Influencing Factors of Stress Wave Method in Testing Mixing Pile

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ABSTRACT

The cement-soil mixing pile measured by stress wave method was analyzed in this paper. The influence on the test results of different sensors, folder soil properties, the soil around the pile nature and pile nature was researched. The research results show that the speed sensor can get a better signal, the changes of folder soil nature affect the reflected waveform directly, especially when the lower strength of folder soil will affect the speed of the stress wave more. According to the relationship between dynamic elastic modulus of pile and speed of stress wave, corresponding formula was established.

KEYWORDS: Deep mixing pile; Pile detection; Stress wave; Propagation characteristics; Numerical simulation

INTRODUCTION

Stress wave method in testing pile has the advantage of detecting speed, low cost, and for non-destructive testing, this method has been widely used in the testing of concrete pile[1-4]. Currently this method was also applied to detect cement mixing pile[5-8], but due to the differences of cement mixing pile and concrete pile, there are many problems in detecting worth exploring, it is likely to cause miscarriage of justice for pile length and pile defect in practical application[9-10]. The problem of the detection signal has been studied in literature [5], it is mainly using wavelet transform to analysis the measured waveform. The cement mixing pile test of hammer mode, receiver position, and pile waveform corresponding types of defects were studied in literature [7]. But there are still many issues worthy of continued research, such as the impact on the detection result of the receiver, soil properties, etc., are no definite conclusions. Therefore, this article will be analyzed to address these issues.

When these issues were studied, using the measured data to analyze is more difficult, using model pile experiments, some problems cannot be analyzed, such as the impact of soil around the pile to detect effects, so numerical simulation was used to study in this article, the large finite element software ANSYS was adopted. The main content is analysis of difference between speed sensor and acceleration sensor, the pile strength, pile folders soil properties, soil around the pile, and influence of these factors to the reflected wave signal characteristics, this study has some significance on-site testing.

STRESS WAVE ANALYSIS MODEL

Detection principle stress wave

The stress wave method in testing pile is based on the theory of reflected stress wave[11]. Use hand hammer, the exciting force rods and other equipment to tap pile, under the impact of the incident wave excitation, the particle of pile top first vibrates, then vibration propagate down the pile in the form of fluctuation, the abnormality will is reflected, so we can take advantage of the characteristic reflection wave signal to identify long pile, defect location, defect types.

Establish of numerical model

When stress wave was used to test pile, the applied pulse load was small, pile and soil are in the elastic state, The interface of pile soil will not slip, deformation between pile and soil is continuous. Therefore, simulation analysis using the following conditions: piles of soil are used in linear elastic constitutive model; not consider the contact surface between the pile and soil; ignore the influence of gravity factor calculation.

When calculated using isotropic half space geometry, mixing pile diameter 0.6m, length 13m, to eliminate the influence of the boundary echo signal acquisition, models take 10 times than the diameter of the pile diameter, 6m, lengths are 17m. In order to make the results are more representative, the calculation is set defects at 1/3 of the pile necking.

Since the pulse load is small for cement mixing pile, the bottom of the model does not produce displacement even a pile bottom, so the bottom of the model can be considered fixed end, the linear displacement freedom of nodes in bottom of the model are constrainedin the calculation. Since the model taking a diameter of 10 times the size of the pile diameter, can be considered around the model does not produce displacement, around the model, have this constraint too. Pile soil material parameters in Table 1.

Table 1: Parameters of pile-soil material

	Density (g/cm3)	Dynamic elastic modulus (MPa)	Dynamic Poisson's ratio
Mixing Pile	2.08	763	0.29
Soil	1.72	20	0.38

Model and applied loads

To coincide with the on-site inspection situation, when the input pulse load, select the top of the pile at the center of the four units to load an object, set the monitoring point in the pile head. The whole calculation model shown in Figure 1, the central model is the cement mixing pile. The picture 2 shows simulation result of a intact pile, it is consistent with the experimental result[12].

