

# The Research of Multi-defective Piles for Low Strain Testing and Numerical Simulation

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## ABSTRACT

Based on 3D dynamic finite element method, the low-strain testing of piles was simulated to describe the integrity of defective pile foundation. The velocity time's curve of integrate piles is extracted. There was a good consistency between simulation results and testing curve of pile. Based on the integrate piles analysis, the low-strain dynamic effect of defect piles are researched. The defect is namely the different position of spread cervical, the different position of necking and the different thickness of segregation. The simulation was used to predict of defective pile and the quality diagnosis of the defective pile, which provides theoretical basis to find out the concrete position of defects and damage degree of defective pile in field experiment.

## 1. INTRODUCTION

The pile foundation has been widely used in construction projects in our country, Its engineering quality and properties are the most important factors to ensure the safety of engineering structures(Hoła 2010). The low-strain dynamic testing of pile quality, with its economic, shortcut and lossless has become the most effective method in pile foundation testing.

The method of low-strain dynamic testing is showed (Niederleithinger 2006), the pulsating exciting force is applied on the top of pile by hammer. The stress compression wave that produced by the forced vibration propagate along the pile down. The path of the stress wave changes when the stress wave met the interface that the impedance changes, then reflection and refraction occur. It make a comprehensive assessment for the quality and the integrity of the pile through the analysis of waveform, amplitude, frequency and average velocity which are recorded by the sensor that is on the top of the pile(Fei 2010). The low strain method can only determine the type of the defects, but it can't confirm the degree of the defects quantitatively. It is one of a hot

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spot (Zhang 2012) that how to confirm the sensitive factors which influence the propagation of stress wave and make flaw quantification in relevant research. With the development of the computer technique, numerical simulation can be well applied to solving the dynamic response of pile foundations. One of reliable numerical simulation for dynamic pile testing was to be explored by Li Huobing (Li 2011). The necessity of numerical simulation of solid model was analyzed. The basic data extracted by ABAQUS were provided for the research of base-pile dynamic detection curve. Zhang verified the validity of diagnostic method using 3D FEM (Zhang 2010). The wave velocity signal got from the model validated the reliability verification of the numerical simulation. The stress curve of reflection wave change rule of the defective piles was studied when the defect length and position was changing and determine the integrity of pile foundation (Chen 2015). So it is significance for the engineering that the pile foundation is simulated by 3-D finite element method to diagnose the quality of pile.

In this paper, the numerical simulation of defect piles is researched based on the actual project data. An agriculture project of photovoltaic power generation is located in Tieling of Liaoning Province. The project location is an open area and has no occlusion. The concrete piles with 2m and 2.5m are applied to the foundations of photovoltaic panels. The total number of piles is 38708. According to the requirement of design, the bearing capacity test and the integrity test of the pile foundations are conducted.

## 2. THE SIMULATION OF LOW STRAIN DYNAMIC TEST IN PILE INTEGRITY

### 2.1 The modeling preparation

Considering the low strain dynamic test, the whole pile and soil around pile are in the elastic state. The material model is defined in linear elastic. The relative parameters are shown in Table.1. The thickness of pipe pile is 70mm, the inner diameter of calculation model is 0.16m and the outer diameter is 0.3m. The radius of soil is 10 times than the pile, the length of soil body is 1.5 times than the pile. The numerical model is shown in Fig.1. The friction coefficient of pile-soil interface is 0.46. The hammer is defined as rigid body and is prevented from perforating the pile foundation. The contact between pile bottom and soil is defined as the tie contact that the pile bottom is fixed and the pile is only allowed to the axial displacement. The pile and the soil around pile are all used to the element of C3D8. The exciting force is applied instantly in the low strain dynamic testing.

