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Dynamic response study of buried pipe subjected to dynamic compaction

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Abstract. Monitoring the internal vibration of the soil under dynamic compaction is often influenced by the environment. If the sensor is located in the crushed rock soil, its monitoring data often do not have typical representativeness. Therefore, a monitoring method of sensors placed in pipe is proposed. Based on the experience of earthquake and blasting engineering, the feasibility of the measurement method is studied and the results showed that the sensors placed in PVC pipes can reflect the response of soil. Two field tests, low energy and high energy, were conducted to verify the conclusion. After comparison of various vibration characteristics including waveform, Fourier spectrum, and amplitude attenuations with distance, the velocity of the sensors in PVC pipe showed linear relationship with sensors in soil. It can be concluded that the sensors placed in PVC pipe can be used for the test of vibration in soil and represent the typical vibration of the whole stratum.

1. Introduction

With the rapid development of China's mountainous airport and highway construction, the foundation material materials often obtained locally. Therefore, the crushed rock soil between homogeneous soil and rock fragments formed in the Quaternary are widely used in the embankment engineering. But large scale, high variability, bad gradation and large settlement deformation are the typical characteristics of crushed rock soil [1]. In order to reduce the deformation of foundation and increase the density, the dynamic compaction method is widely applied in the foundation treatment.

Dynamic compaction is a well-known method for its simplicity and economy practice since its first introduced by Menard in 1975 [2]. This technology can be simply described as a tamper (10~20t) being dropped from a height of 10~20m. Several blows are conducted until the ground under the tamper achieved the degree of improvement. The dynamic compaction is a kind of point source vibration that the tamper produces great impact when contact with the ground. The impact firstly induces vibration in the soil particles under the tamping point and then the vibration spread outward in a semi spheroid shape.



Because of the existence of geometrical damping of vibration wave and material damping of foundation soil, the vibration will attenuate exponentially. However, Present researches [3~5] about the vibration induced by dynamic compaction are focused on the propagation and attenuation on the surface of the ground. The results are mostly used to analyze the effect of vibration to the environment and the structures and little researches are made to study the propagation and attenuation of vibration in depth direction which will be useful to determine the degree of influence. It is often difficult to place the sensors in the depth direction especially in crushed rock soil and the common methods are digging trenches or drilling holes. However, digging trenches will change the structure and properties of soil and the depth is limited. For drilling holes, the directions of the sensors, which is an essential factor to the sensor accuracy, are difficult to control in the holes and the depth of sensors will be influenced by human factors. Moreover, the data of the sensors near a large scale rock will be affected. So the sensors should be put in a fairly stable environment and a method of placing the sensors in pipes is proposed. In order to verify the feasibility of the method, some field tests were carried out and presented in this paper. The dynamic responses between soil and pipes induced by dynamic compaction is mainly discussed in which the pipes are horizontal arrangement, and the pipes vertically arranged aren't mentioned which are the emphasis of further research.

2. Feasibility analysis

The method of sensors placed in the pipe to measure the response of soil during dynamic compaction will involve the cooperative movements between pipes and soil. Based on the research of earthquake and blasting engineering, Dowding [6] stated that when the stiffness of pipe was relatively low compared with the soil, and the pipe could be considered to deform with the surrounding soil. A flexibility index was defined [7] as:

$$F = \frac{2E_m(1-\nu_1^2)(D/2)^3}{E_1(1+\nu_m)t_s^3} \quad (1)$$

Where E_m is the Young's modulus of the surrounding soil, E_1 the Young's modulus of the pipe material, ν_m the Poisson's ratio of the surrounding soil, ν_1 the Poisson's ratio of the pipe material, t_s the thickness of the cross-section, and D the pipe diameter.

For F higher than 10, the pipe can be considered enough flexible and to deform with the surrounding soil. If F is lower than 10, the strains in pipe will be smaller than those in surrounding medium. Considering the properties of pipes used in the tests, the F of PVC pipe and aluminum-alloy pipe is 27 and 1.2, respectively, which means the interactions between PVC pipe and surrounding soils can be ignored.

3. Vibration measurement

3.1. Equipment for test

The equipment for measuring vibration included velocity sensors, connectable, 20 m long electric cables, and a recording and storing system. The frequency range of velocity sensor was 4-4000Hz with a measurement range of $\pm 1000\text{mm/s}$. The sensitivity of velocity was $3.95\text{mV/mm}\cdot\text{s}^{-1}$. The recording, storing and data processing system was a YE7600 system, with 16 channel data logging and an amplifier system connected to a computer for storing and processing data. The resolution of the ADC interface was 24 bits and the maximum sampling rate was 96000 Hz.