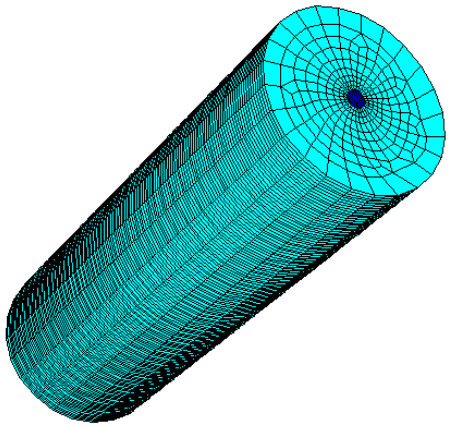


Figure 1: Numerical model

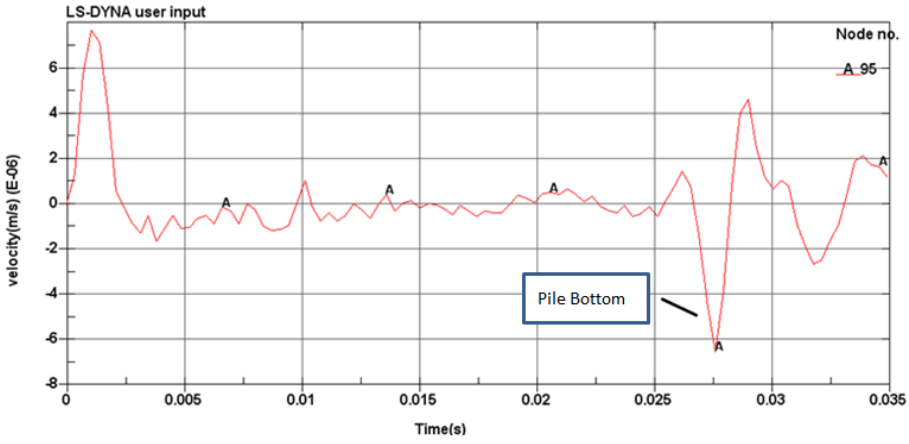


Figure 2: The simulation result of intact pile

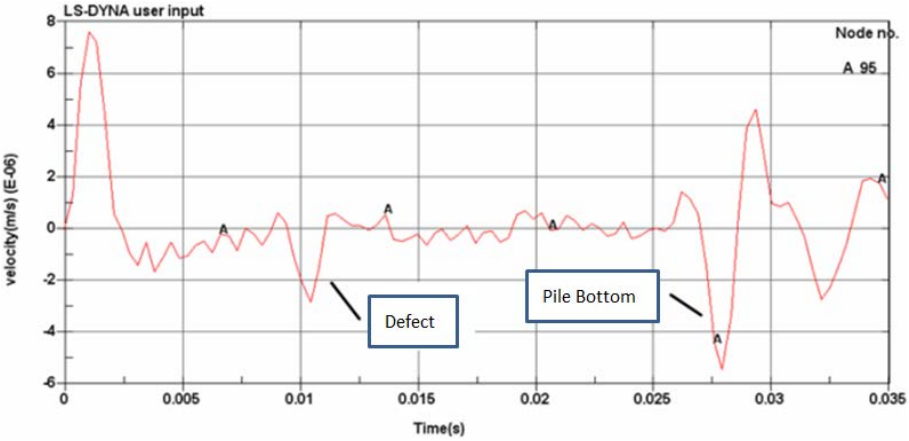
CALCULATION RESULT

Sensor effect

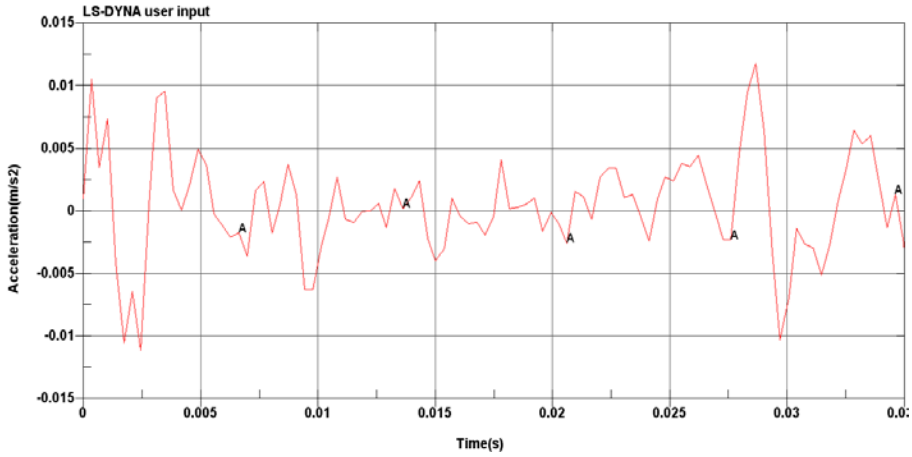
The common sensor type is speed and acceleration, to measure pile with stress wave, the acceleration sensor has a high degree of accuracy than the speed sensor, but due to its high sensitivity, and the sensitivity of greater than 100pc / ms easily lead to false triggering, and the cement pile‘s

sensitivity is low, therefore the applicability of the acceleration sensor is worth exploring. The speed sensor is rugged, inexpensive and easy to install. It is necessary to compare the two sensors, the calculation results shown in Figure 3, the horizontal axis representing time, in seconds, the vertical axis represents the speed and acceleration, which speed unit is 10^{-6}m/s, acceleration in unit is m/s^2.