Using the function of the load time history, the impact load is shown in the Eq.(1). The amplitude is 2.0e6N.

$$p(t) = \frac{I}{T_d} \left( 1 - \cos \cos \frac{2\pi}{T_d} t \right) \quad 0 \leq t \leq T_d \quad (1)$$

In the formulas, the impulse of exciting force and acting time are listed as  $I$  and  $T_d$  respectively. According to the practice, the pulse duration of the force by hammering is 1 millisecond. A wave of analogous inverse cosine is reflected by the function from Eq.(1). The  $t=0.5$  ms is taken to the Eq.(1) and  $I = 0.0005\text{N}\cdot\text{s}$ . The formula is simplified to Eq.(2).

$$p(t)=0.5(1-\cos\cos2000\pi t) \quad (2)$$

Table.1 The parameter of modeling

Name	Length(m)	Radius (m)	Density(kg/m <sup>3</sup> )	Modulus of Elasticity(Pa)	Poisson's Ratio
Pile	2	0.15	2200	3.8e10	0.2
Pile soil Bottom	1.6	1.65	1900	1e7	0.23
soil of pile	3.0	1.65	2500	3e9	0.28
hammer	0.08	0.02	7800	2e11	0.3

The time difference of reflection wave,  $\Delta t$ , is defined as the round trip time of stress wave propagation. The length of pile can be confirmed through the formula  $L=C \times \Delta t / 2$ , when the velocity is known firstly.

The method of peak-peak is used in the process with dynamic testing of reflective wave method in pipe pile. The speed time history curve of reflective wave method in pipe pile is shown in Fig. 2.

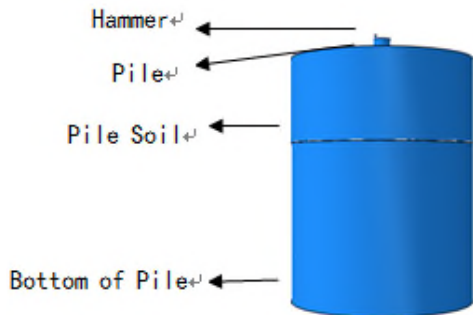


Fig. 1 The model of hammer-pile-soil around pile-bottom soil of pile

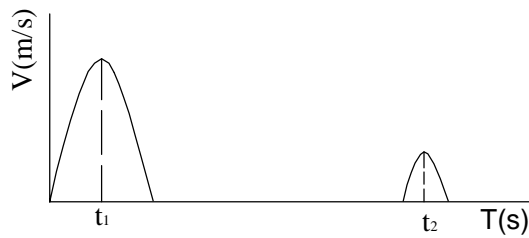


Fig. 2 The speed time history curve of reflective wave method in pipe pile

## 2.2 THE SPEED HISTORY OF THE INTEGRATED PILE

The numerical simulation of low strain in integrity piles in 2.1 is adopted. The curve of speed history in the integrity of pile end is shown in the Fig. 3. It shows that the reflection wave at the bottom of pile. C80 concrete is used in this project. According the formula of  $C^2=E/\rho$ , the velocity of the wave is 4.156km/s. The time difference of peak-peak time in the integrity piles is got through the actual time of reflection wave arrival. And the length of the pile is 1.947m. It is basically same as 2m which is the actual length of the pile. The correctness of the calculation model in the numerical simulation is verified. The monitoring data of the No.1 pile is collected from the low strain instrument of Wuhan in Fig.4, named RS-1616. The measured wave velocity is 4.17km/s, when the length of the pile is 2m. It is basically same as the velocity of the

numerical simulation, 4.156km/s. So it is reliable to simulate the pile integrity of low strain reflected wave method.

