STUDY ON VIBRATION INDUCED BY THE SHAKING TABLES ARRAY IN LARGE SCALE CIVIL LAB

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ABSTRACT

The shaking table array, which is composed of two small tables with maximum capacity 30T and two big tables with maximum capacity 70T, is set in the two trenches with length of 70m and 35m in the newly built civil lab of Tongji University. The four shaking tables can work together or separately. A large mass foundation of about 25000 tons is used for vibration reduction. For the different types of civil experiment, the excitation by the shaking tables is acting on different points of the trenches. As the open trench and the total mass of foundation distributed in a wide range may have influence on the vibration reduction, the vibration induced by the shaking table array is studied in this paper by both the site test and numerical analysis.

The accelerometers were placed on the concrete foundation and outside the foundation. The ground borne micro tremor is tested firstly and the vibration level on the foundation is about the half of the vibration level outside the foundation. As the shaking tables are still in the debugging stage, only one condition as a small table excited by horizontal acceleration of peak value 1.2g can be tested in site. By the analysis of recorded acceleration, the effectiveness of large mass scheme is preliminary verified.

Numerical analysis is also taken to evaluate the vibration under the worst condition. By comparative analysis for the test condition, the finite element model is proved to be of reasonability. Four worse conditions, as 4 tables in full load condition are selected for numerical analysis to simulate the future status of working. In the concrete part, the peak acceleration is reduced by half and more in a distance of about 20 meters away and the vibration is attenuated effectively. And the affected soil region is about 30 meters away from the concrete foundation. The attenuation of vibration induced by the shaking table array can met the requirement of design.

Keywords: shaking table array, large mass foundation, vibration test, numerical analysis, finite element model, vibration evaluation.

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1. ENGINEERING BACKGROUND

A large scale civil lab was newly built in Jiading campus of Tongji University. The shaking table array, which is composed of 4 individual tables of three degrees of freedom, is the important device in the lab. Two small tables with maximum weight 30T and two big tables with maximum weight 70T can move in a 35m long trench and a 70m long trench and work separately or together in combined way, as shown in Figure 1. The peak acceleration for each table is 1.5g and the frequency range for the excitation is 0.1-50Hz.

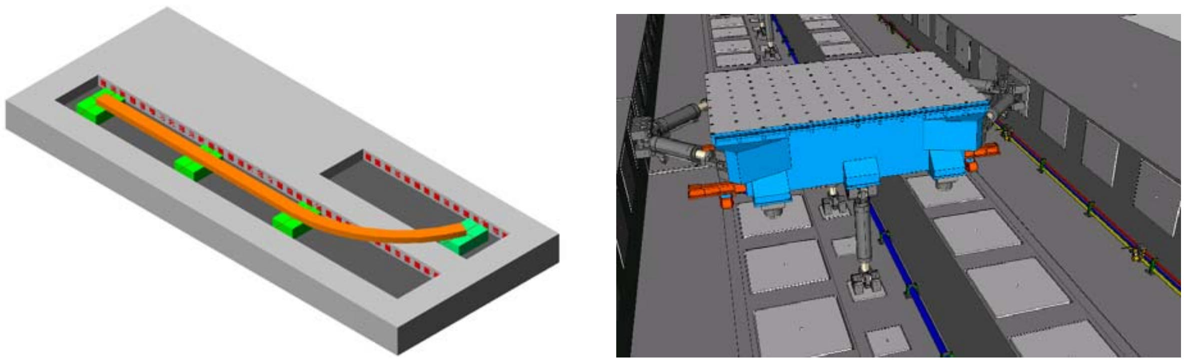

Figure 1: 4 movable shaking tables and 2 trenches

Besides the two trenches, there is a large area of strong floor in the lab. A large mass foundation is set in L shape area of about 6000 square meters for vibration reduction. The maximum depth of the foundation in the trench part and strong floor part is 6.35m and 4.2m respectively. The total weight for the foundation is about 2500T, which means the ratio of the mass of foundation vs. the possible mass of specimens and tables is about 70.

