

Test and analysis of dynamic compaction vibration based on piezoelectric sensor

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Abstract: The paper takes a new campus project site of Shanxi university town for example, tests the influence of dynamic compaction vibration and vibration isolation effect of isolation trench on this ground, and compares the influences of the dynamic compaction vibration on surrounding buildings with isolation trench and without it. Furthermore, the attenuation law of dynamic compaction vibration in fill foundation of the loess area under different tamping energy and how to determine safe distance of dynamic compaction construction are studied. And then the quantitative relationship between acceleration and vibration source in new campus project site is presented. We derive the evaluation method that dynamic compaction construction affects adjacent buildings by contrasting with the existing standards and norms. The monitoring results show that isolation trench makes the amplitude attenuation of the horizontal velocity of dynamic compaction vibration reach above 75%, and the safe distance be 30 m under the tamping energy of 6 000 kN • m. Therefore, isolation trench is better for vibration reduction under dynamic compaction construction.

Key words: dynamic compaction; vibration; safety distance; isolation trench; piezoelectric sensor

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0 Introduction

Dynamic compaction method is that the rammer is enhanced high again and again and then it falls free, which will give the foundation energy of shock and vibration, compact foundation soil, improve the strength of the soil and reduce its compressibility^[1]. Dynamic compaction is widely used because of simple construction procedure and little construction cost. However, the environmental vibration effect of dynamic compaction is more and more significant in the construction. The first thing to be dealt with is vibration and its influence on adjacent buildings. FANG Lei et al.^[2] studied the relationship between vibration and the safety distance of structure; WU Xiao-bo^[3] carried out the field test and analyzed its vibration effect; Gao Fei et al.^[4] analyzed vibration response caused by dynamic compaction which was

based on actual engineering; SHI You-zhi^[5] studied the law of dynamic compaction vibration and environmental effects; LU Wei-dong et al.^[6] gave the method to evaluate the effect of environmental vibration through the mechanism of dynamic compaction; LEI Shang-jun, SHANG Jun-lei et al.^[7] analyzed the harm of vibration on adjacent buildings and discussed the factors which would affect the vibration; LIN Hong et al.^[8] showed that dynamic compaction have effects on adjacent buildings based on the field measured data. The vibration impact of dynamic compaction has been an important factor in the popularization of the dynamic compaction application. The determination of safety distance and research on isolation have not produced satisfying results. Therefore, it is necessary to study the attenuation law of dynamic compaction vibration, the influence on adjacent buildings and the effect caused by isolation trench by

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means of the attenuation of vibration acceleration and velocity.

1 Engineering situation

The new site of Shanxi university town is located in the east of Jinzhong basin. The construction site is I level non-weight wet collapsible loess, but field sections belong to fill soil.

As a result, the whole field of foundation is treated with dynamic compaction. Because time is limited, it is impossible for the campus to carry out the construction of subject after all foundation engineering is over. Therefore, when we were carrying out foundation treatment, the construction of subject was being processed. The vibration caused by hammer would produce negative effect on adjacent buildings. In order to determine the level of influence on adjacent buildings and guide the following dynamic compaction construction, it has practical significance to explore the attenuation law of dynamic compaction vibration and the effect on adjacent buildings.

2 Design of vibration test

2.1 Test method

The experiment was conducted by DH-5956 intelligent dynamic signal test and analysis system with

high precision magnetoelectric speed and acceleration sensor from Jiangsu Donghua Company. The vibration system consists of sensor, charge amplifier, vibration, computer, printer and cables. In order to ensure reality and reliability of test results, a set of test equipment should be calibrated before experiments and calculation will depend on the calibrated value. After the rammer is lifted, the system goes into the collection state and signal acquisition is carried out continuous. As a result, the whole process of dynamic compaction vibration is recorded.

2.2 Arrangement of measuring points

Monitoring line is laid out in a sports center area on the backfill. And the test of horizontal vibration and vertical vibration is carried out. The dynamic compaction points and test points distribution is shown in Fig. 1. The depth of the isolation trench is about 5 m, the width is about 2 m and the distance between tamping point and isolation trench ranges from 14 m to 16 m.

