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PS wave based parallel seismic test for pile length assessment

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Abstract

This paper presents an improved method for conducting parallel seismic tests to detect the unknown length and integrity of piles. The method involves the use of PS waves rather than the PP waves normally applied in conventional parallel seismic tests. Analytical solutions are derived for the *t–d* relationships of the first arrivals of the PS waves in homogeneous and layered soil conditions. Finite element models are also developed to simulate the waves generated by a vertical impact on the top of a pile under these two ground conditions for the purpose of validating the analytical solutions. The study indicates that the proposed method is viable and has several advantages over conventional parallel seismic tests.

Keywords: Parallel seismic test; Piles; Layered soil; Wave propagation; Non-destructive evaluation

1. Introduction

The parallel seismic (PS) test has been used for years to assess the integrity and the depth of existing piles (Olson et al., 1996; Kenai and Bahar, 2003; Herlein and Walton, 2007; Sack and Olson, 2009; Yu et al., 2010) and piles under construction (Wu and Yang, 2009; Huang and Ni, 2012). Compared to other non-destructive evaluation methods, this method is particularly useful in situations where the pile length is unknown or the pile head is not accessible for loading. As schematically shown in Fig. 1(a) and (b), the common practice of the method is to place a hydrophone in a borehole that has been drilled near the pile and filled with water. As the hydrophone is suspended in water, the signals received by the hydrophone are predominantly P waves, while S waves are filtered out. The P waves, traveling downward through the pile shaft and then transmitting to the soil, are referred to as PP waves, as shown in Fig. 2(a). Based on the time-versus-depth (*t–d*) relationship of the first arrivals of PP waves, the location of the pile base can be estimated as the point corresponding to the intersection depth of two fitting lines in the *t–d* plot, as shown in Fig. 2(b). This is the principle of conventional parallel seismic tests (Liao and Roesset, 1995; Liao et al., 2006; Huang and Chen, 2007; Lo et al., 2009; Ni et al., 2011; Huang and Ni, 2012; Niederleithinger, 2012; Lu et al., 2013; Zhang and Chen, 2013). Evidently, the slopes of the two fitting lines are affected by the velocity of the P waves in the pile and the velocity of the P waves in the soil below the pile tip.

For soil, its P-wave velocity (denoted as V_P^{soil}) is always higher than its S-wave velocity (denoted as V_S^{soil}), particularly in the case where the soil is saturated. The ratio of the two velocities can be determined as

$$\eta = V_P^{soil}/V_S^{soil} = \sqrt{2(1-\nu)/(1-2\nu)} \quad (1)$$

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where ν is Poisson's ratio of the soil and it increases with an increase in the degree of saturation of the soil (Du et al., 2013; Yang and Sato, 2000). For partially saturated soil, the value of ν typically ranges from 0.3 to 0.5, yielding $\eta > 1.87$, whereas for saturated soil, the value of ν approaches 0.5 leading to a sharp increase in η (Yang and Sato, 2000). In this context, for a pile installed in saturated soil, the difference between the P-wave velocity in the soil and that in the pile is much smaller than for a pile installed in unsaturated soil. Nevertheless, the difference between the S-wave velocity of the soil and the P-wave velocity of the pile remains almost unchanged in these two situations. Keeping this in mind, it is of great interest to investigate whether the S waves generated from the P waves transmitting from the pile to the surrounding soil can be used