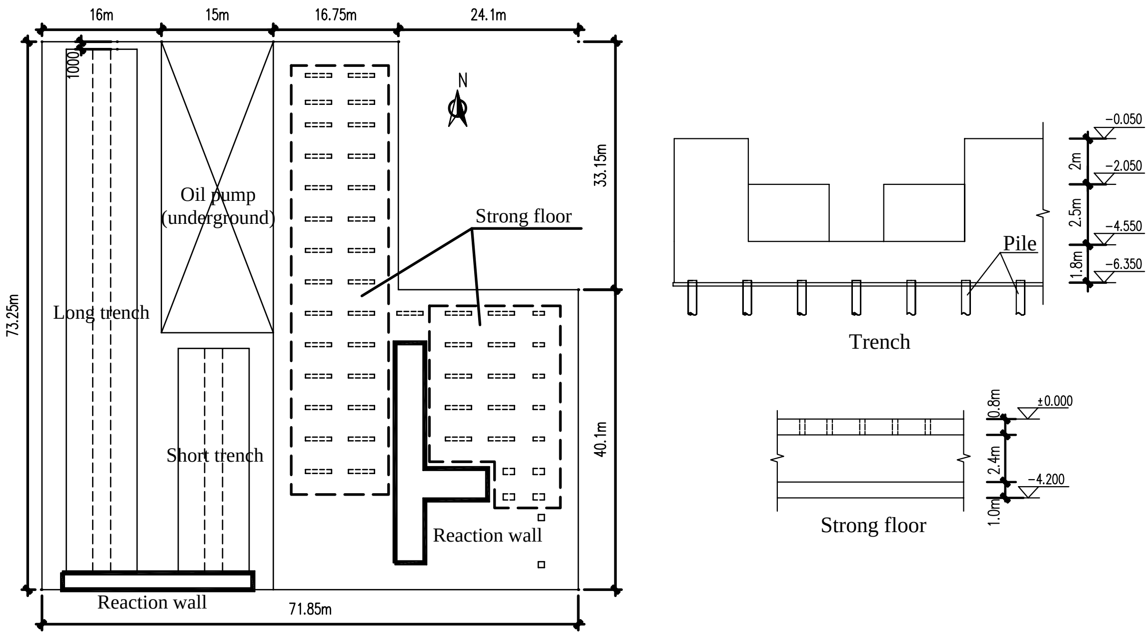

Figure 2: Layout of the large mass foundation and section of the trench and strong floor

The large mass of foundation is widely distributed in the part of open trench and strong floor, which is quite different from the solid mass foundation (National Standards of the People’s Republic of China,1996). As the trenches are open in one direction, the transverse stiffness (vertical to the trench) is smaller than the longitudinal stiffness (along the trench). And the excitation of the tables may take action in the different position on the trench, the vibration condition becomes complicated. This paper presents research work on the evaluation of horizontal vibration induced by the shaking table array. Both site test and numerical dynamic analysis by finite element method are preceded (Liu J.B. et al.2002; Zhang Z.P. et al. 2004).

2. SITE TEST

Firstly, the ground borne vibration was tested inside and outside the lab. The typical time history and power spectral density of the horizontal vibration is shown in Figure 3. The peak acceleration outside and on the large mass foundation is about 0.01 m/s^2 and 0.006 m/s^2. The first dominant frequency is 0.68Hz, which is mainly influenced by the soil. The feature of narrow band vibration inside the lab is found. The large mass of foundation can effectively attenuate the ground vibration.

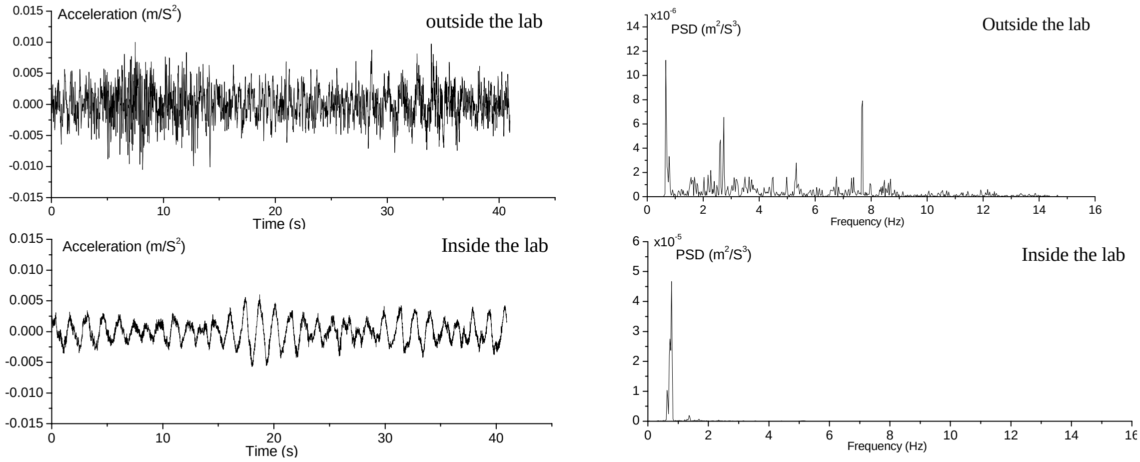

Figure 3: Time history and power spectral density of ground borne horizontal vibration

Besides the condition of ground borne, a work condition as random excitation of frequency range as 0-50HZ and peak acceleration 1.2g on a small table with additional mass of 30T is also tested in site. The time history and power spectral density of the excitation is shown as Figure 4.

