Improvement of Low Strain Pile Integrity Test

Wenzhang Luo[1], Fan Chen[2], and Junling Hu[1]
[1]**Deparment of Mechanical Engineering, University of Bridgeport, Bridgeport, CT 06604**
[2]**National Center for Quality Supervision and Test of Building Engineering, Beijing 100013, China**

Abstract

The low strain pile integrity test (LSPIT) is currently the most widely used method of pile integrity testing. This paper studied stress wave propagation in piles in engineering tests with finite element method (FEM).

From the numerical calculation results and test signals, a location of two thirds of radius away from the source (center point) for solid piles or a distance of 90° arc away from the source for pipe piles on the top face is found to be the best location to place a sensor. The high frequency disturbing signal diminishes greatly at the recommended location when the load impulse is applied. The time difference between initial velocity signals was then studied at different locations to correct the vertical wave velocity and defect depth in some situation.

Introduction

The low strain pile integrity test (LSPIT) is a Non-Destructive integrity test method for foundation piles, especially concrete piles and concrete filled pipe piles. Millions of piles were built in the construction field every year in China. As it is convenient to use LSPIT in construction filed and the cost involved is also low, LSPIT is widely adopted by most construction companies.

The LSPIT is based on the wave propagation theory of the compression wave generated by a small impact. The compression wave travels down the pile at a constant wave speed and was reflected by changes in cross sectional area or material in concrete. The pile can be considered as a one-dimensional elastic bar if it can satisfy two conditions. The first condition requires the wavelength of the incoming wave to be at least 10 times of the pile diameter to ensure planar wave will occur in the pile. The second condition requires the wavelength to be much smaller than the pile length to reduce the effect of rigid body motion of the pile.

Usually the test is performed by applying an accelerometer at the pile top surface where a light impact is applied by a small hand held hammer. Then a compressive stress wave travels down the pile at a constant wave speed c, which is a function of the elastic modulus E and mass density m. Given a known stress wave speed or pile length, records of velocity (integrated from the accelerometer signals) can be interpreted to reveal pile non-uniformities (changes in impedance). The impedance is a function of the cross sectional area, the modulus of elasticity, the wave speed in the pile material and of the soil damping. Interpretation is usually done in the time domain (pulse echo) but data can also be evaluated by analyzing in the frequency domain.

Many factors influence the quality of the result produced by this test method such as the competence of the personnel performing it, and the suitability of the equipment and facilities used etc.

In this paper, the locations of accelerometer on the pile head were studied based on the numerical calculation analysis and test signals. It was found that locations of the accelerometer can affect the test results. The influences of the location on the results will be discussed and appropriate locations of accelerometer will be recommended for better test results.

Numerical Model

Finite element method (FEM) was used to analyze the model. Fig.1 is the FEM mesh of a pipe pile head. Newmark method is used to solve the dynamic equations. The following assumptions were made in the model:

1. The influence of the surrounding soil on the pile is neglected. The pile is considered as a homogeneous body with no constraints.
2. Gravity is neglected in the dynamic equations.
3. Damping is neglected in the pile.
4. The computational domain is considered elastic in the process.

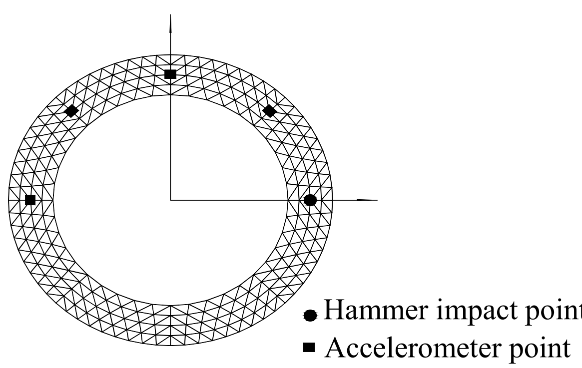


Fig.1 FEM mesh of pipe pile head

Numerical damping is considered in case of the pipe pile to reduce the high frequency disturbance caused by the FEM mesh, which also reduced the useful high frequency wave and the reflection echo from the pile end.

Numerical Calculation Results

Two common pile styles are selected as the samples: a solid pile with diameter of 1.0 m

(Φ1.0m) and a pipe pile with outer diameter of 900 mm and inner diameter of 110 mm (Φ800×110mm). Similar results can be obtained for other types of piles, but the results will not be shown here. The load impact point is at the center of the top surface for the Φ1.0m solid pile. The load impact point for the Φ800×110mm pipe pile is shown in Fig. 1. The accelerometer can be placed anywhere on the top surface, but the test results will be different for each location, as shown in Figs. 2-3.

