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Determination of unknown bridge foundation depths with parallel seismic (PS) systems

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ABSTRACT: This paper discusses the results of parallel seismic (PS) testing for determination of unknown bridge foundation depths. A three-dimensional (3D) finite element model (FEM) for the pile-soil system is established for impulse responses. Under saturated soil or unsaturated soil condition, several vibrating velocity-time histories at different depths in parallel hole are obtained based on the numerical simulation. It shows that the length of the pile and the one-dimensional (1D) P-wave velocity in the pile can be determined easily from the features of the mentioned velocity-time histories. By examining the slopes of the first arrival time plotted versus depth or the depth where the amplitude of the first arrival significantly decreases, the length of the pile can be determined. The effects of the 3D P-wave propagation through the saturated soil and the defect of the cemented soil column on the velocity-time histories are also investigated.

1 INTRODUCTION

Determining the true tip depth and foundation geometry for bridge foundations without documentation is becoming an increasingly important task for the nondestructive testing community. These unknown foundations found under a wide variety of structures, range from bridges to antenna towers to buildings. For most of these foundations, the lack of any information is not a major concern if the structure has been performing adequately for a period of years. However, a variety of situations can arise which can suddenly make the foundation depth and geometry be of prime importance. The most common situation, which arises, is a planned change in loading the foundation element. For antenna towers, this situation occurs when new or heavier antenna elements are added to the tower. For bridge foundations, this can be due to adding lanes to an existing bridge or reusing foundations for a totally new superstructure. The need for foundation information can also be driven by scour safety analyses for bridges, to verify that the predicted or historic scour depths will not undermine the foundations during a major flood event or high tides. Regardless of the actual reason, to use information on foundation depth and type, there is a clear requirement for reliable, fast, and cost-effective test techniques to allow this determination. There are several methods that can be used for unknown foundation evaluation, with the specific utility of each method usually dependent on the actual foundation to be tested. These methods include electromagnetic methods, such as surface and borehole based Ground Penetrating Radar and borehole based Induction Field, various stress-wave based test methods, for example, surface Sonic Echo, Impulse Response, Ultra seismic (US) methods, as well as the borehole-based Parallel Seismic method. Parallel Seismic (PS) test method is considered to be the most versatile and reliable method. This method can be applied to a wide variety of foundation types and almost any foundation depth, and does not require direct physical access to the foundation being tested. The most significant limitation to wider application of the PS method is that it typically requires a cased borehole to be placed in the ground next to the foundation in question using a truck-mounted drill rig.

2 PARALLEL SEISMIC TESTING EQUIPMENT

a. PSI instrument
b. 10000N force hammer transducer included
c. Depth meter
d. Hydrophone with 30m cable
e. Accessories
    i. 2 Channel 16 bit acquisition at 23 KHz sample rate

ii. Auto ranging and manual gain
iii. Waterproof enclosure supplied with rugged polypropylene carry on size case and heavy duty nylon carry pouch
iv. Wipe clean tactile keypad
v. TFT LCD screen with good daylight viewing and backlight
vi. 110/240VAC and 12VDC charging leads supplied
vii. USB data transfer lead
viii. Storage for up to 740 results including all raw data
ix. Site unit can view individual velocity trace
x. Includes PARA analysis software for Windows XP
xi. Site unit weight 1.3kg
xii. Calibration certificates and manual included

Items b, c and d are all connected via dedicated cables to the instrument (Figure 1, Figure 2)

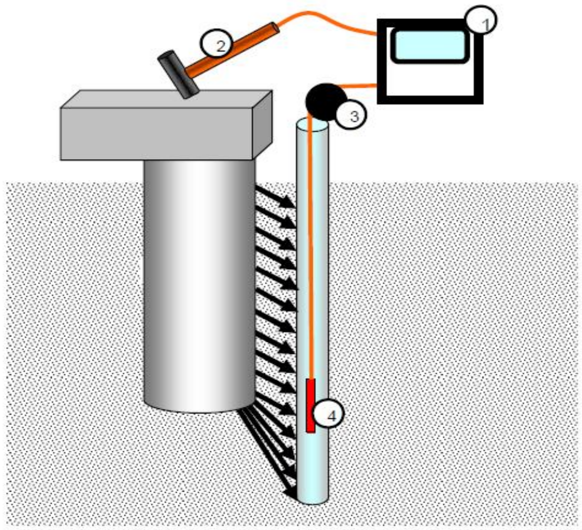

Figure 1. PSI system components

Figure 2. Apparatus set up

3 PARALLEL SEISMIC TEST METHOD

The Parallel Seismic (PS) test is normally performed by impacting an exposed foundation top or side, or impacting a part of the structure above the foundation (such as a pile cap or column). The impacts can be either vertical or horizontal, and are typically done with an instrumented impulse hammer to generate compression waves. Testing can also be done with a non-instrumented hammer, using an accelerometer mounted nearby for the trigger source. These waves travel down the foundation and couple into the surrounding soil as shown in Figure 1. The coupled compression waves are then picked up in the soil by a nearby hydrophone or geophone receiver. This receiver is typically suspended in a water-filled cased borehole, but can also be near the tip of an instrumented cone probe pushed into the ground. The impact data is collected at a series of multiple receiver depths and stored. This data is then used to create a plot of receiver signal arrival time versus depth, from which the analysis is performed.

