used to localize pile damage due to its advantage on phase information attraction.

Three methods, including bending wave (BW), dispersive wave (DW) and mixed dispersive-bending wave (DW/BW) were conducted as schematically shown in Figure 5 through Figure 7. Accelerometers and in-house data acquisition were respectively used for sensing and recording the response of the tested piles subject to lateral and vertical impacts from different strikers including a hard hammer (HH), a baseball bat (BP), 4-lb sledgehammer (4Lb), a bowling pin, and a sphere. Different hammer types can generate different frequencies of vibration. Some test results are presented in Figure 8 across Figure 13. For timber piles, the PI method can effectively be used to detect the pile tip in BW (Figure 8) and DW/BW tests. The BW tests were only able to capture the upper defects (Figure 9). The combination of dispersive-bending wave (DW/BW) was found to accurately determine both upper and lower defects (Figures 10 and 11). For steel piles, the bending wave (BW) test results indicated that the PI method could not find recognizable reflections from upper and lower defects. The results obtained from the DW/BW tests showed that the PI method can only detect lower defects. The reflected signals from the upper defect are complex and hard to interpret. The WT method, however, can detect both upper and lower defects (Figures 12 and 13).

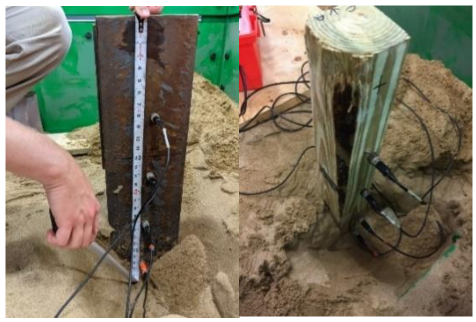

Figure 5. Bending wave (BW) test setup

Figure 6. Dispersive wave (DW) test setup

Figure 7. Mixed Dispersive-Bending wave (DW/BW) test setup

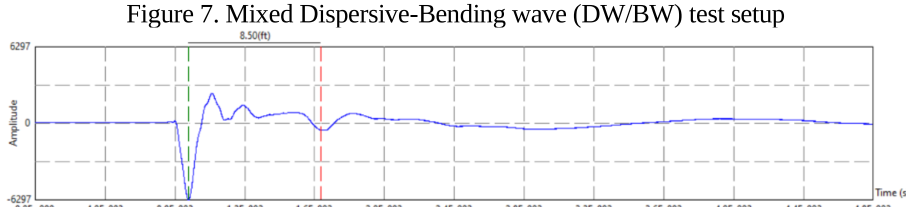

Figure 8. Pile tip location from BW test for timber pile (PI method)

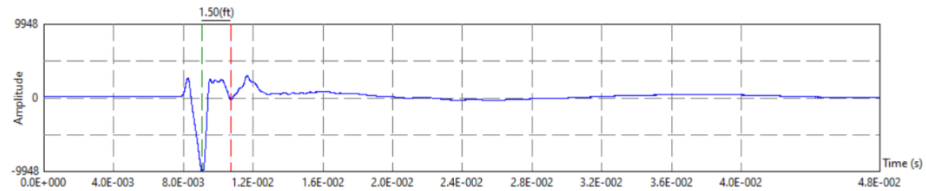

Figure 9. Upper defect location from BW test for timber pile (PI method)

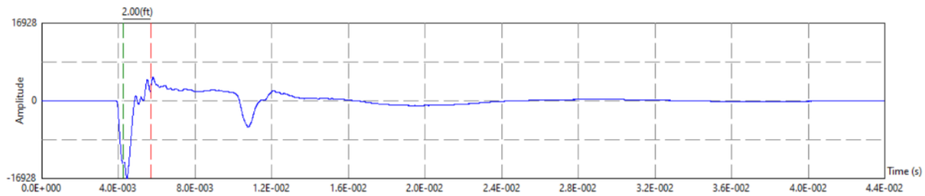

Figure 10. Upper defect location from DW/BW test for timber pile (PI method)

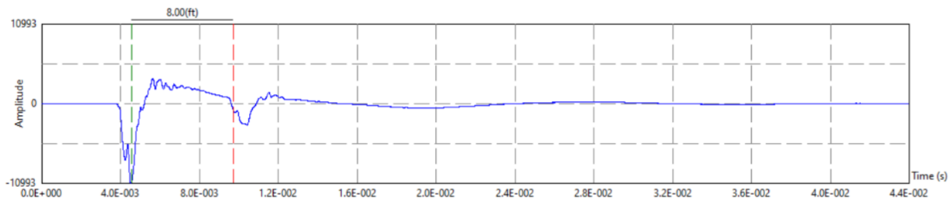

Figure 11. Lower defect location from DW/BW test for timber pile (PI method)

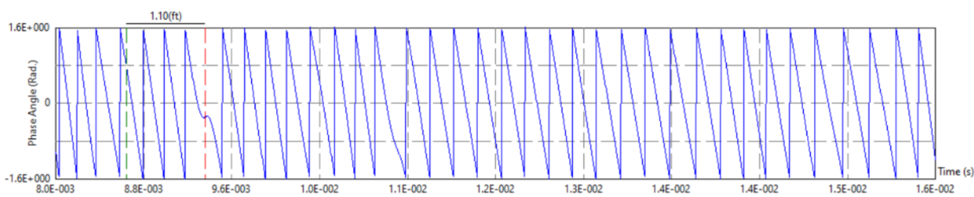

Figure 12. Upper defect location from BW test for steel pile (WT method)