As can be seen from the figure 3, the speed sensor was better than the acceleration sensor, the reflected wave of speed sensor can clearly see the bottom of the pile and reflection defect, less interference, and reflected wave of acceleration sensor although it can be determined that position of pile bottom and defect, but it has large graphic interference, it is difficult to accurately determine, so when stress wave detection cement mixing pile, should select the speed sensors better.



(a) Speed Sensor



(b) Acceleration sensor

Figure 3: Reflected wave received by the different sensors

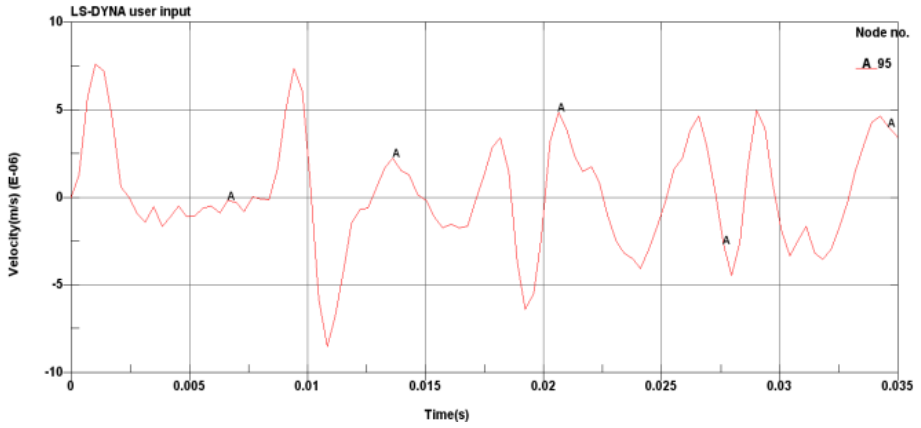
Influence of folder soil properties

In the production process of cement mixing pile, it is prone to the phenomenon of broken piles and piles certain sandwiched soil, the following analysis is the impact intensity of sandwich soil.

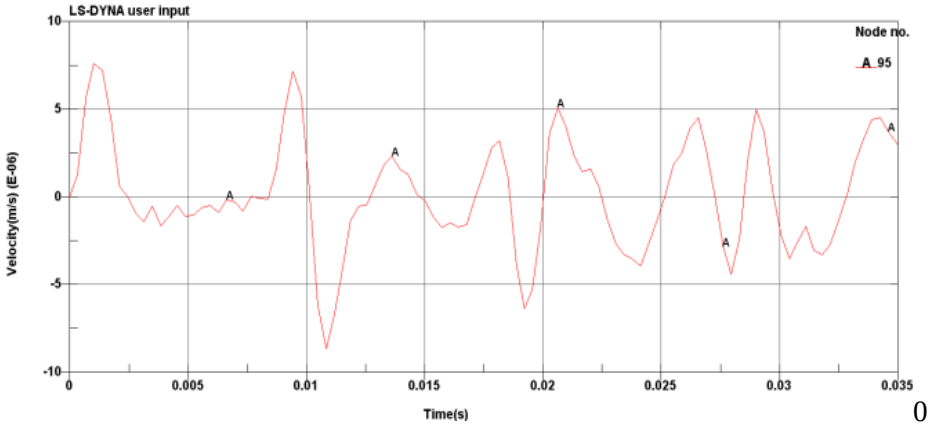
Sandwich substance material parameters are given in Table 2; the position of clip still in the pile 1/3. The results are shown in Figure 4.

Table 2: Parameters of folder soil material

Working conditions	Density(g/cm^3)	Dynamic elastic modulus (MPa)	Dynamic Poisson's ratio
1	1.70	20	0.38
2	1.72	60	0.36
3	1.74	100	0.34
4	1.76	140	0.32
5	1.78	200	0.30
6	1.80	525	0.28