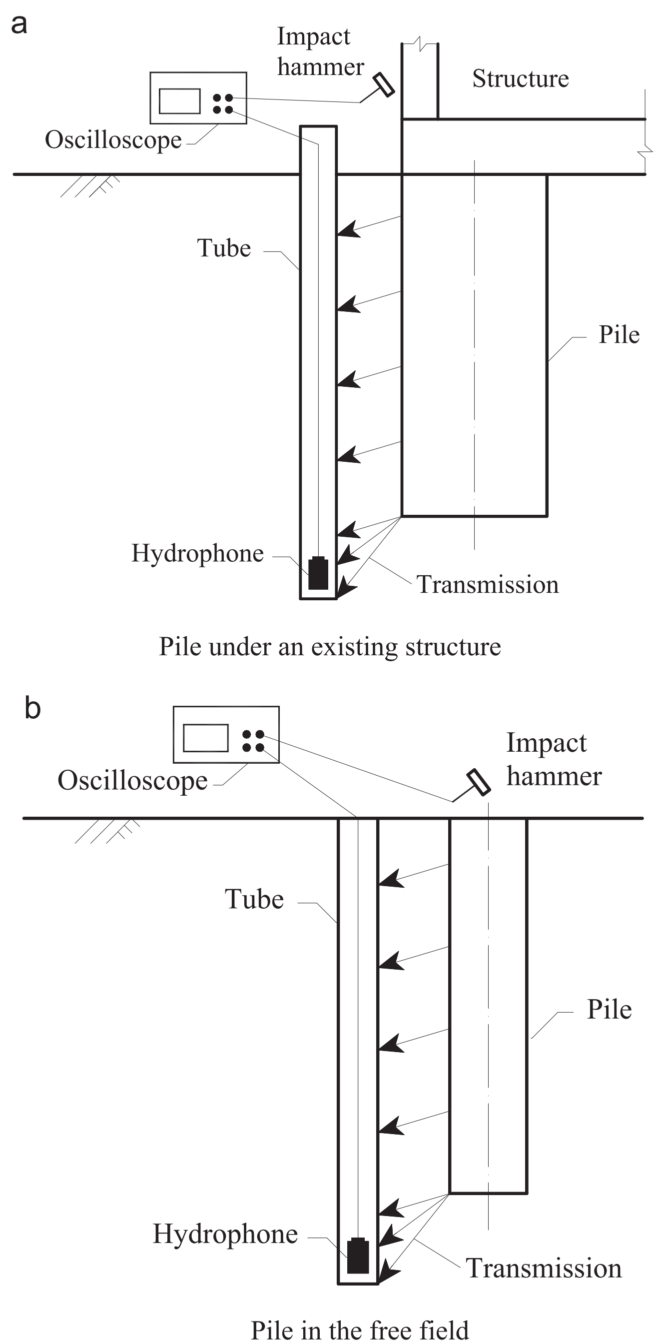

Fig. 1. Schematic illustrations of parallel seismic testing of a pile in homogeneous soil: (a) pile under an existing structure and (b) pile in the free field.

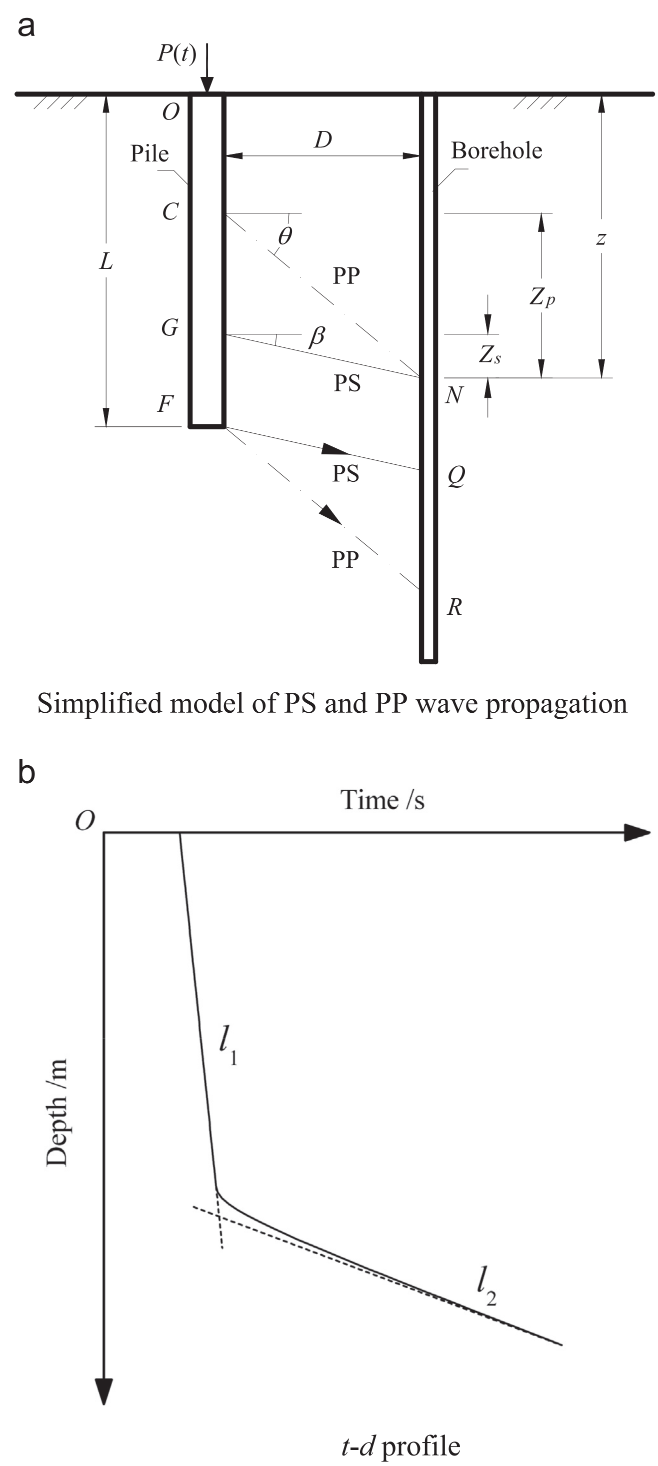

Fig. 2. Schematic illustrations of PS and PP wave-based tests for pile in homogeneous soil: (a) simplified model and (b) *t–d* profile.