Elementary analysis on application of ANSYS/LS-DYNAD in the detection of integrate pile

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Abstract. In this paper, by using the ANSYS/LS-DYNA nonlinear dynamic finite element analysis method. The numerical simulations for the integrity pile, and get the rules and characteristics of stress wave about complete pile. Verify the feasibility of the method of ANSYS/LS-DYNA nonlinear dynamic finite element analysis in the pile integrity detection applications. The research results can provide guidance for the pile integrity detection of different types. Then this paper simulated pile necking. And we get the patterns and characteristics of stress wave reflection about the necking pile, which show the method of ANSYS/LS-DYNA nonlinear dynamic finite element analysis can detect the type and location of pile foundation defect accurately.

1. Introduction

Among forms of foundation, pile foundation has high bearing capacity and smaller settlement. As the pile foundation is able to load transfer from the cover layer to the stable layer, it can achieve a safe and reliable requirements. With the high speed development of society and economy, the pile foundation has been widely used in many engineering fields such as transportation, civil and industrial building, port, bridge etc. However, it has strong concealment in the course of the construction and inevitably leads to various problems in the construction phase being difficult to detect. It is Necessary to accurately determine whether there are defects in the pile foundation. Therefore, in order to ensure the quality of construction projects and the degree of the specific location of the defect, the pile foundation must be strictly tested, to prevent accidents to taking remedial measures economical, efficient and easy to operate. Thus, only by improving the detection reliability of pile foundation, whole pile foundation construction quality and safety can be guaranteed. So, with the continuous progress of human science and technology, theoretical methods and engineering applications of pile foundation detection become the research areas of many scholars. For a long time, scholars have concluded that some of the more effective methods, such as method of reverberation-ray matrix, dynamic testing techniques based on the wave theory, etc.

In this paper, solving nonlinear analysis program of ANSYS/LS-DYNA conducts a preliminary numerical simulation to display the stress wave pile foundation, establishes the model of complete pile, and draws a waveform graph complete pile of post-processing program by Lsprepostd to compare with
the theoretical curve by method of reverberation-ray matrix. This shows that the applications of ANSYS / LS-DYNA is feasible in the pile integrity testing, and studies further the stress wave propagation characteristics of the pile.

2. The introduction of ANSYS
ANSYS finite element analysis software is a multi-purpose computer design program, which can integrate all kinds of structures, fluids, thermal, acoustic, electromagnetic, and collision sports, so that it has been widely used in various engineering fields in recent years. The finite element method (the finite element method) is a numerical method used in the current engineering analysis most widely. It is highly valued in the engineering sector, because it has high versatility and effectiveness, etc. With the rapid development of computer technology and science, ANSYS finite element analysis software has now become an integral part of computer-aided design and aided manufacturing. In this paper, ANSYS only provides the necessary pre-processing and post-processing for LS-DYNA, and specific solving procedure is completed by the LS-DYNA solver.

LS-DYNA is a highly versatile display dynamic analysis package which has complete function. It can simulate reality in a variety of complex issues, particularly suitable for solving a variety of two-dimensional, three-dimensional geometric nonlinearity, material nonlinearity, non-contact linear, explosions and other problems; LS-DYNA is focusing on showing algorithm for solving, especially for analyzing the impact of various nonlinear structural dynamics.

3. Computational model of complete pile

3.1. The basic assumption
The pile foundation, the pile length is generally much larger than the cross-sectional diameter or side length of the pile. So we can treat it as a one-dimensional elastic body. When momentary vibration is applied to top of the pile, there will be elastic wave passing along the pile, According to the basic principles of stress wave reflection method. The propagation of elastic wave obeys theory of one dimensional wave equation, and meets the following basic assumptions:

1) Top of the pile is applied to the momentary vibration in the elastic range.
2) Pile material is homogeneous or segmented homogeneous and isotropic.
3) Cross-section of the pile remains flat when it happens longitudinal vibration, and the stress is distributed uniformly in each of the cross-section, and they are the axial stress, and all the stress components are zero in the other direction.
4) The length of the longitudinal wave is much larger than the cross-sectional size of the pile. So do not consider the lateral displacement will affect the longitudinal motion.