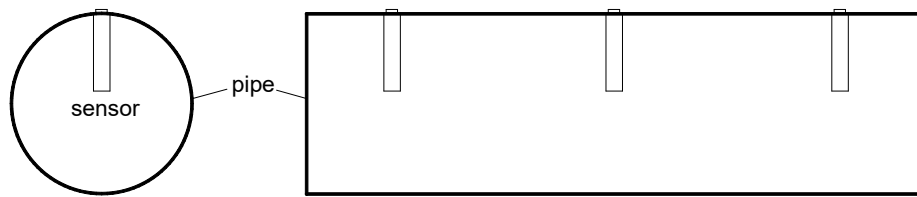


Figure 1. The placement of sensor

3.2. layout of field test

The crushed rock soil is inhomogeneity and consist of many big rock block (Fig.2). In order to study the dynamic response of soil and pipe conveniently, the pipes are arranged horizontally. The field tests included the low energy test and the high energy test. The high energy test was the main test and the low energy test was a pre-test of which the results would be selectively used in the analysis of the main test. A hammer with a diameter of 5cm was used in low energy test to exert impact and a 20cm*20cm*5cm plate was placed at the tamping point to increase the vibration effect. In high energy test, a heavy tamping machine with energy of 1000KN·m (weight 17 tones, height 7.6m) was used.

The two tests have similar layouts which showed in Fig.3 and Fig.4. A1A2, B1B2 and C1C2 were three methods of placing the sensors. A1A2 and B1B2 buried aluminum-alloy pipe and PVC pipe respectively. The sensors in C1C2 were buried in soil directly. All the three trenches were arranged horizontally with a depth of 0.5m.



