Determining the Length of Timber Piles in Transportation Structures

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Abstract

Knowledge of pile length is a vital component for calculating the scour resistance of bridges. A nondestructive evaluation technique based on longitudinal stress wave propagation has been developed to determine the length of timber piles. A total of 33 piles from different bridge sites were selected for equipment evaluation and verification testing of the pile length technique. The piles were evaluated by the stress wave technique, then compared to construction records for verification of length. The stress wave technique has been proven to reliably estimate pile lengths between 20 and 60 ft with an accuracy of ± 15 percent. Additional field tests have been conducted on several bridges in Tennessee and Colorado. Based on these field tests and signal processing refinements, length estimates are possible for greater than 90 percent of piles tested.

Introduction

During the late 1980's, nationwide attention was directed toward bridge failures due to scour. Recognizing the need to uniformly evaluate bridge scour, the Federal Highway Administration (FHWA) published a Technical Advisory on the scour of bridges (Federal Highway Administration 1988). This Technical Advisory is used to address the effects of bridge scour in the design process and inspection of existing structures within the National Bridge Inspection Standards Program.

Knowledge of pile length is a vital component for calculating the scour resistance of a bridge. However, records of timber pile lengths may, in many cases, be nonexistent or incomplete due to the construction practices for timber piles. Piles are typically driven until they reach a predetermined resistance, then trimmed at the end to provide a solid level surface for substructure construction. Records that specify initial pile length, depth of driven pile or length of pile trim are often unavailable, especially in older structures. Thus, it is difficult to obtain timber pile length data for scour evaluations.

Research on Timber Pile Length

Limited research has been conducted on evaluating the length of embedded timber piles. Davis (1994) described use of sonic echo and parallel seismic methods for estimating pile length. The sonic echo method is based on impacting the head of the pile and measuring the time for the reflected stress wave to reach an accelerometer, also mounted on the head of the pile. Davis reported several difficulties using this method when a structure is resting on the pile: (a) damping of the stress wave and multiple reflected waves made determination of the echo from the pile tip difficult; (b) attaching the accelerometer to the side of the pile was difficult and (c) delivering a direct impact to the side of the pile was difficult.

The parallel seismic method used by Davis (1994) avoids the difficulty of not having access to the head of the pile. An access hole is drilled parallel to the pile, lined with a plastic tube, and filled with water. The water acts as a couplant for a transducer (typically a geophone or hydrophone) submerged in the tube to detect the transit time of impacts delivered near the top of the pile. By lowering the transducer at known increments it is possible to determine the length of the pile from a plot of transducer depth versus transit time. Cost is a primary limitation to conducting the parallel seismic test on timber piles. The parallel seismic method has achieved acceptance for concrete structures and a modified sonic echo technique (termed ultraseismic) also shows promise for higher-value structures (Jalinoos and Olson, 1996).

Douglas and Holt (1993) used analysis of bending waves in timber piles to estimate length. A signal processing technique, termed the short kernal method, was developed to allow for processing of dispersive bending waves. Dispersive waves have frequency components which travel at different velocities and therefore, render signal processing more difficult particularly when dealing with unknown geometries. Nonetheless, these researchers were able to evaluate lengths of 26 piles with reported accuracies of approximately $\pm$ 10 percent.

Research on timber poles and piles (Anthony et al, 1989; 1992) resulted in nondestructive evaluation (NDE) techniques based on longitudinal stress wave propagation that provided the means to evaluate the length of timber piles. To adapt the technology for pile length determination modifications to existing impact methods and sensor attachments were necessary, coupled with further testing on piles of known lengths. Field testing of the technique was conducted to identy the accuracy, limitations and the means of applying the pile length determination technology. Details of this development are provided in the report to the Timber Bridge Information Resource Center (Engineering Data Management 1992). References to the technique are descrii below.

Technical Approach

The timber pile length determination technique is based on longitudinal stress wave propagation. Stress waves, produced from a hammer impact travel along the length of a pile and are reflected at boundaries until dissipation of the impact energy. The stress waves travel at a velocity that is dependent on the pile density, moisture content and material quality.

Pile length can be evaluated by measuring the time required for the stress wave to travel to the base of the pile and return. The reflection time is related to the resonant frequency of the pile. The measurement of reflection time or resonant frequency and stress wave velocity enable the calculation of pile length.