In order to study the effect of dynamic compaction vibration strength on the surrounding buildings, the energy of 4 000 kN · m is used to tamp for field test. Sensors are placed outside the building the foundation. At the same time, equipment records the tamping vibration velocity in the whole process.

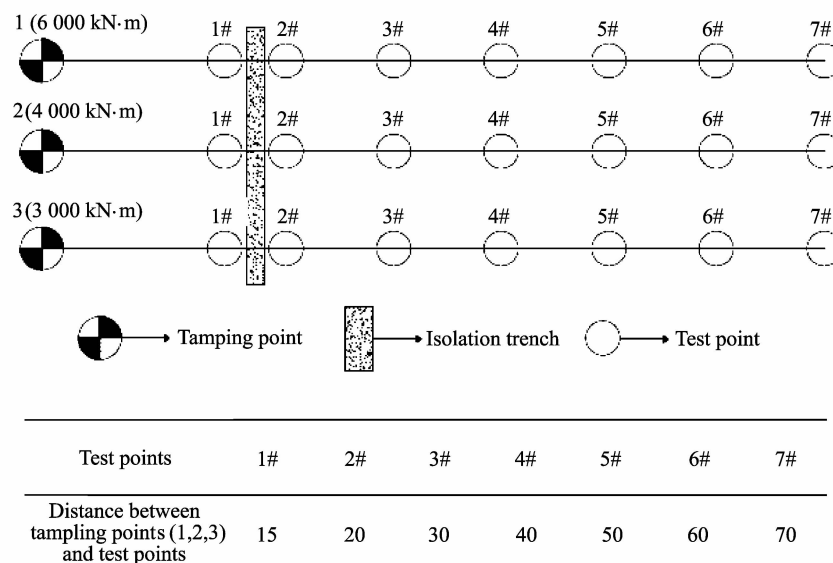


Fig. 1 Dynamic compaction points and test points layout

3 Analysis of test results

3.1 Attenuation law of dynamic compaction vibration

The amplitude of dynamic compaction vibration decreases with the increasing distance of tamping points from the test points, this phenomenon is called the ground vibration amplitude attenuation with distance, namely, vibration attenuation. The previous studies show that the amplitude value increases sharply with increasing of tamping point distance in the form of power exponent function. The relationship between the vibration velocity of dynamic compaction and the distance is described as^[9].

$$v = kr^{-\beta}. \quad (1)$$

Considering deformation partitioning under the action of dynamic compaction, the distance between elastic, plastic zone boundary and tamping center is set at 3.0 m, which is the source, namely $r_0 = 3 \text{ m}$ ^[10], then

$$\frac{v}{v_0} = \left(\frac{r}{r_0}\right)^{-\beta}. \quad (2)$$

We further derive

$$v = v_0 \left(\frac{r}{r_0}\right)^{-\beta} = v_0 r_0^\beta r^{-\beta}, \quad (3)$$

where β is attenuation index, which is dimensionless quantity; r_0 denotes the distance from the boundary of elastic and plastic zone to tamping center; r is the horizontal distance between tamping points and test points; v_0 is vibration velocity of elastic plastic zone boundary of particle, mm/s; v is maximum velocity of test points.

1) The influence of tamping energy level on the propagation law of the vibration wave whether there is isolation trench or not.

It can be seen from Figs. 2 and 3 that the attenuation law of the peak of ground vibration velocity conforms to the power law function, that is to say, the peaks of vibration velocity and dynamic compaction energy are of positive correlation with increasing and decreasing of the dynamic compaction energy level. Isolation trench is between the first test point and the

second test point. In Fig. 3, due to the existence of the isolation trench, the peak of vibration velocity is reduced by 64.5%. In Fig. 2, the peak of vibration velocity attenuation is not obvious, which indicates that the effect of vibration isolation is good.