Figure 2. The crushed rock soil

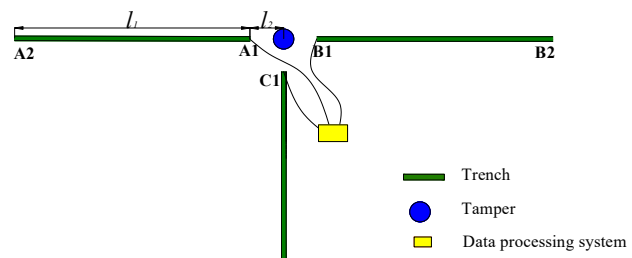


Figure 3. The layout of trench

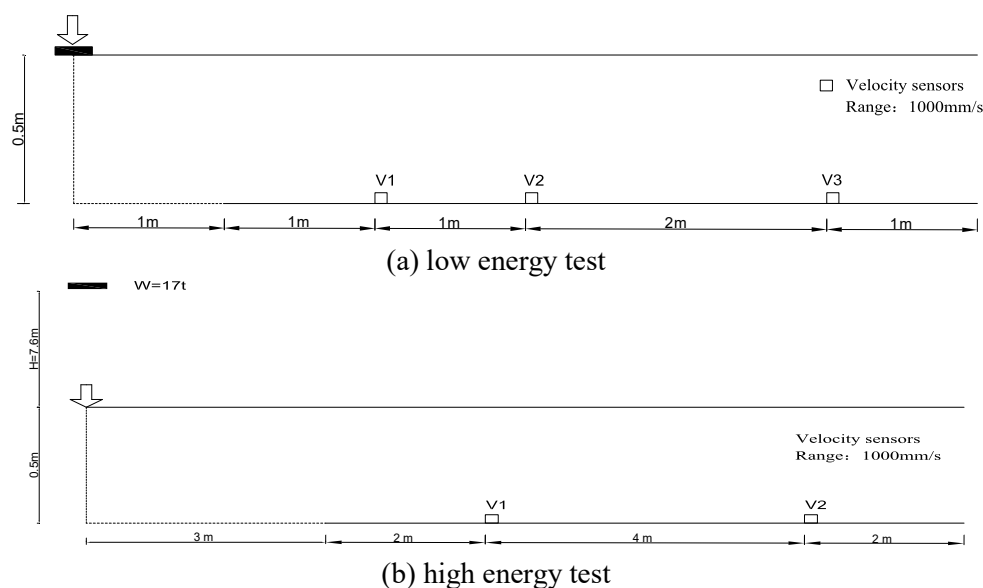


Figure 4. The layout of sensors

4. Data analysis

4.1. Time history and Spectrum analysis

Fig.5 shows the time history of acceleration and velocity at the same position of three layouts. It is obvious that the time history of three methods are all typical vibration response under the dynamic compaction. The take-off time and wave form of soil and PVC pipe are more approach than the aluminum-alloy pipe. Moreover, the aluminum-alloy pipe is easy to produce wave noise during vibration (Fig.5). The Frontier spectra of velocity at various distances from the tamping point is showed in Fig.6. The peak of spectrum at a near distance is more conspicuous than the far distance. The primary frequency of three methods are all located in 4~10Hz which is similar to the study of Hwang^[8]. The peak amplitude of PVC pipe and soil are nearly equal and the change is within 5%. For aluminum-alloy pipe, the peak amplitude is less than 60% of soil. In the far distance, a gap reduction appears in the spectrum among three methods, but the curve of PVC is more slippery than that of soil which means the PVC pipe can isolate the adverse effect.

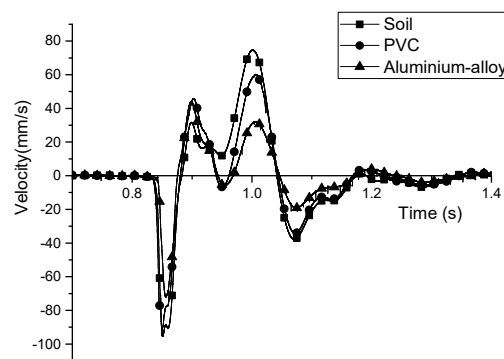


Figure 5. The time history of velocity

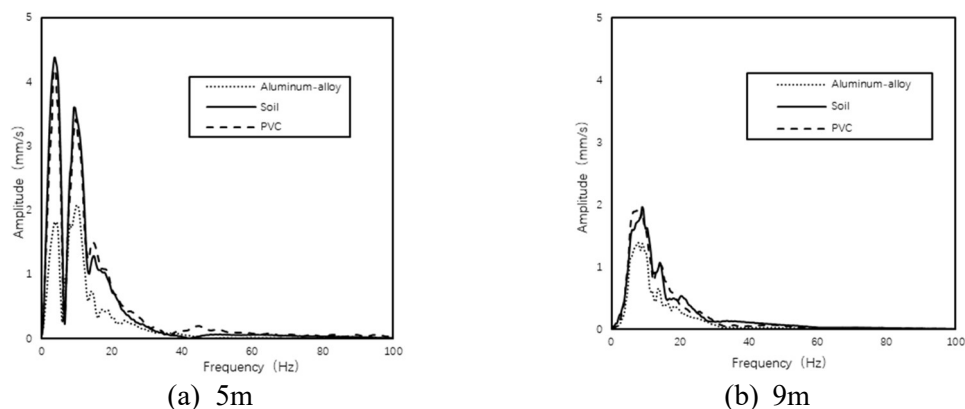


Figure 6. The spectrum of vibration velocity

4.2. Peak velocity analysis

Fig.7 shows the analysis of the relationship between soil and pipe under low and high energy. Compared with peak acceleration, the peak velocity of soil has a more linear relationship with PVC pipe which can be represent by the linear formula $v_{soil} = kv$ (Fig.7). The fitting coefficients at low energy of PVC and aluminum pipe are 0.9451 and 0.9538 respectively. For high energy, the fitting coefficients change to 0.9374 and 0.4251 which shows the relationship between the aluminum-alloy pipe and soil are instable.

After integration the velocity of low energy and high energy, relationship of PVC pipe and soil can be represent by the linear formula $v_{soil} = 1.1586v_{pvc}$ with a fitting coefficient of 0.9891. The coefficient k is greater than 1 because of the difference of properties between pipe and soil and the energy loss on the interface.

