Experimental study and theoretical analysis on impact characteristics of single pile

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Abstract. The impact characteristics of a single pile are the theoretical basis of the high-strain detection technology of piles and pile driving. Firstly, a series of pile model experiments are conducted to study the characteristics of single pile penetration, axial force and friction of the pile under impact loads of different rammer loads and falling distances. Then, the dynamic model of a single pile under impact load under the condition of pile-soil slippage was established by using the elastodynamic method, and the analytical solution of the pile axial force was obtained. The results show that the theoretical solution is in good agreement with the model test results. This shows that the completely bonded model without considering slippage overestimates the frictional resistance between the pile and soil, and the pile-soil slippage model can better simulate the impact of a single pile in sand.

1 Introduction

The study of the characteristics of foundation piles under impact loads is the theoretical basis for techniques such as pile driving and high strain testing of foundation piles, mainly through field tests or model test methods as well as theoretical analytical methods. Most of the results of model test studies of piles focus on static load tests [1,2] or steady-state vibration tests [3], while relatively few research results of impact tests are available. Ashlock and Pak studied impact model tests of piles [4], but the scaling ratio they used was too large. To simulate the impact effect of piles, Yan Shuwang et al. established a modified static resistance model to carry out the theoretical study of the static resistance model of the soil around the pile and its application in pile driving [5], and Deeks and Randolph established an analytical model of the heavy hammer impact of pile driving [6]. The dynamic contact conditions at the pile-soil interface are an important factor affecting the theoretical simulation of foundation piles under impact loading. Most of the existing models use the pile-soil fully cohesive model. However, it has been shown that the fully cohesive model overestimates the pile-soil dynamic interaction [7,8]. Li Qiang by using a model with vertical presence of disturbed areas in the soil around the pile, the results of this model better reflect the pile-soil interaction during pile driving [9]. Therefore, it is important to carry out model tests and theoretical studies on the dynamic response of a single pile under impact loading for an in-depth understanding of the pile-earth dynamic interaction.

In this paper, the model test method is used to study the impact characteristics of foundation piles in the saturated sandy soil foundation, and the impact theory model of foundation piles is also established to verify the reliability of the dynamic model of non-fully cohesive slip piles by solving the vibration control equations and comparing the results of the test results.

2 Model test method

The test model follows the corresponding rules in terms of geometry, model material, mechanical properties, loading conditions, etc, which can reflect the whole process of physical phenomena of the prototype test through the model test. The test is mainly to simulate the dynamic characteristics of a model pile of PVC pipe subjected to vertical static loading and different equal impact load excitations.

2.1 Test instrumentation and material preparation

(1) Test equipment

In this test, a model box is used for loading, and the box is welded with steel plates with length, width and height of 2 m, 1.5 m and 3 m respectively. The instruments for the test observation mainly include a JHBM-M miniature pressure transducer with the range of 0-200kg, electronic percentage meter, strain gauge, resistance strain gauge, and acceleration sensor. The installation diagram of the apparatus is shown in Figure 1(a). As seen from the schematic diagram of the impact principle shown in Figure 1(b), the system consists of two parts, one is the heavy hammer impact system and the other is the dynamic response system generated by the pile subjected to the impact load. The test uses 1.25kg, 2.5kg, 3.75kg three kinds of hammer weight respectively in the drop distance.

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of 10cm, 20cm, 30cm, 40cm, 50cm drop excited by the
impact energy to test.

2.2 Test Method.

The impact simulation test involves applying an impact
with a certain amount of energy at the top of the pile
to create penetration into the pile, with the impact pulse
causing strain on the pile as it travels down the pile. This
in turn excites the resistance at the side and end of the pile
in turn from the bottom up. Impact tests are carried out on
single piles of different pile lengths to analyze the
relationship between the penetration, pile shaft force and
pile side frictional resistance of the model pile, and the
hammer weight and drop distance of the impact load. The
optimum values of hammer weight and drop distance for
different pile lengths are investigated.

3 Test results and analysis

The results of the impact tests with three different hammer
weights and three different drop distances were obtained
according to the test method described above, and the
variation curves of penetration, pile axial force and pile
lateral frictional resistance with hammer weight and drop
distance are given in Figures 2-4, respectively.