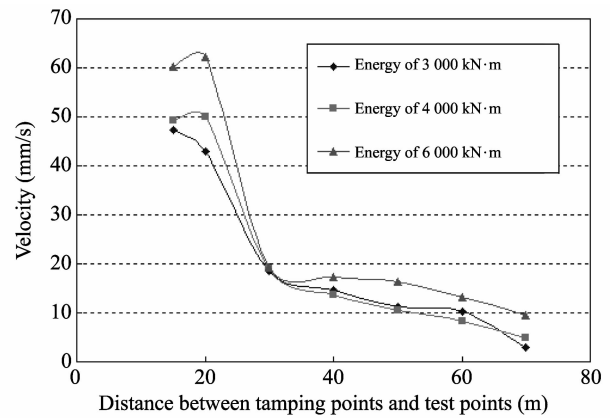


Fig. 2 Relation curve of horizontal vibration velocity and test points (without isolation trench)

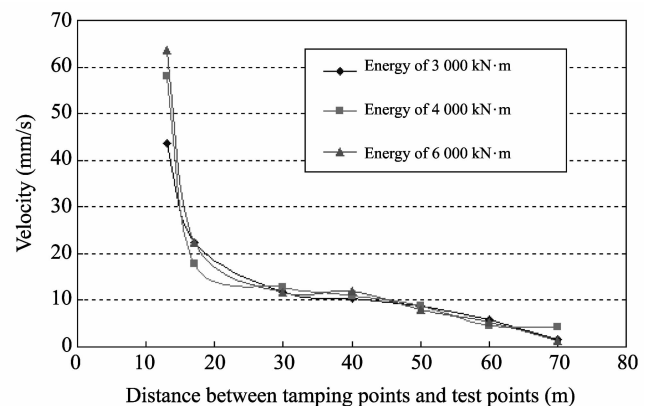


Fig. 3 Relation curve of horizontal vibration velocity and test points (isolation trench)

2) The attenuation law of horizontal vibration velocity of the ground particle at the same energy level with or without isolation trench.

Fig. 4 shows that the higher dynamic compaction energy level is, the faster it is attenuated. At energy of 6 000 kN · m and 4 000 kN · m and in the absence of isolation trench, the velocity of the second test point velocity increases compared with the first test point, which could explain the existing near and far field. At energy of 3 000 kN · m, the velocity is contrasted due to measurement error; The attenuations of the second point compared with the third point are in turn 47.5%, 27.2% and 46.8%. It shows that,

dynamic compaction level with isolation trench has certain influence on the peak of vibration velocity attenuation.

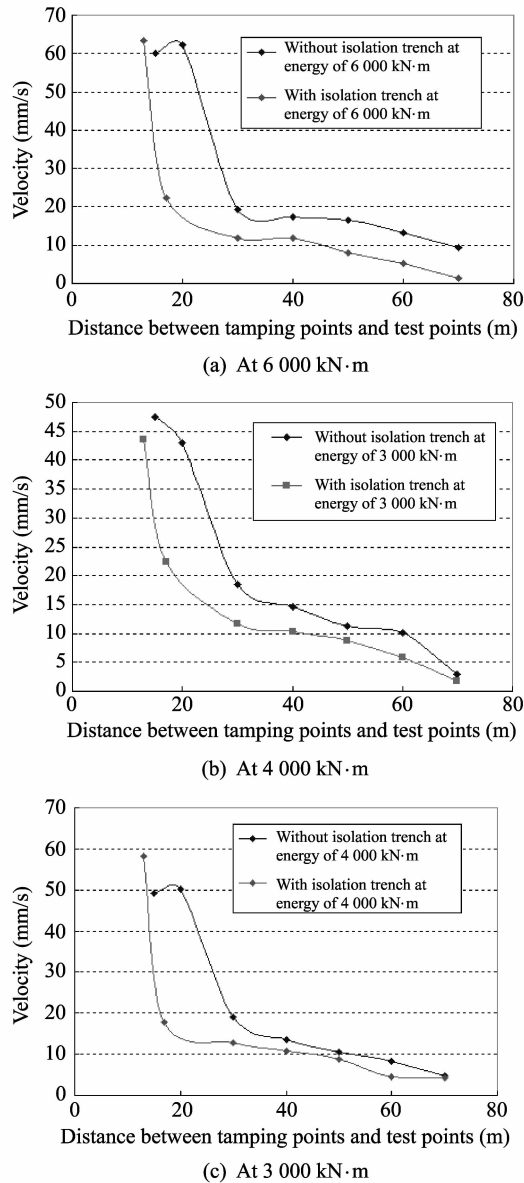


Fig. 4 Relation curve of horizontal vibration velocity and test points at different energy level