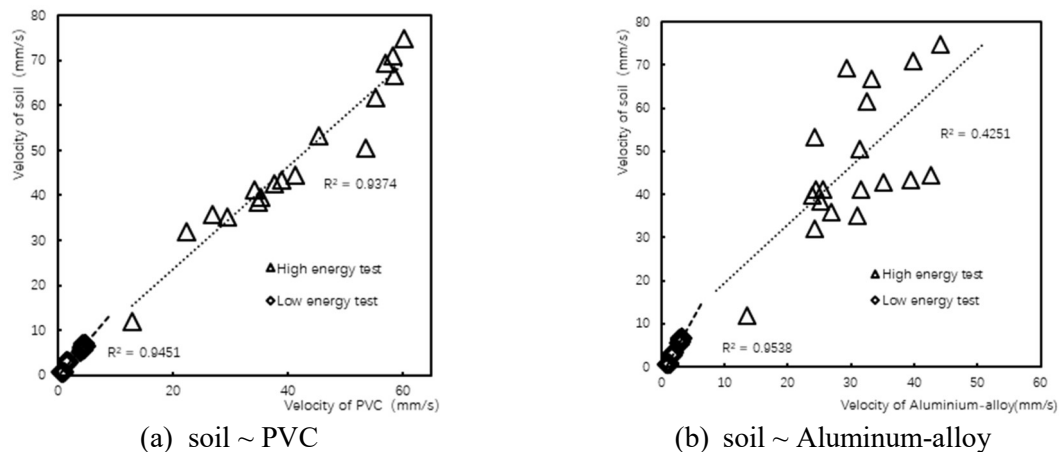


Figure 7. The relationship between soil and pipe under low and high energy

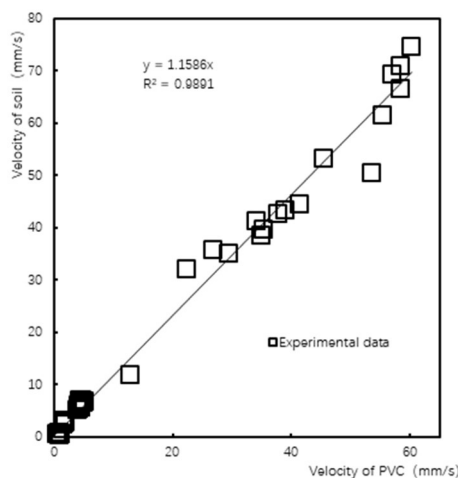


Figure 8. The relationship of vibration velocity between soil and PVC

4.3. Elastic wave velocity analysis

Fig.9~10 is the elastic wave velocity of three methods calculated by take-off time. In low energy test, the compaction has little effect on the surrounding soil. So with the number of blows increases, the elastic wave velocity of three methods are in the same range. For the high energy test, the wave velocity is smaller than the velocity in low energy test because of the difference of soil properties. However, the velocity of three methods are also similar and mainly located in 200~300m/s. On the whole, the average propagation velocities are close in value and it means the velocity has little connection with the material properties.

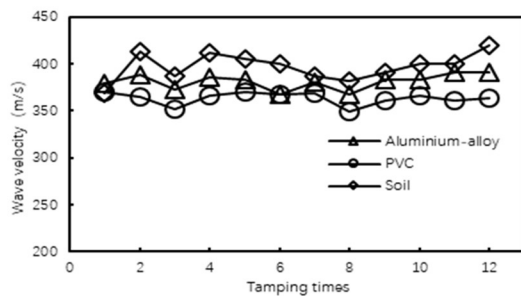


Figure 9. The wave velocity of low energy test

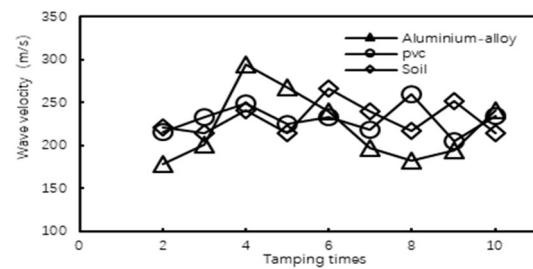


Figure 10. The wave velocity of high energy test

5. Conclusion

In order to improve the measurement technique for the response of dynamic compaction, a method of sensors placed in pipe is proposed. Based on the experience of earthquake and blasting engineering, the feasibility of the measurement method is studied and the results show that the sensors placed in pipes can reflect the response of soil. For this conclusion, low energy and high energy test are carried out and the following conclusion can be drawn:

- (1) The analysis of time history curves shows that the vibration forms and peak values are similar between the PVC pipe and the soil. Compared with aluminium-alloy pipe, the vibration attenuation law of PVC pipe is more closer with soil and a linear relation is existed between the PVC pipe and soil. Therefore, the sensors in PVC can reflect the distribution and attenuation of impact energy in soil.
- (2) The shapes of Frontier spectra are similar at different distances and the primary frequency are located in 4~10Hz and the spectrum of aluminum-alloy pipe is obviously small than that of PVC pipe and the soil, especially the point near the vibration sources. The peak amplitude of PVC pipe and soil are nearly equal and the change is within 5% which is more less than that of aluminum-alloy pipe.
- (3) For both the low energy test and high energy test, the elastic wave velocity of the three methods are stable and similar in value. The velocity calculated are located in the same range and it mean the velocity has little connection with the material properties. Therefore, the propagation velocities measured by the sensors in pipes are consisted with the value of the soil.

Acknowledgments

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