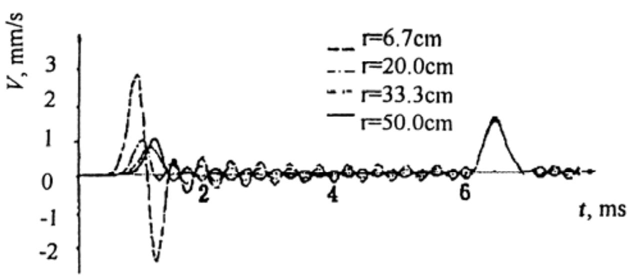


Fig. 2 Computed velocity at different locations along the radial direction of a Φ1.0m solid pile (L = 10.0m)

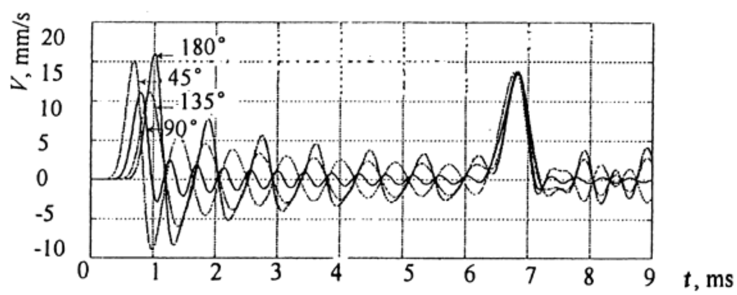


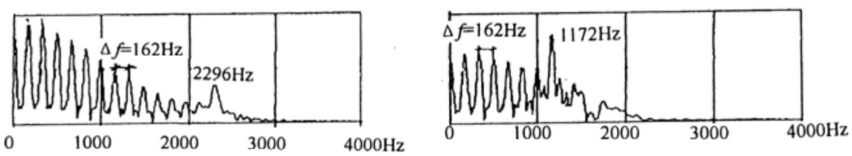
Fig. 3 Computed velocity at different locations of a Φ800×110mm pipe pile (L = 13.0m)

Suitable Locations to Place an Accelerometer

The high frequency waves that is not caused by the defects in the actual signals affect the evaluation of the test results and, thus, is called disturbing high frequency content.. Generally when the piles was impacted, the longitudinal and transverse vibrations modes mixed together to produce the disturbing high frequency content. The disturbing high frequency content should be diminished for better signals.

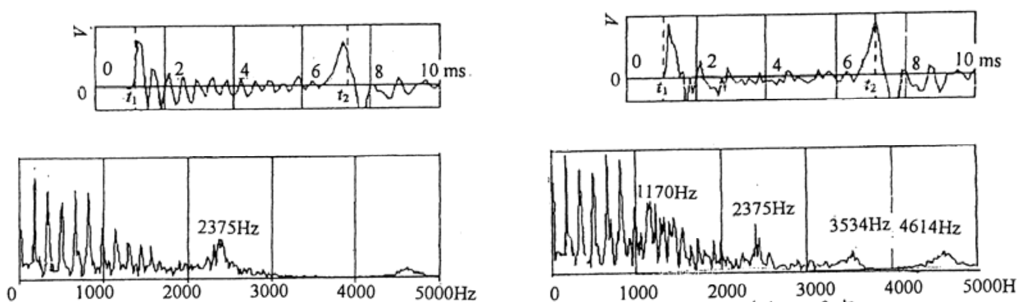
In Figs. 2 to 4, the disturbing high frequency content is weaker than at other points on the top surface when it is at the point of $\frac{2}{3}R$ away from the source (center point) for solid piles or a point which forms a 90° angle with the source point for pipe piles. These two locations are recommended to place an accelerometer.

The frequency domain of the results in Fig. 3 is shown in Fig. 4 for two locations: at 90° point and 135° point. The frequency domain of the results at the 45° point and at 180° point are similar to that at the 135° point. It can be inferred they are influenced by different vibration mode. The signal at the 90° point is not influenced by the 1st transverse vibration mode as that at other points. Hence, the disturbing high frequency content is easier to diminish at 90° point when a suitable impact shape is applied. The actual test signals showed the same pattern in Fig. 5



(a) 90° point (b) 135° point

Fig. 4 Frequency domain of Fig. 3.



(a) 90° 点 (b) 135° 点

Fig5 Test velocity curve and its frequency domain at different points of Φ800×110mm pipe pile （L = 13.0m）

The results for the solid pile are the similar to those in the pipe piles. [1] The results here are especially helpful for the pile with big radius, which might fail to detect defects when the final test signal has the disturbing high frequency content.

Stress Wave Propagation at the Top Surface and its Influences

After the impact on the top surface of the pile, the longitudinal, transverse and surface waves propagated in the pile body and reflected back on the boundary. All the stress waves mixed together and influenced the final velocity signal. From Fig. 2 and Fig. 3, it is apparent that the peak value of the impact impulse varies with the location and time to collect the signal. However, the peak value and its time to reach the peak value of the reflection impulse from the pile end do not vary with the location of the accelerometer. A formula is obtained to calculate the time to receive the impact impulse peak at different locations from the numerical results and actual test signals.