3.2 Analysis of safety distance of dynamic compaction vibration^[10-18]

Usually, people use the vibration velocity as the safe distance of dynamic compaction. The paper studies the influence of dynamic compaction construction on the surrounding buildings including industrial and civil buildings, and the main frequency of dynamic compaction vibration is less than 50 Hz, which is re-

duced with the increase of distance. According to the safety regulations for blasting (GB6722-2014) clause 6.2.2, the safe vibration velocity that the type of the building allows is from 3.5 m/s to 4.5 m/s. In this paper, vibration velocity whether there is isolation trench of 6 000 kN·m or not is analyzed.

Table 1 shows that, without isolation trench, at the dynamic compaction energy of 6 000 kN·m, velocity attenuation is decreased to 19.18 mm/s at 30 m, less than 35 mm/s, namely, the safe distance of dynamic compaction of industrial and commercial buildings is 30 m. After setting isolation trench, horizontal speed drops to 22.44 mm/s at 20 m, and safe distance is less than 20 m, that is to say, the effect of isolation trench is obvious.

Table 1 Velocity of each measuring point

Distance of tamping points(m)	Vibration velocity of dynamic compaction at energy of 6 000 kN·m (mm/s)		
	Without isolation trench	With isolation trench	Attenuation amplitude (%)
15	62.27	63.49	—
20	60.18	22.44	62.7%
30	19.18	11.9	38.0%
40	17.29	11.78	31.9%
50	16.42	8.02	51.1%
60	13.27	5.36	60.0%
70	9.45	1.27	86.6%

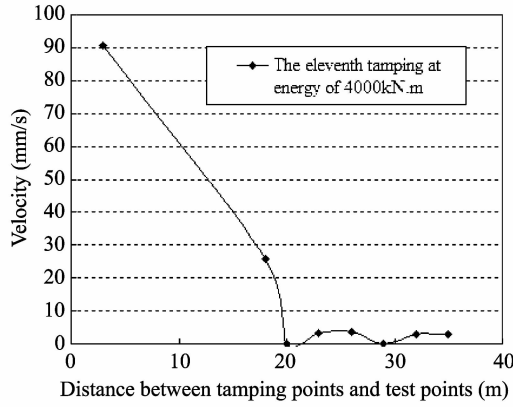
Single-point tamping is used for field test foundation compaction. There are 14 times of tamping for each tamping point, and the test results of the 14th acceleration and the 11th horizontal velocity are taken as effective data for structural safety evaluation. Table 2 is the measured values of acceleration.

Table 2 Measured test values of acceleration

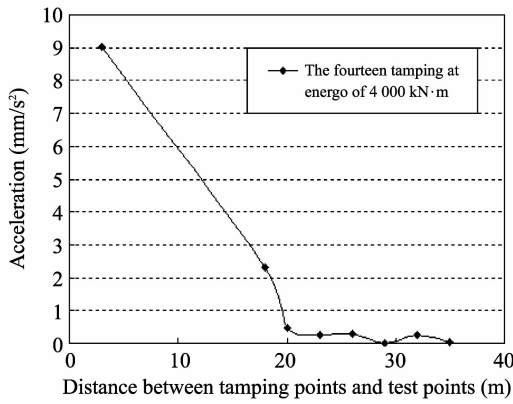
Test point	Distance of tamping points and test points (m)	Vibration acceleration of dynamic compaction at energy of 4 000 kN·m
1	3	9.04
2	18	2.32
3	20	0.48
4	23	0.24
5	26	0.28
6	29	0.27
7	32	0.26
8	35	0.039

Fig. 5(a) shows the curve of the ground horizontal velocity peak value varying with the distance after setting the isolation trench. Fig. 5(b) shows the

curve of the ground vertical acceleration peak value varying with the distance after setting the isolation trench.