3.2. Computational models
First, select a single complete pile. Pile - Soil relations is soil around the pile but bottom soilless. The pile length is 8m, and pile sectional side length is 0.5m, and soil-sectional side length is 0.6m, and soil depth is 9m. The top of the pile is expressed with 1, and pile bottom with 2. According to the above parameters and using ANSYS/LS-DYNA, it can build a finite element model of complete pile, showing in Figure 1. Selecting the first 49 nodes at the top of the pile top as the research object, recording the coordinates ID displayed on the toolbar, it can be named that x equals -0.0833333582, y equals -0.08333333582, z equals 0. The wave curve is shown in Figure 2.
Fig. 1 Finite Element Simulation of relationship between complete pile and soil

Fig. 2 Velocity waveform curve in the z-direction about the 49 node in the top of the complete pile

3.3. The analysis of the computation result

(1) Contrasted with the theoretical curve

Using the principle of reverberation ray matrix convention to building the MATLAB program, it will produce a complete pile top node velocity waveform curve in the Z direction, which is the theoretical curve. Figure 3 is comparison chart of a model curve and the theoretical curve.
Fig. 3 Comparison between measured curve and fitted curve of complete pile

From the figure 3, the model curve fits well with the theoretical curve, indicating it is able to use ANSYS / LS-DYNA to establish complete pile model and get fine and available data.

(2) Reverse calculate model parameters

By velocity waveform curve of complete pile top the 49 node to reverse calculated model parameters, and it is shown in Figure 2. Elastic modulus of pile is $E = 2.7 \times 10^{10} \text{ N/m}^2$, and the density is $\rho = 2500 \text{ kg/m}^3$.

Computational process is following:

① It can obtain the stress wave propagation velocity in the pile. $c_0 = 3286.34 \text{ m/s}$.

② The incident peak time of incident wave is 0.5ms.

③ The first reflection wave's peak time is 5.393ms, and the propagation path is 121, and the total spreading length is 16m. Because of the stress wave propagate from the top of the pile reaches the bottom of the pile, and pile bottom is overhead. So elastic modulus of pile becomes smaller, which means impedance becomes smaller too, resulting the incident wave and the reflected wave are in the same direction. The difference time $\Delta t$ equals 4.893ms, and get the $L = \frac{\Delta t c_0}{2} = 8.04 \text{ m}$, which is very close to the simulation of the pile length.

(3) Waveform characteristic curve analysis

① The complete pile has only two interfaces that top and bottom. Elastic modulus of pile becomes smaller when the stress wave reaches the top or bottom of the pile, which means impedance becomes smaller too, resulting the incident wave and the reflected wave are in the same direction. There is a relatively smooth transition between any two of the reflected wave of reach pile interface. The entire waveform curves no obvious glitches phenomenon, which is the typical characteristic of a complete pile different from defective pile.

② The reflected wave reaches the bottom of the pile in the correct position, and the peak of the peak is about twice the peak incident;

③ All the reflection wave peak appear the natural decay phenomenon, which indicate damping pile and the pile of subsoil body has consumed the role of stress wave signal.

(4) Comparison between measured values and fitted values of complete pile is shown in Table 1.
### Tab. 1 Comparison between measured values and fitted values of complete pile peak time of the reflected wave (ms) measured values (m) fitted values (m) errors propagate path

|                  | measured values | fitted values | errors | propagate path |
|------------------|-----------------|---------------|--------|----------------|
| 5.393            | 8.04            | 8             | 0.5%   | 121            |

4. Calculation model of necking pile

4.1. Causes of defects

Necking pile is the phenomenon that pile cross-sectional dimension of the pile local necking pile narrow after the molding. There are many causes constriction, for instance, in the usual place pile, the infusion finished after estuation cause excessive necking, as well as the absence amount of concrete in the tube, or concernment workability not meeting the requirements, will result in a corresponding reduction neck phenomenon. Furthermore, the soil around the pile itself has a more significant impact, because the greater the moisture content of water of the soil, the greater the viscosity, the easier soft soil necking occurs which is due to the higher moisture content of the clay, a common place pile produce construction process to the surrounding soil and squeeze more intense disturbance, and it will bring a greater excess pore water pressure, so after pulling out the tube, the water pressure will act directly on the body of the new cast concrete piles, if the water pressure is greater than the new cast concrete piles lateral pressure, it will produce shrink neck phenomenon.

If the constriction of the cross-sectional dimension of the pile is reduced, the strength will be decreased, and the bearing capacity will fall, so the effective and accurate method for detecting the position of the defective pile is necessary.

4.2. Computational models

Pile - Soil relations is the end of a pile has soil but pile has no soil. The pile’s length is 8m, and pile’s sectional side length is 0.6m, and the length of a partial sectional side in expanding part is 0.5m, and the length of soil-sectional side at bottom of the pile is 1.2m, and the soil height is 1m. The top of the pile is expressed with 1, and pile bottom with 2, and constricted portion starting with 3, and constricted portion of termination point with 4. According to the above parameters and using ANSYS/LS-DYNA, it can build a finite element model of necking pile, showing in Figure 4. Selecting the first 145 nodes at the top of the pile top as the research object, recording the coordinates ID displayed on the toolbar, it can be named that x equals -0.150000006, y equals -0.150000006, z equals 0. The wave curve is shown in Figure 5.