(a) Condition 1



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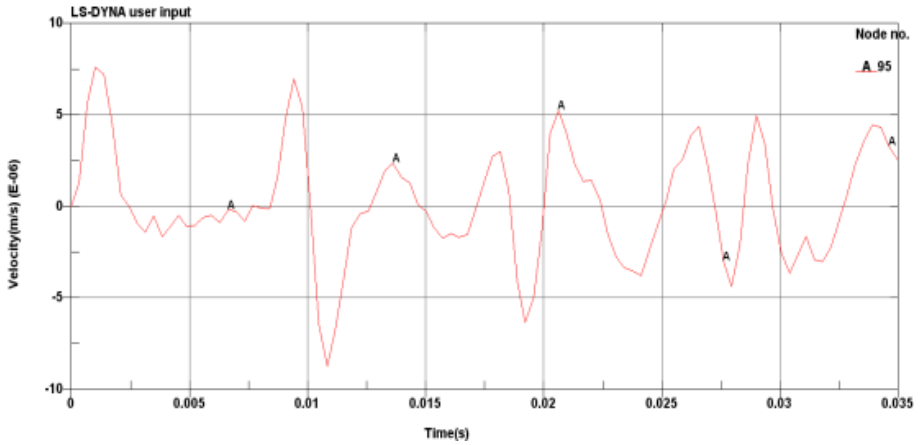
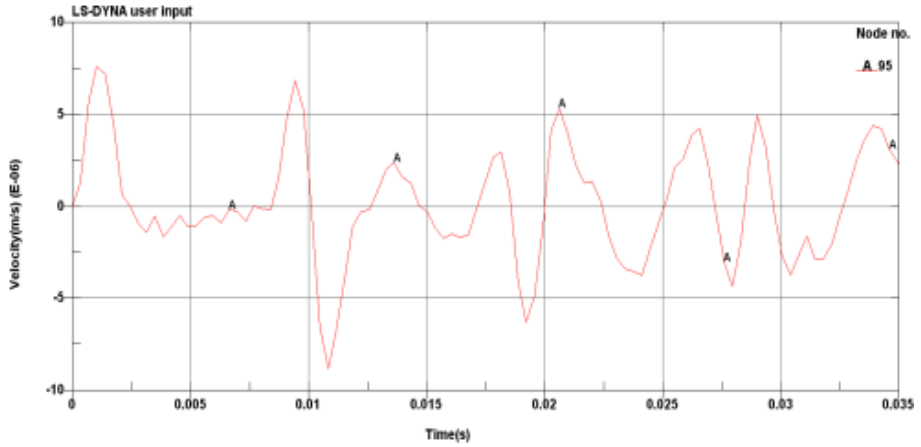
(b) Condition 2

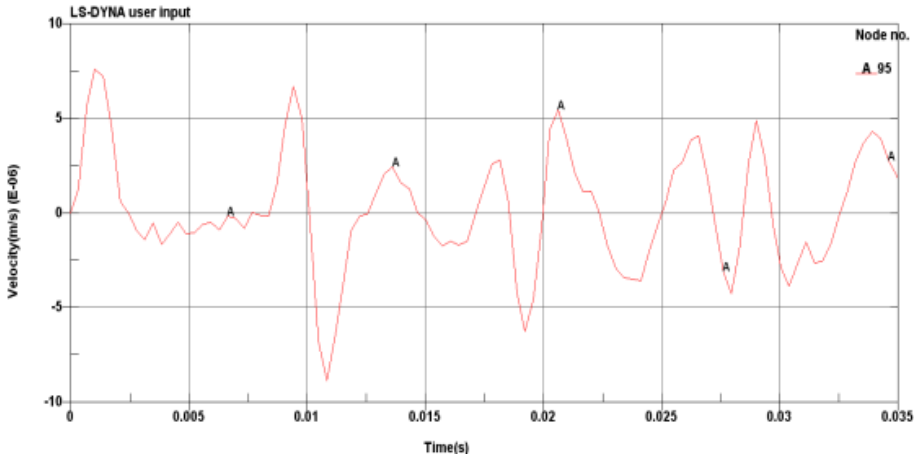
Figure 4: Speed curve at different interlayers- *Continues*



(c) Condition 3

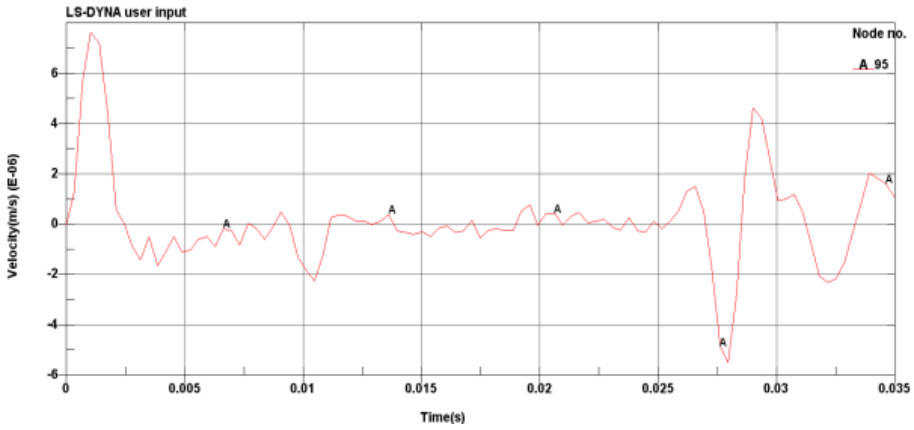


(d) Condition 4



(e) Condition 5

Figure 4: Speed curve at different interlayers- *Continues*



(f) Condition 6

Figure 4: Speed curve at different interlayers

Figure 4 show the velocity curves under different sandwich material properties, can be seen, the change of sandwich material properties has a little effect on the velocity of stress wave, it has on impact on the judge of pile length or defect locations. When the dynamic elastic modulus of folder soil located within 20 to 200MPa, the defect occur a secondary reflection, and reflection pile bottom is difficult to identify. However, the dynamic elastic modulus of folder is increased to 525MPa, that is, near cement mixing pile, the stress wave reflection is similar to 1/3 necking reflection as described above, and pile bottom reflection is clear. So the characteristic of folder soil has greater impact on the detection.