Regardless of the type of equipment used to collect the PS data, the tip depth of a foundation is typically indicated by an inflection point in the arrival time versus depth curve, along with a sharp drop in signal amplitude. Diffraction of wave energy from the foundation bottom has also been found to be indicative of foundation tip depth in PS tests as well.

Before performing the test, a vertical plastic tube should be inserted into suitable hole drilled in the ground, parallel and as close as possible to the tested foundation element. The tube, with a watertight cap at the bottom should have an inside diameter of not less than 40 mm and go down not less than 3 m below the assumed toe of the tested foundation element. In dry soil, the annular space between the tube and the drilled hole should be filled with cement grout throughout its length. The plastic tube is filled with clear water. A suitable dummy weight shall be used to assure that the tube is free of obstacle geophone, sensitive to audio frequencies, is lowered into the tube in predetermined stages not exceeding half a meter. At each stage, the top of the foundation element or an appropriate spot on the superstructure is hit with the hammer. The location of this point should be kept constant during the whole test. The hammer blows create longitudinal waves that travel down the foundation element and through the soil to the hydrophone inside the tube. The waves, which arrive at the hydrophone, are transmitted to the PSI and recorded in the computer connected to it. Upon completion of the test, the recorded waves are plotted at the respective Hydrophone depths. When the first arrival times (FAT) are connected, the resulting line clearly shows three distinctive zones (Figure. 3). In the top zone, the FAT values form a straight line with a slope S1. In the bottom zone, the FAT values form a straight line with a slope S2. In the intermediate transition line, the FAT values form a curve.

The intersection between the top and bottom lines indicates the toe level of the foundation element (or, alternatively, a total discontinuity).

4 PARALLEL SEISMIC DATA INTERPRETATION

The Parallel Seismic test is used primarily to determine the depth of unknown foundations, although information as to foundation type can usually be determined by an experienced testing firm Prosoil Foundation Consultant based on the foundation velocity, inflection points, etc. Several criteria were established for determining the foundation depths based on Parallel Seismic data as follows:

i. Breaks in the slope of the lines in a plot of depth versus recorded time (see Figure. 3)
ii. Drop in energy amplitude below the bottom of the foundation
iii. Diffraction of wave energy at the bottom of the foundation

Examination of Figure 3 shows the case where subsurface conditions are uniform with depth (this usually means saturated soil conditions where the compression wave velocity is that of water, i.e. about 1500 m/s or 4900 ft/s). This allows one to determine the velocity of the foundation element, and to clearly see the foundation bottom as the point where the wave velocity is slower and the amplitude is weaker. The foundation bottom is then taken as the intersection of the foundation velocity line with the soil velocity line as shown in Figure. 3.