(a) Horizontal velocity peak value



(b) Vertical acceleration peak value

Fig. 5 Vibration attenuation curve at dynamic compaction of 4 000 kN · m

Setting the isolation trench makes acceleration decay faster with the increase of distance and the quantitative relationship of acceleration and vibration source can be expressed by

$$F'(r) = E \ln(r + c), \quad (4)$$

where E and c are constants, r is the source distance, $f(r)$ is the parameters of ground vibration varying with vibration source distance. Let $c=0$, then

$$F'(r) = E \ln r. \quad (5)$$

In our tests, the type can be written as

$$\frac{\partial a}{\partial r} = E \ln r. \quad (6)$$

We further obtain

$$a = Er \ln(r - 1) + f,$$

where f is the constant of integration.

Taking the values of two arbitrary points of vibration isolation trench line into Eq. (7), there is

$$\begin{cases} 904 = 3\,000E \ln(3\,000 - 1) + f \\ 232 = 18\,000E \ln(18\,000 - 1) + f \end{cases}$$

where $E = 4.4 \times 10^{-5}$ and $f = 768$.

The acceleration of regression equation of the isolation trench is

$$a = Er \ln(r - 1) + f =$$

$$4.4 \times 10^{-5} r \ln(r - 1) + 768.$$

4 Evaluation method of influence of structure vibration

Vibration, caused by mechanics, blasting, construction machinery, etc., spreads to surrounding structures through the stratum. If the vibration of the building exceeds the permissible threshold, it is possible to cause a series of damage to surrounding buildings. At present, the rules about the effect of dynamic compaction vibration on adjacent buildings are not perfect. According to technical specification of dynamic consolidation to ground treatment, when the click tamping reaches 1 000 kN · m, safe distance should be more than 15 m. When it is more than 1 000 kN · m, the safe distance of instrument workshop and high-sensitivity buildings still should regress statistics and be calculated according to compaction test results. According to the Chinese seismic intensity scale (GB/T17742-2008), from the above graph, the values at the central point of vibration acceleration on building floor when the trial ramming are higher than the acceleration values of seismic intensity V. According to the safety regulations for blasting (GB6722-2014)^[19], when main vibration frequency of central point on building floors is less than 10 Hz, vibration velocity is not higher than required security limits of reinforced concrete structure building (main vibration frequency < 10 Hz, the velocity of security permissions is 3.0–3.0 cm/s) and the new pouring mass concrete (age: initial setting of 3 days, vibration velocity of security permission of 2.0–3.0 cm/s).

5 Conclusion

1) When dynamic compaction vibrates, the velocity peak of ground vibration conforms to attenuation law of power function. With the increase of distance of tamping points, peak vertical velocity attenuates soon. The tamping energy has much influence on the amplitude of vibration.

2) When isolation trench exists, the amplitude of attenuation of horizontal vibration is velocity of dynamic compaction reduced to around 75%.

3) People can use the natural earthquake intensity and velocity of blasting safety for the building control of impact of dynamic compaction vibration.

4) Quantitative relationship between acceleration and vibration source is given. Just for the purpose of expression of these site geological conditions, by collecting and analyzing monitoring data of dynamic compaction vibration, the attenuation law of dynamic compaction vibration is derived, and dynamic compaction vibration model is established. It has important effect not only on the evaluation of dynamic compaction vibration, but also on study of geotechnical engineering liquid property in dynamic compaction vibration research field. By accumulating more data, the relationship between different properties of rock mass and the effect of dynamic compaction and the corresponding relationship among the site dielectric functions are established. It will make people clearly understand constitutive relation between the physical or mechanical properties and its dynamic characteristics of engineering rock mass.

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基于压电式传感器的强夯振动测试分析

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摘 要: 以山西大学城某新校区工程场地为例, 对该场地强夯振动影响以及隔振沟的隔振效果进行了测试, 对比了有无隔振沟工况下强夯振动对周围建筑物的影响, 研究了不同夯击能下强夯振动在黄土地区填方地基中的衰减规律及如何确定强夯施工安全距离, 提出了该场地的加速度和振源距的定量关系。通过与现有标准、规范的规定进行比较, 分析得出了强夯施工振动对相邻建筑物影响的评价方法。监测结果表明, 隔振沟在强夯施工中减振效果好, 隔振沟对强夯振动水平速度的衰减幅度高达 75%, 且在 6 000 kN·m 夯击能下, 强夯安全距离为 30 m。

关键词: 强夯; 振动; 安全距离; 隔振沟; 压电式传感器

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