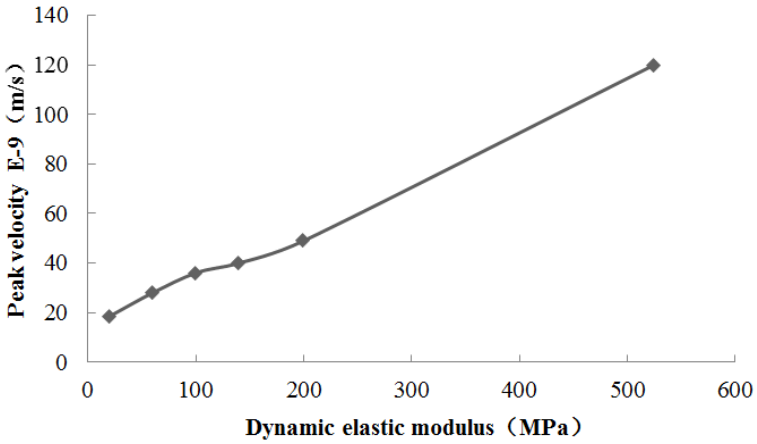


Figure 5: Relationship between speed peak at the bottom of the model and dynamic elastic modulus

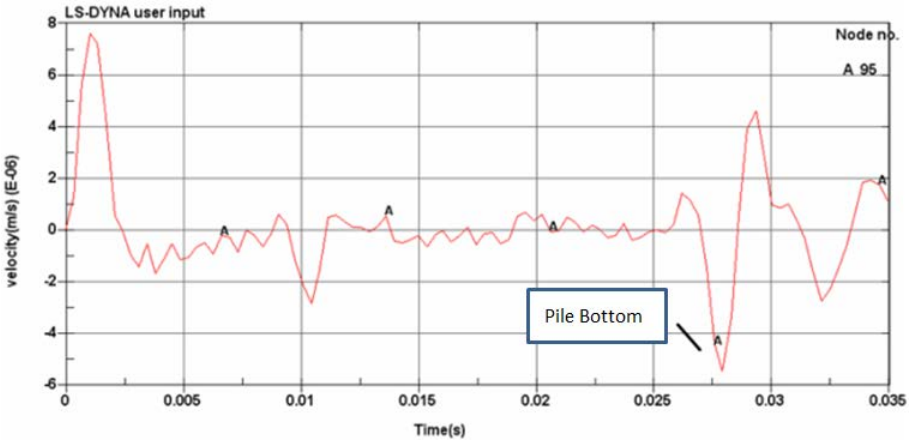
Figure 5 show the relationship of peak velocity of the bottom in model and dynamic elastic modulus of folder soil under different conditions of mezzanine nature, when the dynamic elastic modulus of folder soil increase, the speed peak of bottom in the model also will increase, along with the folder soil strength increasing, the energy of the stress wave attenuation be reduced, indicating that the properties of folder soil play an important role on attenuation of stress wave.

Influence of properties of soil around pile

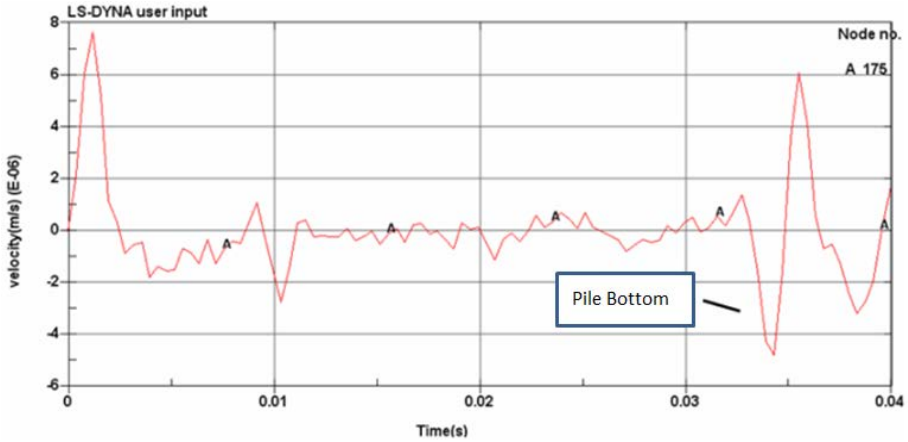
The simulation analysis aforementioned, the soil as a single homogeneous soil, in order to reflect the impact of properties of soil for the reflected wave, now set four-layer soil around the pile with different properties, simulate the impact of layer soil on the reflected wave, the specific parameters in Table 3. Other conditions remain unchanged.