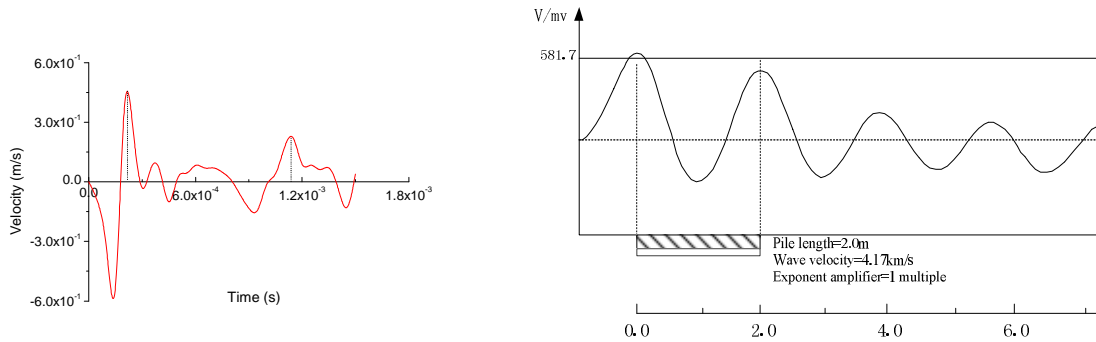


Fig. 3 The velocity-time curve of the end of the integrated pile

Fig.4 The monitoring curve extracted by the instrument

### 3 THE NUMERICAL SIMULATION OF LOW STRAIN OF DEFECTIVE PILES

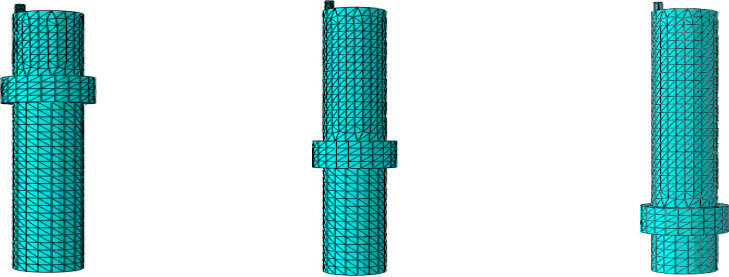
There are many kinds of defective piles, such as spread cervical, necking, segregation and so on, caused by various reasons. The defects of piles are formed easily in the process of transportation and construction. The characters and law, the reflection of low strain of defective piles, can be summed by the numerical simulation, and instruct the application of experimental testing.

#### 3.1 PILE WITH EXPANDING NECK

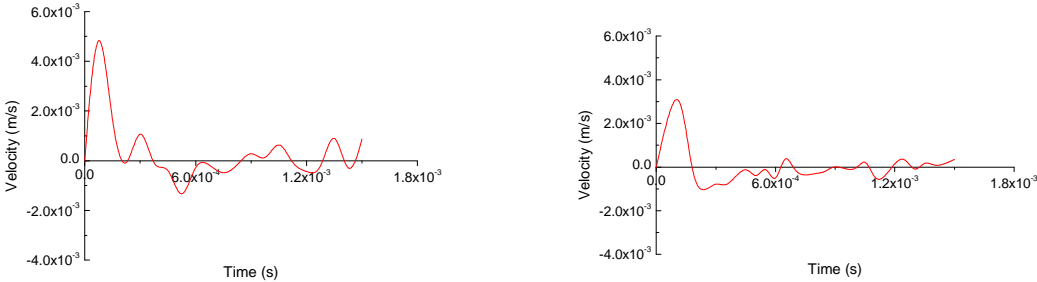
The outer diameter of the modeling pile is 0.3m and the thickness is 0.07m. The thickness of pile with expanding neck, 0.2m, is supposed to be invariable. The inter diameter is 0.2m and the outer diameter is 0.4m. The distances from the position of the expanding neck to the pile head are 0.4-0.6m, 0.9-1.1m and 1.4-1.6m. The position of each defective pile is shown in Fig.5. The various reflection of low strain testing can be obtained through the numerical simulation.

The velocity-time curve got from the numerical simulation is shown in Fig.6, the time difference can be calculated from the crest of incident wave and defects wave. The distance got from the numerical simulation is 0.467m, 0.945m, 1.455m. It is basically same as the velocity of the measured data. It is obviously that the different defect position cause the different reflection of defect pile with expanding neck. The position of expanding neck is much closer to the top of pile, the reflected crest of wave is less obvious. And the wave is smooth, the oscillation is weak. So it is easy to judge the position of the defective piles. When the position of the expanding neck is in the middle of the pile, the wave is smoother and the amplitude is lower. So it is easy to judge the position of defect. When the position of the expanding neck is far from the pile head, there is a length of slip in the middle of wave. And then there be more obvious oscillations. Various continuous expanding neck will be judged by mistake in practical engineering. There is superposition between the reflection wave from the