3.1 The relationship between penetration degree
and impact hammer weight and drop distance

Figure 2 gives a comparison of the results of pile
penetration, pile axial force and pile lateral frictional
resistance excited by the heavy hammer when the top of
the pile is subjected to 1.25 kg, 2.5 kg and 3.75 kg falling
from three different drop distances (10 cm, 30 cm and 50
cm) at a pile length of 2 m, respectively. As can be seen
from the figure, the penetration of the pile increases with
the increase of impact energy, and the penetration of the
pile increases significantly at the hammer weight of 2.5 kg
and 3.75 kg when the drop distance is greater than 40 cm.
3.2 The relationship between pile shaft force and impact hammer weight and drop distance

Figure 3 shows the variation curves of the pile shaft force at three different hammer weights at three drop distances along with the pile side measurement points respectively.

3.3 The relationship between pile shaft force and impact hammer weight and drop distance

The variation curves of the pile lateral friction resistance along the pile body for the three different hammer weights are shown in Figure 4, which is calculated from the pile shaft force. In this case, the pile lateral friction resistance is replaced by the average lateral friction resistance at the midpoint between the two measurement points. As can be seen from the figure, the heavier the hammer weight, the greater the pile-side frictional resistance excited, and the greater the drop distance at the same hammer weight, the greater the pile-side frictional resistance. The average frictional resistance of the pile side at different impact energies varies along the pile body, but all produce extreme values somewhere in the lower section of the pile, as shown in the figure around 1.4m.
4 Theoretical calculation model and discussion

The controlling equation of elastic soil dynamics described in the form of displacement vector is:

$$\vec{R} \nabla \cdot \vec{u} - \mu \nabla \times \nabla \times \vec{u} = \rho \frac{\partial^2 \vec{u}}{\partial t^2} + \frac{\partial \vec{u}}{\partial t}$$

(1)

where $\vec{u}$ represents the displacement field vector, $\rho$ is the soil density, and $\mu$ is the shear modulus.

The pile is simplified as a one-dimensional rod, and its vibration control equation is expressed as:

$$E_b \pi a^2 \frac{d^2 w_p}{dz^2} - f(z) = \rho_b \pi a^2 \frac{d^2 w_p}{dt^2}$$

(2)

where $f(z) = -2 \pi a \tau_{zx}^{(s)}(1, z)$ is the pile circumferential frictional resistance $\tau_{zx}^{(s)}$ denotes the pile lateral shear stress in the soil layer, $w_p$ is the pile displacement, and $a$ is the pile radius. $E_b$ and $\rho_b$ are the elastic mode and density of the pile, respectively.

The boundary conditions of the soil layer are:

$$\left. \frac{\partial w_p}{\partial z} \right|_{z=0} = 0, \quad \left. \frac{\partial w_p}{\partial z} \right|_{z=H} = 0$$

(3)

The parameters in the formula refer to the literature [8].

When a half-sine transient force is applied at the top of the pile, the time domain response of any point of the pile can be obtained using the Fourier inversion as

$$P_z(t) = \mathcal{IFT} \left[ \bar{P}(i\omega) \cdot F_{\text{max}} \frac{1 + e^{-i\omega t}}{\omega^2 + s^2} \right]$$

(7)

where $F_{\text{max}}$ is the peak value of the half-sine impact load, determined experimentally from the measured pulse width.

According to the above theoretical formulae, MATLAB was used to prepare a numerical calculation program to obtain the theoretical and test values of the pile shaft force at three different drop distances for a hammer weight. Comparison of theoretical and experimental values of pile axial force at three different drop distances. The calculated parameters are: pile diameter ratio 125, soil elastic supports factor $k_{sb} = 1.0$, pile lateral damping factor $D_f = 0.02$, pile lateral frictional resistance factor $k_f$ is 0.001, 0.001 and 0.0015 depending on the drop distance 100mm, 300mm and 500mm respectively, and the elastic...
support factor $k_{pb}$ at the bottom of the pile is 10, 5 and 1 for the three different drop distances respectively. The calculation results are shown in Figure 5. It can be seen that the pile axial forces basically match for the three different drop distances, indicating that it is reasonable to use the pile-soil slippage model to simulate the impact action of pile.

![Graph showing comparison of theoretical calculations and actual measurements of the floating pile using slippage model](image)

**Figure 5.** Comparison of theoretical calculations and actual measurements of the floating pile using slippage model

## 5 Conclusion

In this paper, the impact test of long piles in sandy soil foundations was firstly carried out by using the pile-soil impact model test device, and the variation rules of pile penetration, pile axial force and pile lateral frictional resistance were obtained for different hammer weights and different drop distances. Then the analytical solutions of pile displacement and axial force were obtained by establishing the pile-soil interaction model under the impact load considering the slip between piles and soil. The numerical calculation results show that the model can achieve a good agreement with the model test.

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