![Fig. 4 Finite Element Simulation of relationship between necking pile and soil](image-url)
4.3. The analysis of the computation result

(1) Contrasted with the theoretical curve

Using the principle of reverberation ray matrix convention in the third chapter to building the MATLAB program, it will produce a complete pile top node velocity waveform curve in the Z direction, which is the theoretical curve. Figure 6 is comparison chart of a model curve and the theoretical curve.

(2) Reverse calculate model parameters

By velocity waveform curve of segregation pile top the 145 node to reverse calculated model parameters, it is shown in Figure 2. The Pile elastic modulus is \( E = 2.7 \times 10^8 \text{N/m}^2 \), and the density is \( \rho = 2500 \text{kg/m}^3 \).

Computational process is following:
1. Obtaining the stress wave propagation velocity in the pile. $c_0 = 3286.34 \text{m/s}$.

2. The incident peak time of incident wave is 0.489 ms.

3. The first reflection wave's peak time is 2.9 ms, and the propagation path is 131, and the total spreading length is 8 m. Since the stress wave propagation across the interface impedance when it reaches constriction, so cross-sectional area of pile becomes smaller, which means impedance becomes smaller too, resulting the incident wave and the reflected wave are in the same direction. The difference time $\Delta t$ equals 2.471 ms, and the $L$ is the starting position of the constriction, which is very close to pile necking analog design flaw location.

4. The peak time of the second reflected wave is 3.499 ms, and the propagation path is 13431, and the total length is 10 m. On account of encountering the interface impedance after the stress wave propagates through the constriction, pile cross-sectional area enlarge and the impedance becomes larger, so the reflected wave occurs which is in reverse direction which the incident wave, and the time difference is 0.599 ms. We know that $L = \frac{\Delta t}{c_0} = 0.98 m$, which is the length of the neck portion and is very close to the length of the construction defect pile analog design.

5. The third wave's reflection peak time is 5.395 ms, and propagation path is 1342431, and the total propagation length is 16 m, which is in the same direction with the incident wave, and the wave peak time difference between them is 4.906 ms. We know that $L = \frac{\Delta t}{c_0} = 8.06 m$, which is the total length of the pile and is very close to the length of analog design.

6. The position of termination point of the pile neck is 4.05 plus 0.98 equals 5.03 m, that is very close to 5 m which is design position of a pile necking partial termination point.

7. The length of following pile under the pile body is 8.06 minus 5.03 equals 3.03 m, which is very close to the length of 3 m of analog design.

| Tab. 2 Comparison between measured values and fitted values of necking pile |
|---------------------------------------------------------------|
| type of pile       | peak time of the reflected wave (ms) | measured values (m) | fitted values (m) | errors | explanation | Propagate path |
| necking pile      | 2.9                             | 4.05               | 4                   | 1.2%   | starting point of the necking portion | 131             |
|                   | 3.499                           | 5.03               | 5                   | 0.6%   | ending point of the necking portion | 13431           |
|                   | 5.395                           | 8.06               | 8                   | 0.7%   | pile bottom                          | 1342431         |

(3) Waveform characteristic curve analysis

1. In the initial interface and termination interface of the necking part, it will produce reflection wave which is in the same direction with the incident wave or in the reverse, which is caused by the change of impedance what is affected by the change in cross-sectional area of the pile. That means the cross-sectional area of the pile changes more, the wave impedance changes well, and the same direction or reverse reflection wave peaks will become increasingly prominent;

2. If reflected wave reaches the bottom of the pile in the correct position, the peak of the peak is about twice the peak incident;

3. For the necking pile, the first reflected wave which will reach the starting point of the reduced-diameter portion and the incident wave in the same direction, and the reflected signal in the necking porting and the incident wave are the same direction too, which is typical characteristics between the pile necking and widening piles, piles segregation;

4. All the reflection wave peak appear the natural decay phenomenon, which indicate damping pile and the pile of subsoil body has consumed the role of stress wave signal.
5. Conclusion
In the paper, using ANSYS/LS-DYNA, it establishes finite element model for dynamic testing of reflection method which is aimed at complete pile. By analysing the final results can be seen the numerical simulation can effectively show that process, rules and features of stress wave in the pile. Besides, this paper also establishes finite element model for dynamic testing of reflection method which is aimed at pile necking. By analysing the final results, it can be seen that the model has fine simulating effect for necking piles and reflects rules and characteristics of the waveform curve of the pile necking.

However, this method is still in its infancy, and the future remains to be further developed so that it can detect the various types of defects of pile foundation.

ANSYS/LS-DYNAD can better simulate the stress wave under transient loads. It can also clearly see the waveform curve at the each location of pile. It can also display the stress state of each cell, and the dynamic stress of pile. These show that ANSYS/LS-DYNAD has the powerful capabilities to solve the problem of nonlinear simulation.

In short, testing the integrity of pile foundation is a complex problem, and hoping this article to provide a theoretical reference for other engineering personnel.

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