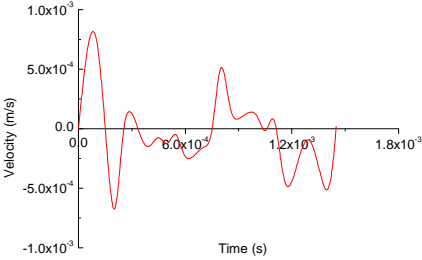
defect and the bottom of the pile. It will lead to the trend of the growing amplitude. With the position of the expanding neck farther and farther away from the pile head, much interference produces in practical engineering.



(a) 0.4-0.6m                      (b) 0.9-1.1m                      (c) 1.4-1.6m  
 Fig.5 The different positions of the expanding neck from pile head



(a) 0.4-0.6m                      (b) 0.9-1.1m



(c) 1.4-1.6m

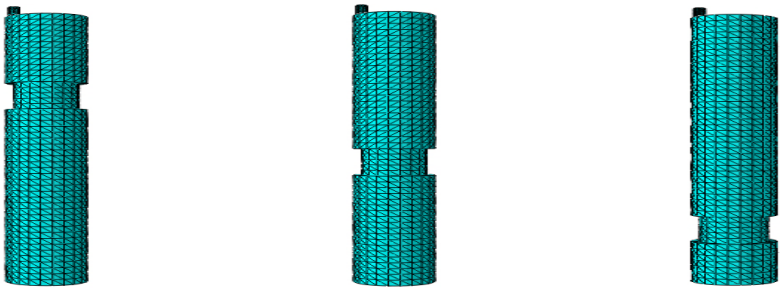
Fig.6 The velocity-time curve of the expanding neck pile

The influence of the integrity of the pile with expanding neck in the different positions has been studied. The cross section area and the thickness are all the influencing factors to the pile with the expanding neck.

**3.2 PILE WITH CONTRACTIVE SECTION**

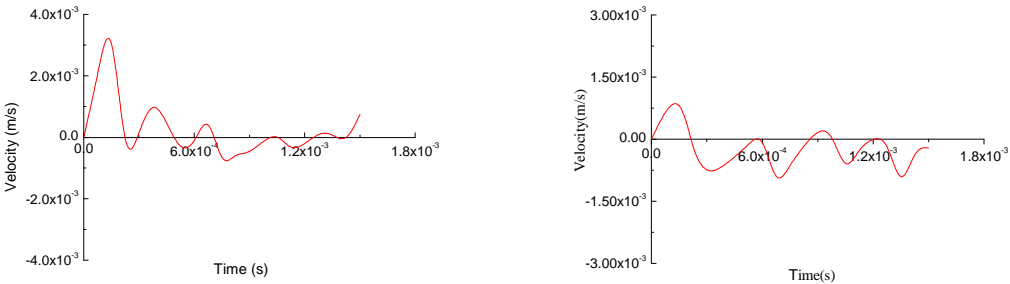
The outer diameter of the model pile is 0.3m and the thickness is 0.07m. It is assumed that the contractive thickness of pile is 0.2m. The inter diameter is 0.08m and the outer diameter is 0.12m. The distances from pile head to the position of contractive

section are 0.4m-0.6m, 0.9m-1.1m, 1.4m -1.6m. The relative position of the contractive section is shown in Fig. 7.

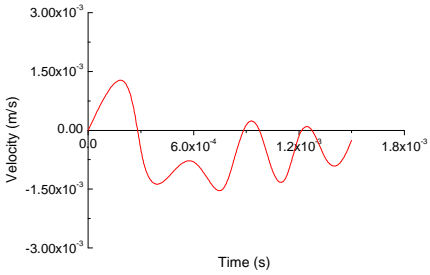


(a) 0.4-0.6m                      (b) 0.9-1.1m                      (c) 1.4-1.6m

Fig.7 The different positions of the contractive section from pile head



(a) 0.4m-0.6m                      (b) 0.9m-1.1m



(c) 1.4m-1.6m

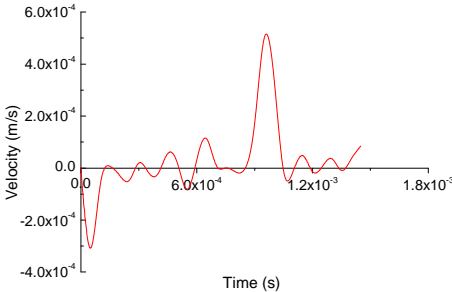
Fig.8 The velocity-time curve of the contractive section pile