Table 3: Parameters of soil material around pile

Depth	Density(g/cm^3)	Dynamic elastic modulus (MPa)	Dynamic Poisson's ratio
1~3	1.72	27	0.42
3~6	1.78	38	0.38
6~8	1.78	112	0.32
8~15	1.81	135	0.30



(a) Single soil



(b) Layered soil

Figure 6: Waveform diagram for the soil around the pile is layer

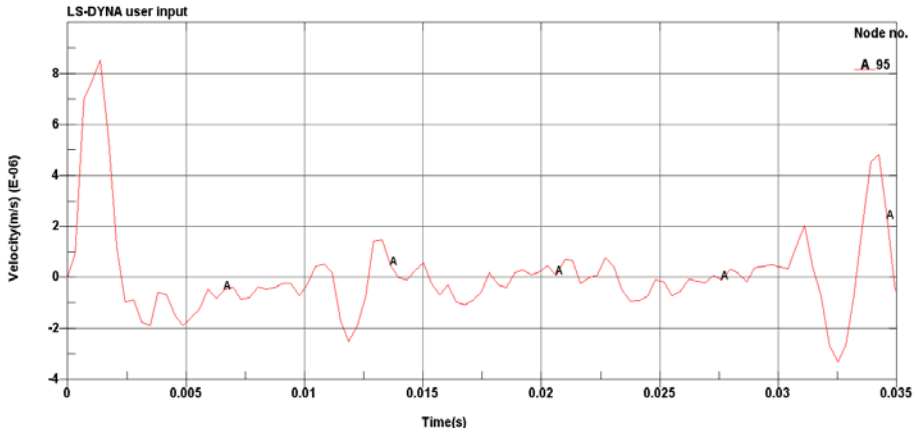
Figure 6 is the comparison of waveform for layer soil and single soil, we can see that the layer soil around the pile has no effect on the reflected waveform, however, the arrival time of the reflected wave appears quite different, especially the pile bottom reflection, a difference of nearly 6.5ms, it has a great influence on velocity of stress wave propagation, when the pile length is determined based on the reflected wave, the pile response speed is necessary to analysis.

Influence of properties of pile

The influence of pile‘s material parameters on the test results mainly reflected in the velocity, the velocity can be used in terms of pile length, so the impact of pile material parameters on test results worthy of analysis. After calculated that Poisson’s ratio of pile has a little effect on the test result, due to the limited space here, it is no longer to give the calculation, so the main impact analysis is pile‘s dynamic elastic modulus, the Poisson’s ratio and soil around pile remain unchanged. The parameters are shown in Table 4.

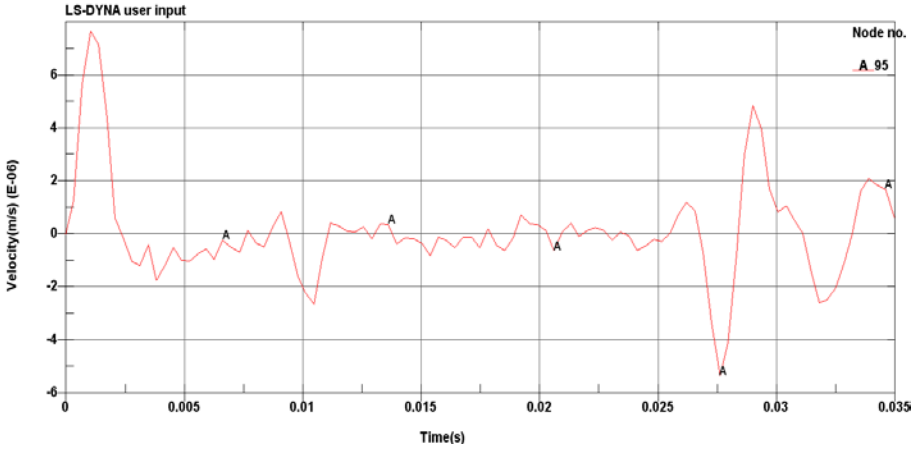
Table 4: Parameters of pile material

Working conditions	Dynamic elastic modulus (MPa)	Dynamic Poisson's ratio
1	500	0.29
2	760	0.29
3	1000	0.29
4	1200	0.29
5	1500	0.29