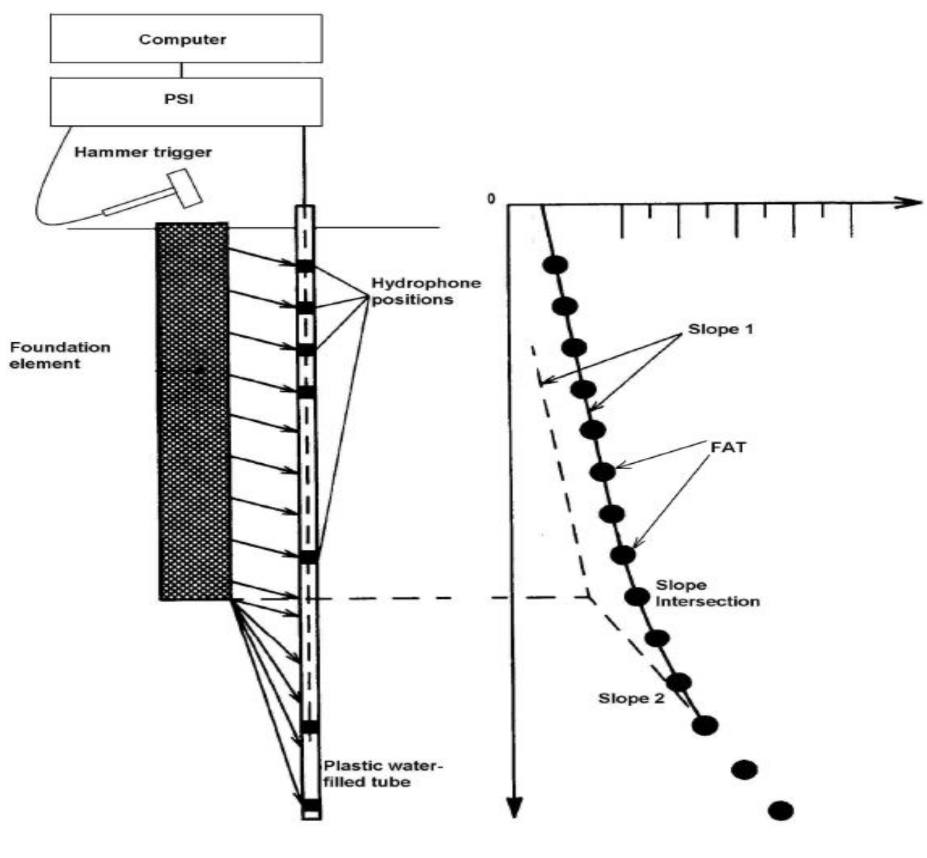

Figure 3. Interpretation of the results

5 TESTING METHODOLOGY

i. The remote sensor shall be lowed to the base of the tube in increments of either 0.5m or 1.0m. At each increment, the pile/structure shall be struck with the instrumented hammer and the transit signal from hammer to sensor recorded and plotted.

ii. Transit signal profiles shall be plotted sequentially and the signal arrival time marked on each structure of hammer. The change in signal arrival gradient indicating the point at which the sensor drops below the pile base.

6 TEST RESULTS

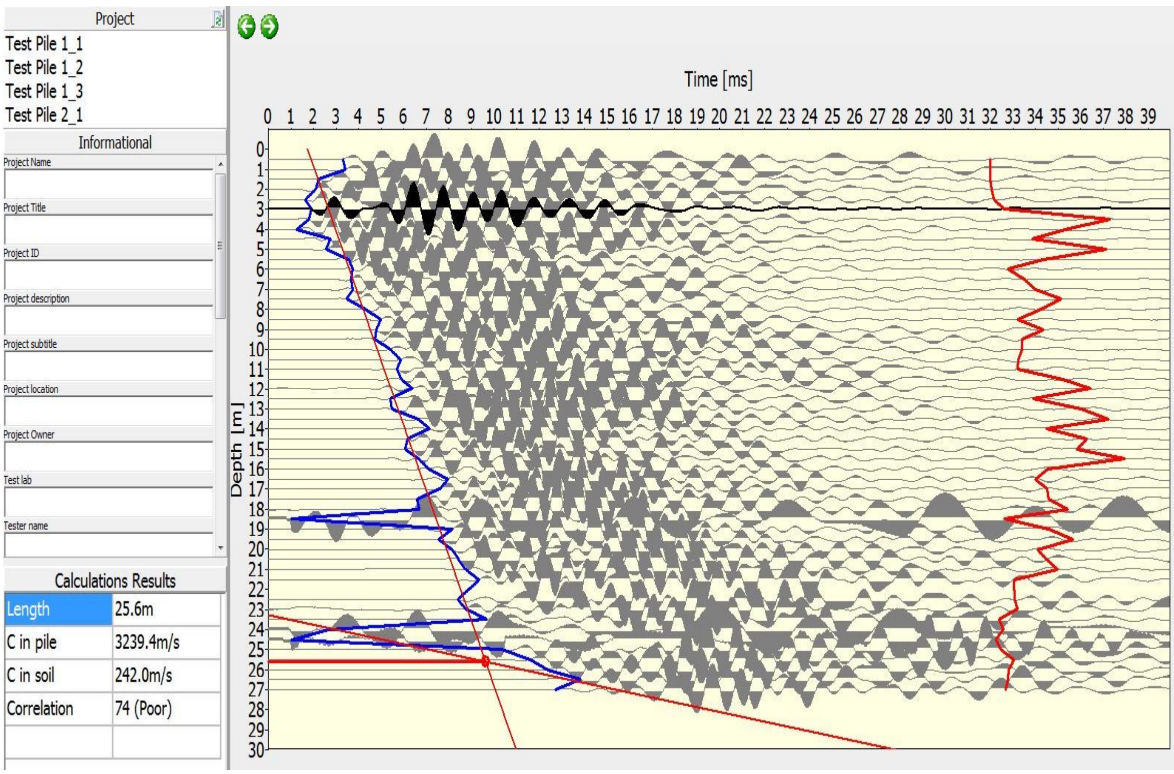

Figure 4. Graph of Tested Result in Bangladesh Road Research Laboratory (BRRL)

Length of the pile 25.60m.
Wave velocity in pile 3239.4 m/s.
Wave velocity in soil 242.0 m/s.

7 CONCLUSIONS

The examples provided demonstrate reasonable means for estimating the length of unknown pile foundations. The clear break is seen (Figure. 4) because the velocity of the concrete is much higher than the velocity of the surrounding soil. When the wave must travel through more soil below the pile tip, the wave arrives at the transducer later in time. This generates difference in first wave arrival times that occurs at the tip of the pile indicating its depth at 25.6m in the PS data example (Figure 4).Parallel Seismic (PS) system provides definitive information concerning pile lengths with results that can be interpreted with relatively little training.

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