The three components of the data collection process for the pile length technique, shown in Figure 1, are the excitation source for inducing the stress wave (hammer), accelerometers for measuring the pile response and a data acquisition system for recording and processing the stress wave data. When determining pile length using this technique it is crucial that the induced stress wave propagate primarily along the longitudinal axis of the pile, avoiding transverse excitation of the pile as much as possible. Moreover, the induced stress wave must be of sufficient energy to travel the length of the pile and back.

After evaluating several approaches, it was determined that a direct impact to the pile induces the most desirable stress wave. However, since the end of the pile is generally not accessible, the impact must occur below the pile cap through an attachment on the side of the pile. The attachment (a lag screw inserted at 45 degrees) is positioned such that the operator can easily swing a hammer without the interference of the bridge stringers or other components near the pile cap.

Stress waves induced from the hammer impact travel through the pile and are reflected at the ends of the pile. From the information recorded by the two sensors, located at a fixed distance apart an estimate of stress wave velocity is obtained. Pile length is calculated from stress wave velocity and the reflection time. Reflection time is the time taken for the stress wave to travel from the impact point to the bottom of the pile and back.

The resonant frequency of the pile is the inverse of the reflection time required for the stress wave to travel twice the length of the pile. The resonant frequency of a pile is, therefore, related to pile length and stress wave velocity. Thus, the length of the pile can also be estimated using the resonant frequency of the piles.

Evaluation of the Pile Length Technique

A total of 33 piles from different bridge sites were selected for equipment evaluation and verification testing of the pile length technique. The bridge sites were in four different states. Table 1 lists the number of piles tested, the age and condition of the piles for the different sites. The Colorado piles were used during the initial stages of the project to evaluate multiple sensor configurations and hammer impact methods. The Louisiana, Tennessee and Minnesota bridge sites each contained piles of various lengths which had been recorded during construction. The piles were evaluated by the stress wave technique, then compared to construction records for verification of length.

Pile lengths from Colorado and Louisiana were estimated using only the resonant frequency method whereas piles from Tennessee and Minnesota were evaluated using both the resonant frequency method and the reflection time method.

The advantage of using both the resonant frequency and the reflection time is that it is possible to evaluate and predict lengths for a greater percentage of piles tested. There are some piles for which an estimate of the length cannot be obtained using resonant frequency because of difficulties in interpreting the frequency record. In many such cases, it is possible to obtain an estimate of the length using the reflection time. In general, the reflection time method provides a more accurate estimate for the length of piles.

As an example, a frequency record for which it is difficult to determine frequency spacing is shown in Figure 2. This frequency record has only one dominant peak (at approximately 500 Hz). It is difficult to obtain an estimate of the resonant frequency from a single peak because spacing between peaks is used to calculate the resonant frequency. For the same pile, a time domain record of the stress wave and its representation after filtering are shown in Figure 3. From Figure 3(b), an estimate of the reflection time is obtained as the time between the two marked points. Using reflection time, the length of this pile was estimated to be 30 ft The actual length obtained from the construction records, was 31 ft.

Figure 4 depicts the relationship between the actual and estimated pile length for the 33 piles listed in Table 1. Points on the figure marked with a filled circle represent the piles from Tennessee and Minnesota. These piles were evaluated using both resonant frequency and reflection time. As shown in Figure 4, the range of pile length estimates fall within ± 15 percent of the actual pile length as defined by the two lines.

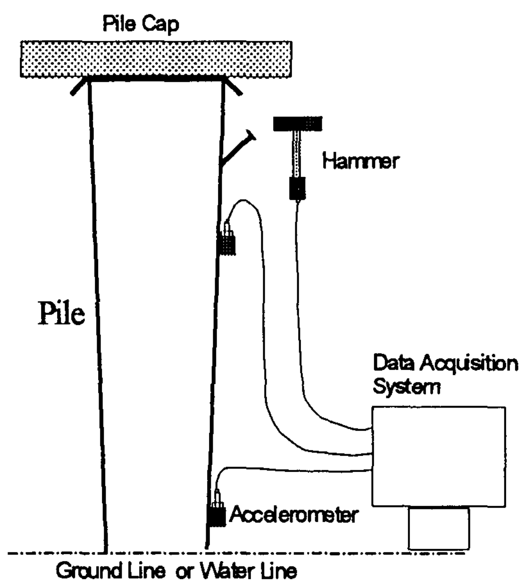


Figure 1—Configuration for conducting pile length evaluation.

Table 1—Number, age and condition of piles located at specific test sites.