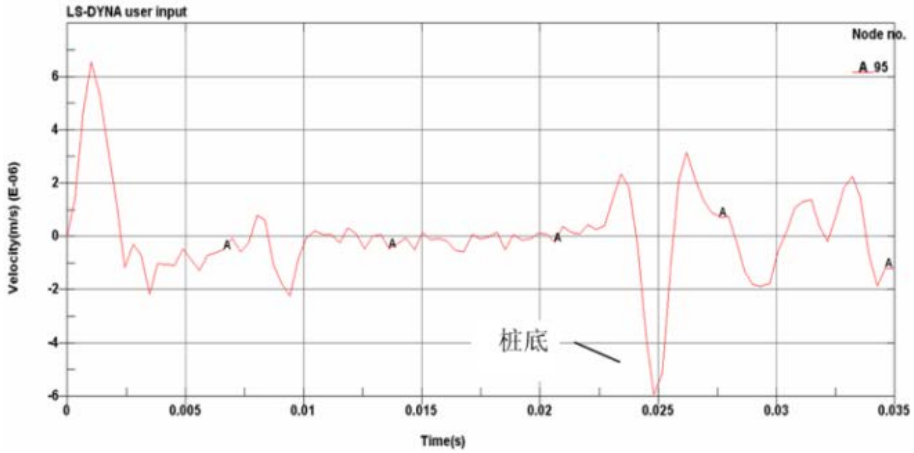


(a) Condition 1

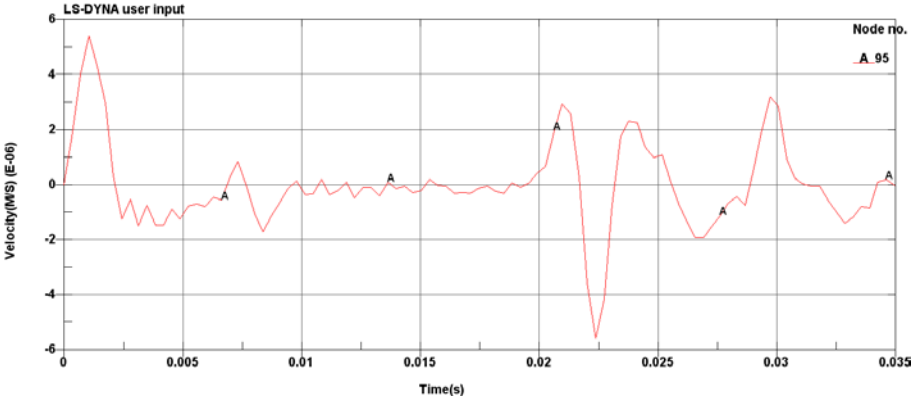
Figure 7: Speed curve under different dynamic elastic modulus of pile-*Continues*



(b) Condition 2

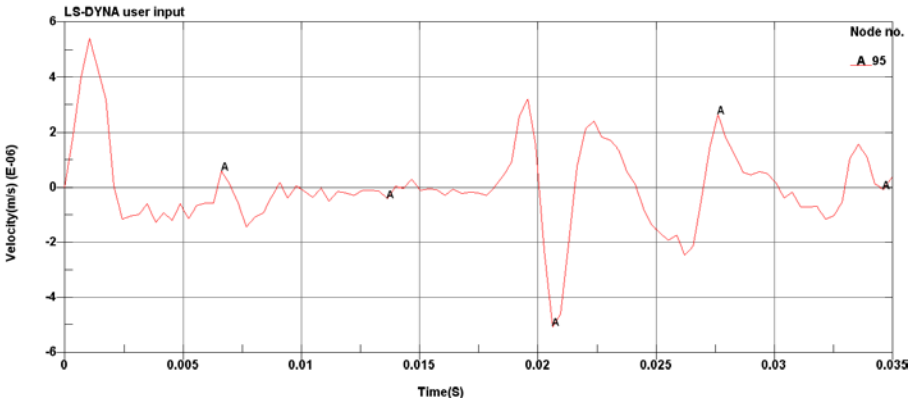


(c) Condition 3



(d) Condition 4

Figure 7: Speed curve under different dynamic elastic modulus of pile-*Continues*



(e) Condition 5

Figure 7: Speed curve under different dynamic elastic modulus of pile

Firstly, the impact of dynamic elastic modulus has been analyzed, dynamic Poisson's ratio is fixed at 0.29, the results shown in Figure 7. As it can be seen, the velocity of stress wave increases with the increasing of the elastic modulus of pile. For reflection of defects, in the process of dynamic elastic modulus increasing, reflecting of defect has a slight change.

