

## **Defects of Drilled Shaft and Effects of Surrounding Geo-materials Predicted by Sonic-echo Tests**

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### **ABSTRACT**

The sonic-echo signals of full-scaled drilled shafts embedded into bed rocks were analyzed in terms of the changes of the stiffness ratio between the shafts and the surrounding rocks. Built-in defects simulating the reductions of the cross-section at the soil-rock interface as well as segregation in the middle of the shaft were investigated by the sonic-echo tests. Moreover, the correlations between the reflected signals from the surrounding ground and the initial shear stiffness of the surrounding grounds were obtained from static load tests.

**KEY WORDS:** Drilled shaft; integrity; sonic-echo; defect; reflection; shear resistance; stiffness.

### **INTRODUCTION**

Sonic-echo test, or impact-echo test is used to evaluate the integrity of drilled shafts. When a stress wave generated by hand-held hammer at the pile head penetrates along the pile and meets different media like defects and embedded ground, it is reflected to the pile head and received by the accelerometer or velocity transducer. The test is also called the low strain test because a small hammer induces a low strain on the pile head upon impact. Hearne, Stokoe and Reese (1981) introduced test procedures and their equipment arrangements consisting of accelerometers on the pile head as well as embedded geophones bonded to rebar cages.

Hearne *et al* (1981) concluded that sonic-echo test is a crude method for verifying pile integrity. O'Neill and Reese (1999) presented some limitations of this test. An upper limit to the depth to which this test with modern equipment is useful is about 20m. They reported that some experts relate the upper depth limit to length-to-diameter ratio and stiffness of the surrounding soil, with a maximum depth-to-diameter ratio of about 30. Wave energy is not likely to be reflected from defects unless the defect is either relatively thick or extends nearly across the

entire cross-section of the shaft. Samman and O'Neill (1997) reported an experimental study, in which defects that were about 25 mm thick could not be reliably detected experimentally by this method. They also concluded that false positives were frequently reported from sonic echo tests on short drilled shafts. Baker *et al.* (1993) already insisted that sonic-echo methods are not reliable in identifying thick defects that covered less than about 50 percent of the cross-sectional area of the shaft. Beyond the fact that the defect must be significantly large to be detected reliably by this method, present sonic echo technology cannot determine the actual size of a defect.

The stiffness of geo-materials surrounding a pile influences the sonic-echo signals (O'Neill and Reese, 1999). It is difficult to receive signals reflected off the pile tip when the pile is surrounded by stiff soils because the stress wave energy would be dispersed into the ground (Stain, 1982). Previous numerical analyses suggested that it is possible to detect reflected waves from the bottom of pile when the ratio of the pile length (L) to the diameter (D) is less than 30 and the stiffness ratio represented by the ratio of the Young's modulus of the pile ( $E_c$ ) to that of the soil ( $E_s$ ) is more than 50 (Liao and Roesset, 1997). Reflected signals from the pile tip may not be detected if the stiffness ratio of pile to surrounding ground is less than 77, or the shear wave velocity ( $V_{ss}$ ) of the ground is less than 10 % of that of the pile ( $V_{sc}$ ) when  $V_{ss}$  exceeds 300 m/sec (Kim, 2003). Useful studies related to sonic-echo methods and impulse-response methods for the full-scale drilled shafts have been done (Baker *et al.*, 1993; Likins *et al.*, 1993; Finno *et al.*, 2002), but they did not directly account for the difference in stiffness between the pile and the ground.

In terms of the stiffness of the surrounding geo-material, it is especially important to reveal the applicable limitations of the sonic-echo method for a drilled shaft embedded into a bedrock to allow a large bearing capacity. Model tests showed that reflected signals change according to the stiffness of rocks and the length of the rock socket (Kim and Kim, 2004). But the received signals in model tests are relatively simpler and clearer than those in the field because of the homogenous pile and