Location of Test Site	Number of Piles	Age of Piles (Yrs.)	Condition of Piles
Colorado	13	46 to 59	Decayed to Good
Louisiana	9	0 or Unknown	Good to New
Tennessee	7	0	New
Minnesota	4	Unknown	Good

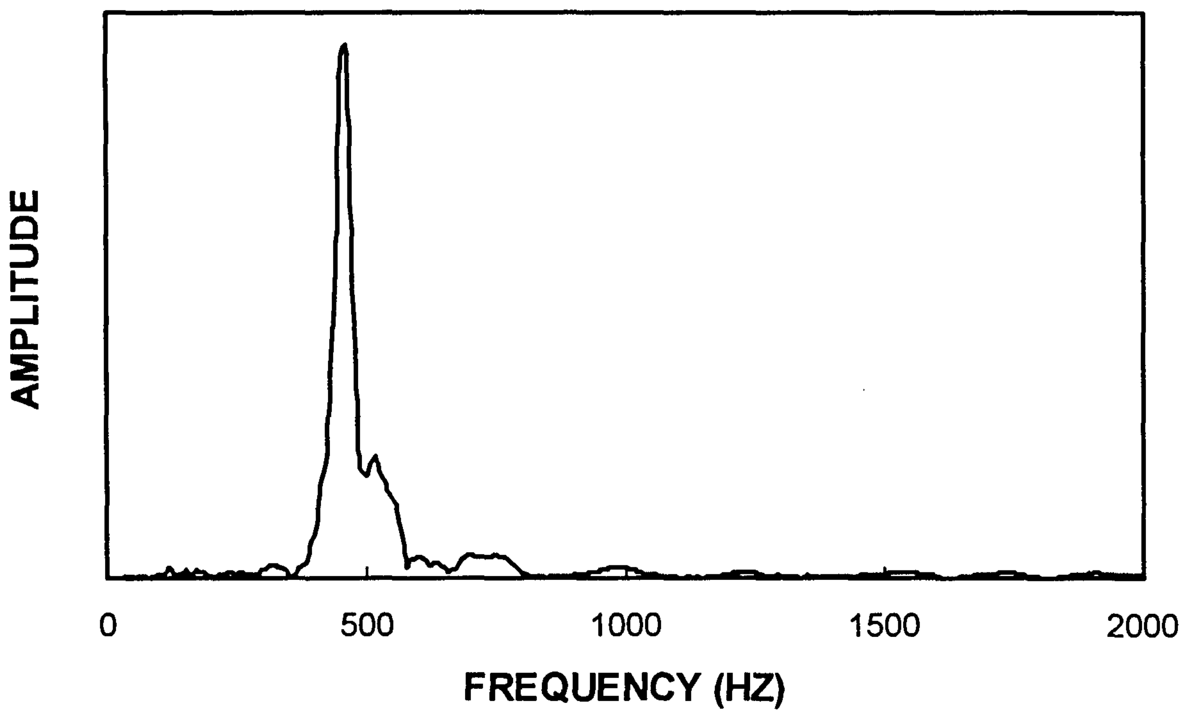
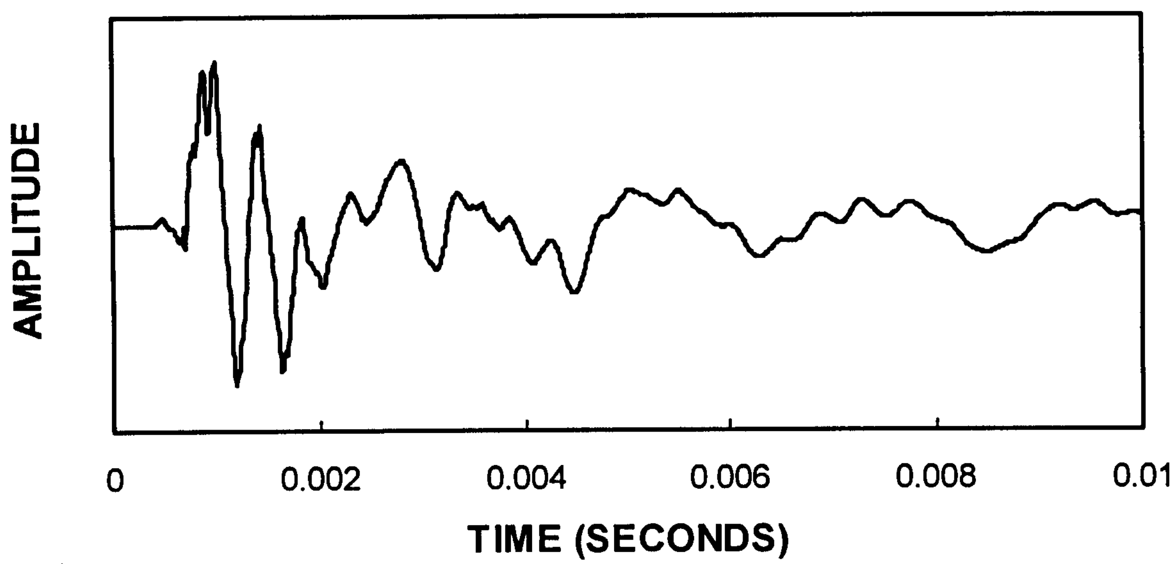
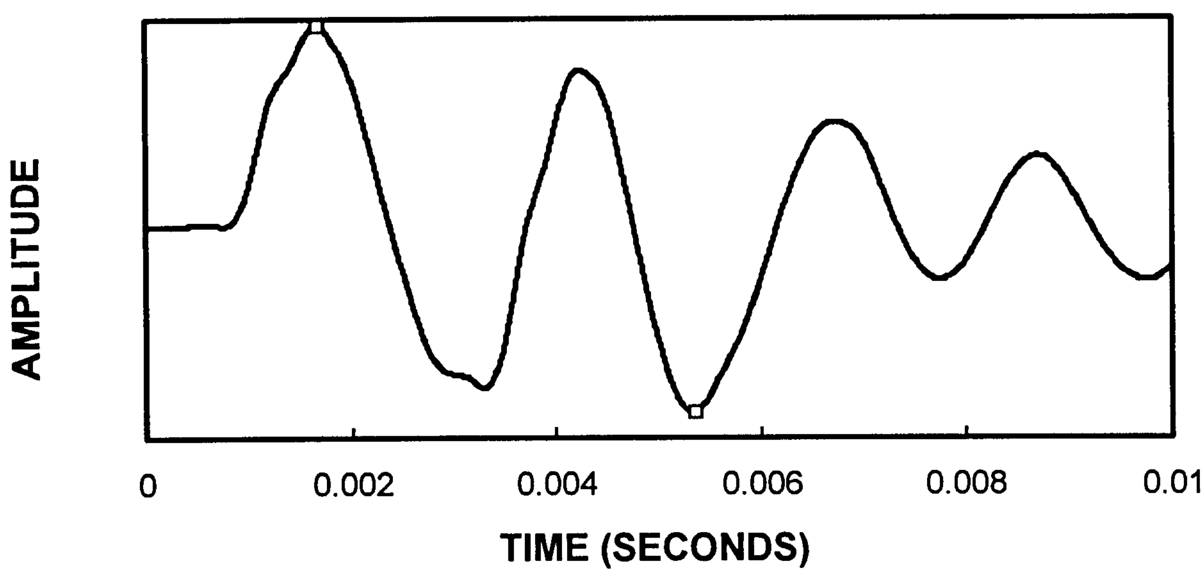