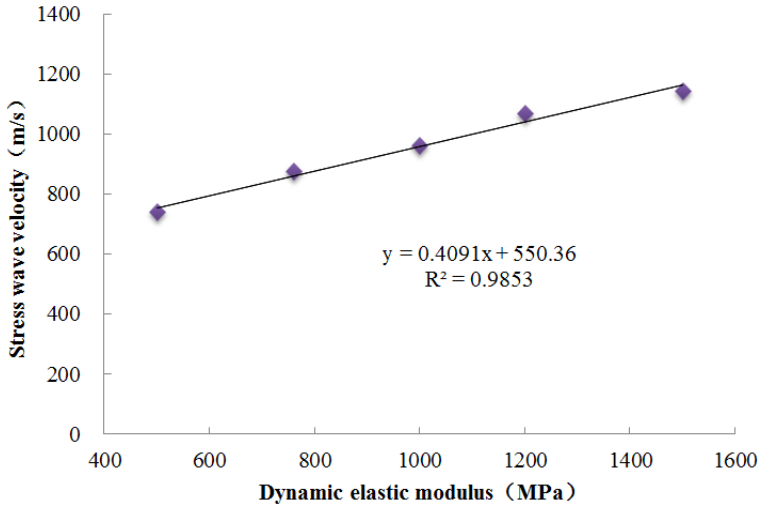


Figure 8: Relationship between dynamic elastic modulus and velocity curve of stress wave

Figure 8 is shown the relationship of velocity and dynamic elastic modulus of pile. Curve fitting correlation coefficient is 0.9835, close to a straight line. So it has a good correspondence for dynamic elastic modulus of pile and velocity of the stress wave.

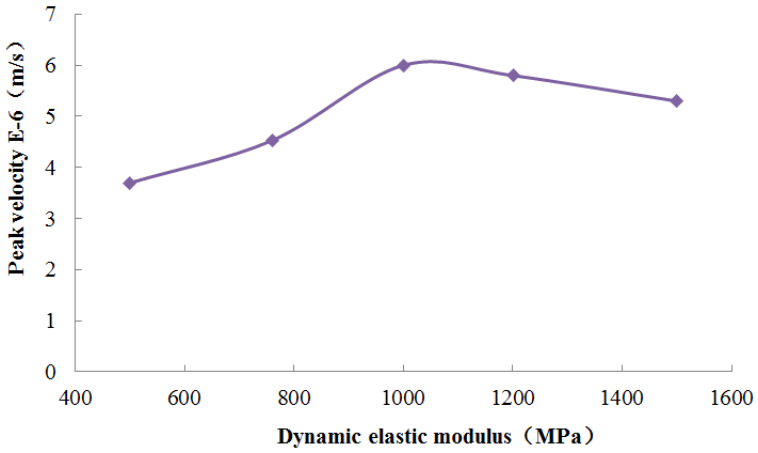


Figure 9: Relationship between speed peak at the bottom of the model and dynamic elastic modulus-

Figure 9 is shown the relationship of the reflected wave peak and dynamic elastic modulus of pile, which can be seen, on the reflected wave peak of bottom reduce after increasing, indicating that, the dynamic elastic modulus of pile increases to a certain value, the attenuation level did not decrease but increased. This is because in the calculation process, the dynamic elastic modulus of the pile is increased and soil around the pile has not changed, thus causing an increase in the difference between the two media, according to the wave theory, the reflection at the defect becomes more obvious, so when the stress wave returning from the bottom of pile hampered by deficiencies will increase, resulting in a reduction of reflected wave peak in the bottom of pile.

In addition, when the dynamic elastic modulus of pile reached 1200 and 1500MPa, reflected waveform of defect appeared both positive and negative phase, similar to the waveform of folder soil pile, it can also be explained for increasing of media diversity.

On the process of on-site detection, based on the relationship of stress wave velocity and the elastic modulus of pile, the inversion of stress wave velocity can be made according the elastic modulus of pile, which will help calculate the pile length and defect location. Also inversion of elastic modulus of pile can be made according the stress wave velocity, the elastic modulus and strength has a corresponding relationship, therefore indirectly show the strength of the pile, which is very beneficial for on-site inspection work.

CONCLUSIONS

(1) The test method of stress wave for cement mixing pile, the choice of speed sensor is more appropriate, is better than the acceleration detection sensor.

(2) the nature of the folder soil has little effect on mixing pile’s velocity, but due to the strength of folder soil is low, multiple reflections are produced, increasing the judgment difficult of length and

defect position, in order to avoid false positives, the associated analysis software should be adopted to deal with.

(3) The nature of the soil around the pile has a certain influence on the velocity, in determining of the defect position and pile length, the relevant test analysis should be made.

(4) The elastic modulus of pile and velocity of stress wave has a good linear relationship, the establishment of curve may reduce the actual amount of work.

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