The velocity-time curve of the pile with contractive section is shown in Fig. 8. The time difference can be calculated from the crest of incident wave and defects wave. The distance got from the numerical simulation is 0.468m, 0.935m, 1.41m. It is basically same as the velocity of the measured data. Only the velocity-time curve of the different position of the contractive section be simulated in this paper. It is less difference between the pile section with contractive and section of the integrity pile. So the oscillator curve shape is not obvious difference, but there are difference from the peak points .There is a obvious slip, the path of the wave along the pile, where the

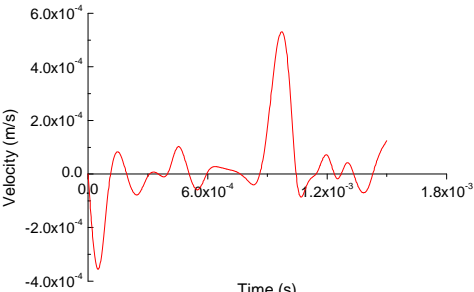
position of the contractive section is 1.5m far from the top of pile. The peak is appeared, when the wave meets the defect, and we can confirm the position of the defect. In the three kinds of pile with contractive section, the second reflective oscillation is obviously near the interface of pile with contractive section. With the increasing of distant between the defective position and the pile top, considering the influence of the amplitude of the reflected wave from the pile bottom, the change of the amplitude of the reflected wave is not much. But the difference is increasing between the peak of the incident wave and the defected wave.

### 3.3 PILE WITH SEGREGATION

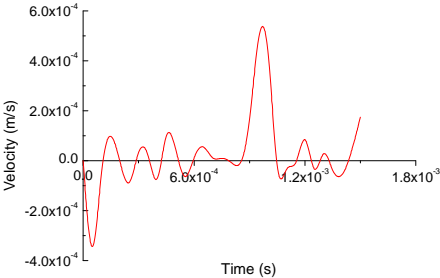
The segregation of pile refers to the separating of the concrete mixtures in pile foundation, which lead to the phenomenon of the quality defect because of the asymmetry of the internal structure.



(a) Segregation thickness is 0.2m



(b) Segregation thickness is 0.4m



(c) The thickness of segregation is 0.6m

Fig. 9 The velocity-time curve of different thickness of segregation

The distance of segregation position is supposed to 1m form the pile top. The thickness of the segregation is 0.2m, 0.4m, 0.6m respectively. The C30 concrete is used. With the thickness of the pile increasing, the reflected wave of pile is the same as the reflected wave of bottom pile in Fig. 9. So it is difficult to judge the influence of segregation thickness to the pile integrity by the velocity-time curve. The reason is that the pile is not long, the material of segregation is not low enough and the strength of

pile foundation can't reduce too much. The influence of the different thickness of segregation still remains to be further studied when pile of the segregation is tested.

#### **4. CONCLUSIONS**

In this paper, the method of low strain reflected wave to different types of defective piles is simulated by using the finite element software of ABAQUS/Explicit. The model of hammer-pile-soil is established. The velocity-time curve of pile head is extracted in the transient exciting force. The simulated data and the actual data show good agreement. The simulation is certified the reliability. Then the positions of defective piles are confirmed by simulating the defective piles with controlling variables. This paper forecasts various types of defective piles and diagnoses their quality, which provides theoretical basis to the concrete position confirming and damage degree of defective pile in pile field testing. It can also be simulated to analysis of the thickness and cross section area of spread cervical and necking and the material, cross-sectional area and different position of segregation.

#### **5. ACKNOWLEDGEMENTS**

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