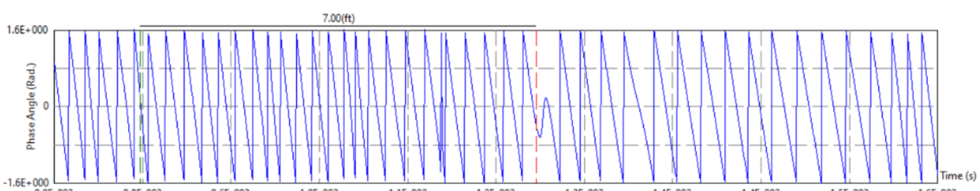

Figure 13. Lower defect location from BW test for steel pile (WT method)

The parallel seismic test was able to find both upper/smaller defect at the 12th strike (~3 ft), and lower/larger defect at the 36th strike (~ 9.0 ft) for timber pile and between the 16th and 17th strikes (~2.9 ft), and lower/larger defect at the 61st strike (~ 8.5 ft) for steel pile, as shown in Figure 14 and Figure 15.

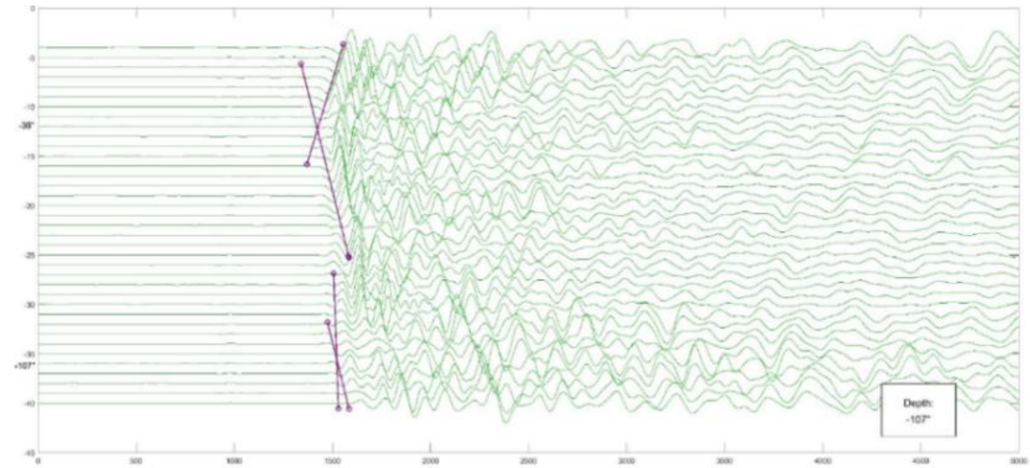

Figure 14. Parallel seismic test results of the timber pile

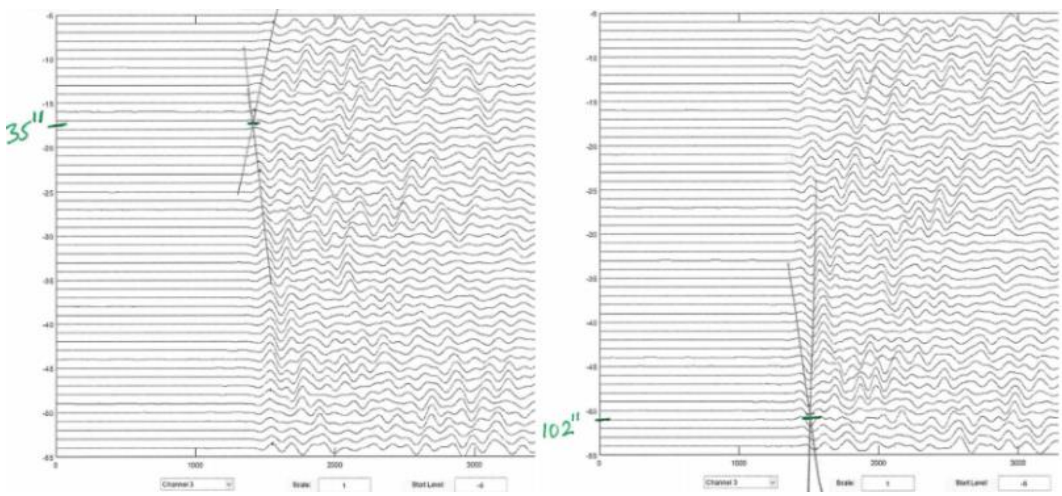

Figure 15. Parallel seismic test results of the steel pile

CONCLUSIONS

From the obtained test results, the following conclusions were drawn:

- For timber piles, a peak-signal reflection method known as "peak identification (PI)" can effectively be used to detect the pile tip in both BW and DW/BW tests. However, the BW test was not able to capture the lower defects. The combination of dispersive-bending wave (DW/BW) was found to accurately determine both pre-planned defects (i.e., in upper and lower sections of the pile).
- For steel piles, the PI method could detect only the deeper defects in the DW/BW tests. The reflected signals from the shallower defects had a relatively high signal-to-noise ratio and were hard to interpret. The wavelet transform approach was successfully used to detect both the shallow and deep defects in all the piles.
- The parallel seismic (PS) test accurately and effectively captured both upper and lower pre-planned defects in the timber and steel piles.

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