Figure 2—Frequency record representing a 30 ft pile.



(a)



(b)

Figure 3—Time-domain representing data for a 30 ft. pile, including (a) raw data and (b) filtered data.

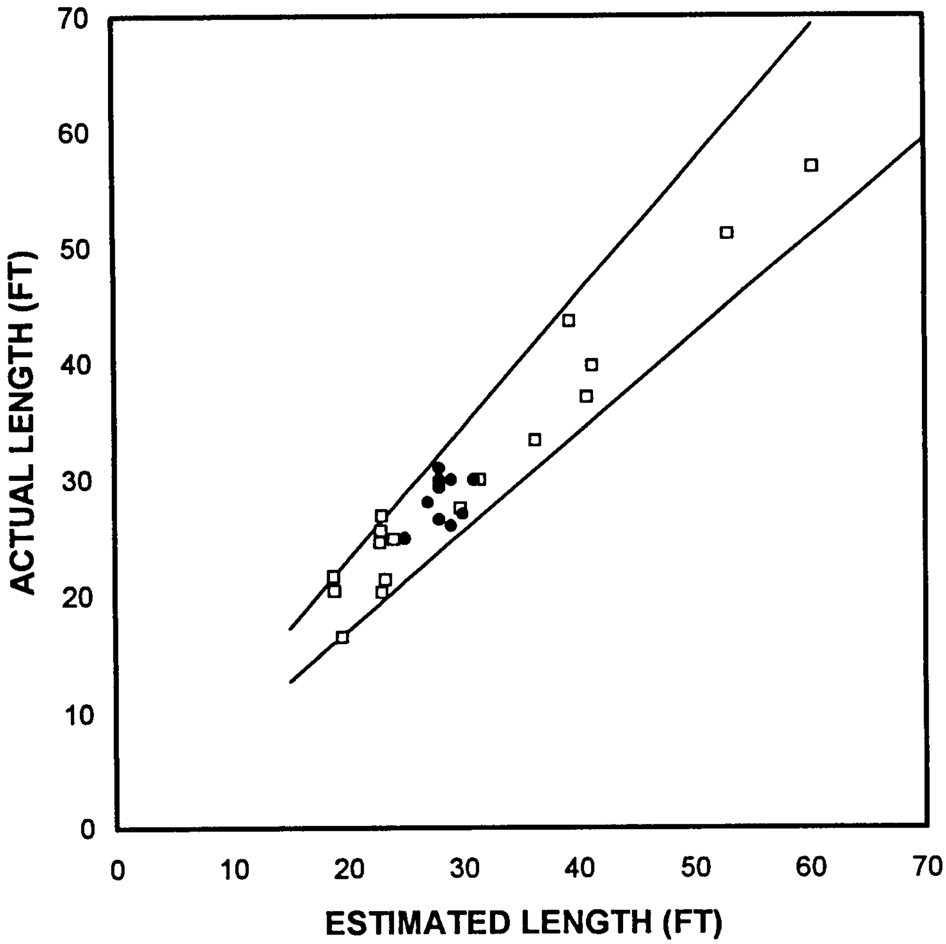


Figure 4—Plot of actual and estimated pile lengths for 33 piles of known length listed in Table 1.

Application of the Pile Length Technique

In addition to the piles discussed above, tests have been performed on several other bridge sites in Colorado and Tennessee. NDE data on 26 piles from three bridge sites in Tennessee were collected for predicting unknown pile lengths. These piles were older with conditions ranging from good to badly weathered. Using the pile length technique, it was possible to obtain an estimate of length for most of the piles tested.

The Colorado Department of Transportation (CDOT) proposed to use the technique to evaluate five scour-critical bridges supported by timber piles. Further, the CDOT desired to define the accuracy of the nondestructive technique in rocky and sandy soils which were not evaluated in previous research.

The pile length technique was evaluated and refined on the bridge over South Platte River near the town of Snyder. This bridge consisted of several timber pile bents with some being in water. Data were collected on 60 piles from 12 bents from the bridge, including some of the bents that were in water. Digital filtering techniques were used to smooth the wave propagation data. The data were analyzed using both time domain and frequency domain analyses. From the predicted lengths, an average length for the piles in a bent was calculated.

One task of the Colorado project was to further define the accuracy of the technique in a Colorado soil. This was to be done by extracting piles from the Snyder bridge and comparing the actual lengths to the predicted lengths. Unfortunately, the pile extraction process was extremely difficult. In spite of CDOT's efforts, the pile extraction had to be abandoned without obtaining any actual lengths for the piles. Therefore, the technique's accuracy could not be further verified.

Task 2 of the Colorado project involved evaluation of five bridges that were identified to be in scour-critical regions with unknown timber pile lengths. These bridges were dispersed throughout southern Colorado and represented typical Colorado soils. Data were analyzed for each pile and an average length for the piles in a bent was calculated. The technique was successful in determining the length of all of the 68 piles tested. The use of the two analysis methods for determining length, one in the time domain and the other in the frequency domain, makes the technique more robust in predicting the unknown depth.

Summary

A reliable NDE method to evaluate the length of timber piles has been developed. Field-rugged impact methods and sensor attachments are available which are simple to install and use. The stress wave technique has been proven to reliably estimate pile lengths between 20 and 60 ft with an accuracy of $\pm$ 15 percent. Use of both resonant frequency and reflection time makes the technique more robust in predicting unknown length. Length estimates were possible on greater than 90 percent of the piles tested in field projects in Tennessee and Colorado. Engineers and maintenance personnel who require knowledge of pile length to evaluate the effects of scour on pile capacity will find this technique invaluable for acquiring previously unavailable information.

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Acknowledgments

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