For solid pile, the time of the impact pulse to reach the peak velocity at the location of accelerometer can be calculated by [1]

$$t = t_0 + r / c_R \tag{1}$$

where t_0 is the time of the impact pulse to reach the peak velocity at the impact point (center), r location of the accelerometer, c_R is the surface wave velocity.

For pipe pile, the time of the impact pulse to reach the peak velocity at the location of accelerometer can be calculated by

$$t = t_0 + \frac{\theta \pi \overline{R}}{180 c_R} \tag{2}$$

$$\overline{R} = (R_1 + R_2)/2$$

where R_1 and R_2 are the inner and outer radius of the pipe pile and θ is the angle formed between the impact point and the point to place the accelerometer at the pipe center.

Equation (3) is used to calculate the longitudinal wave velocity:

$$c = 2L / \Delta t \tag{3}$$

where L is pile length, c is the longitudinal wave velocity, and Δt is the time interval to get the impact impulse peak velocity and reflection signal peak velocity.

Because the impact impulse peak velocity occurs at different time as shown above, Eqs. (1) and (2) can be used to adjust the calculation results in Eq. (3). Because the accelerometer is impossible to be placed at the impact point, c calculated by Eq. (3) is greater than the actual velocity. It is especially important to test piles with short length and big radius. After the adjustment it is equal to the result obtained from the frequency domain.

$$c = 2Lf_0 \tag{4}$$

where f_0 is the frequency of the 1st longitudinal vibration mode.

The accurate value of c can also be obtained by replacing Δt in Eq. (3) with the time difference of the 1st and the 2nd reflection signal from the pile end. However, even the 1st reflection signal from the pile end cannot be detected in actual engineering field test, as the low energy of the light impact is not enough to travel a long distance,.

Equations (1) and (2) are also useful to decide the depth of the defect along the pile. When the time difference is not considered in time domain, the depth of the defect is usually deeper than the calculated result. The difference depends on the radius of the pile and the distance between the points of impact and the accelerometer. When the defect exists, the reflection signal from the pile end is delayed compare to that from a good pile, see Fig. 6. This phenomenon can be explained by the longer distance which the stress wave passes through the defect part.

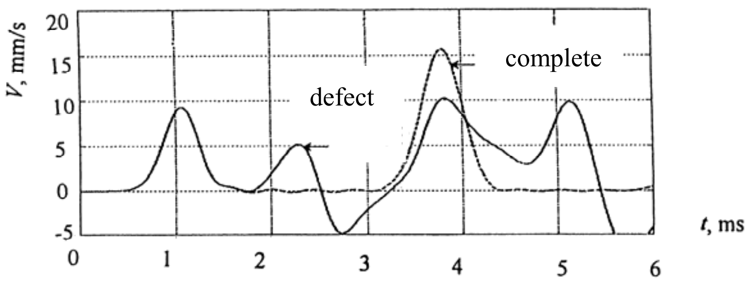


Fig 6 Comparison of computed velocity at 90º point of complete pile and defect pile (L = 6.0m)

Conclusion

This paper has studied the low strain integrity test of two types of piles. The influence of locations of the accelerometer on the signal and the signal interpretation are discussed. It was found that the best location to place an accelerometer in the test is at the point of $\frac{2}{3}R$ away from the source (center point) for solid piles or a point which forms a 90° angle with the source point for pipe piles. At these locations, the disturbing high frequency content is weakened. Equations were also developed to correct the longitudinal wave velocity calculation and the depth of defects.

Further study should continue to improve the low strain pile integrity test, especially for long pile. As the energy of the light impact is very small that the produced stress wave cannot travel a long distance, the reflection signal can not be detected by a accelerometer when the pile is very long. The influence of surround soil on the test should also be considered for better results.

References

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Biography of authors

Mr. Wenzhang Luo is a graduate student of Department of Mechanical Engineering at

University of Bridgeport. He has a BS in Hydraulic Engineering from Tsinghua University and a MS in Civil Engineering from China Academy of Building Research. He has 8 years work experience in Civil Engineering field.

Mr. Fan Chen is a professor of National Center for Quality Supervision and Test of Building Engineering, Beijing, China. He is the vice chairman of National Center for Quality Supervision and of Test of Building Engineering and the editor of Technical code for testing of building foundation piles.

Dr. Hu is an assistant professor of Mechanical Engineering at University of Bridgeport. She received her Ph.D from the University of Missouri-Rolla in 2005. Dr. Hu's research area include computational fluid dynamics, heat transfer, welding, laser material processing, and thermal management of electronic devices and systems, micro-/nano- scale energy transport and finite element analysis of industrial applications.