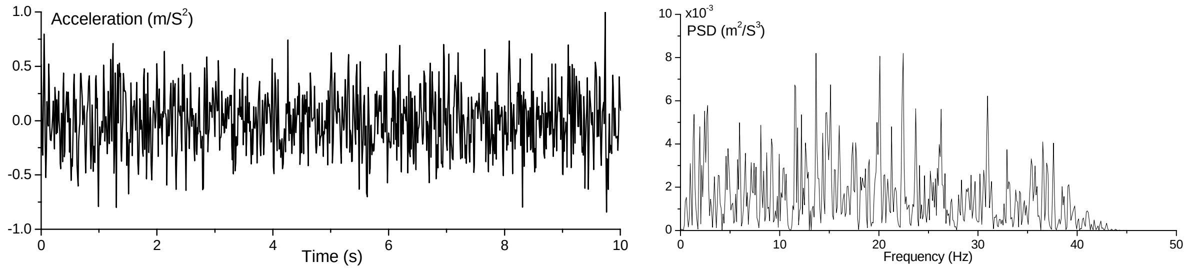

Figure 4: Time history and power spectral density of the excitation on table 2

Five acceleration meters were placed on the ground inside or outside but near the range of the concrete foundation, as shown in Figure 5. The peak acceleration of each test point and the typical acceleration curve on the edge of concrete and on the nearby soil are also shown in Figure 5. It is seen that the vibration is mainly attenuated in the concrete foundation with little influence on the soil outside the concrete part.

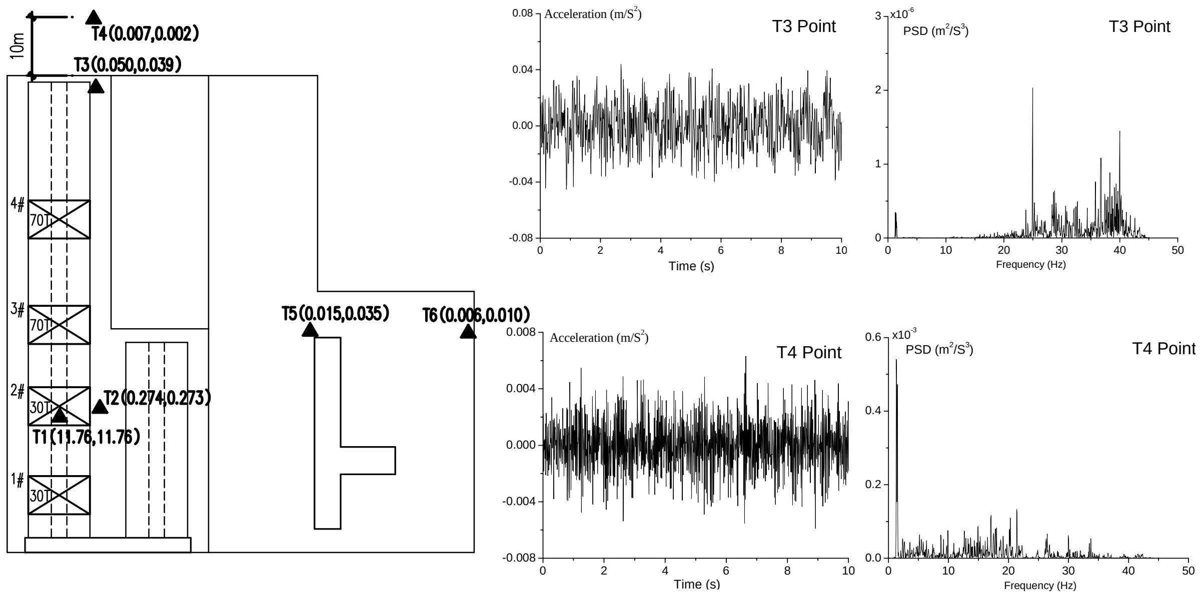

Figure 5: Peak acceleration and transverse acceleration of T3 and T4 (unit:m/s^2)

(Figures in brackets denote the peak acceleration in transverse and longitudinal direction.)

3. FINITE ELEMENT MODEL

A finite element model with 283m, 96m and 241m in three dimensions is established for numerical analysis, as shown in Figure 6. Besides the concrete part, the soil and pile are also included in the model. Only the reaction walls above the ground is considered in the model and no member as column, beam and roof of the upper structure is considered for their relative small size and little influence on the ground vibration. The total number of joints and elements are 56268 and 51736. The maximum size of element is 12m , 6m and 6m for concrete, soil and pile. Auto meshing is done in the boundary for the size change of the element.

The parameters of concrete is 2500 kg/m^3 for density, 0.2 for Poison's ratio and 30000 MPa for elastic modulus with no consideration of the steel bar. The soil is assigned to be elastic material, whose density, Poison's ratio and elastic modules are chosen in the range of 1837-1960 kg/m^3, 0.28-0.35 and 4.8-40 MPa. The visco-elastic boundary is set in the model (Lysmer et al.1969). The assumption of hysteretic damping is used and the damping ratio for the dominant frequency of concrete and soil is chosen as 0.05 and 0.02. (Clough et al. 1975; Hart et al.1975; Li et al.1995;Lou et al.2004)

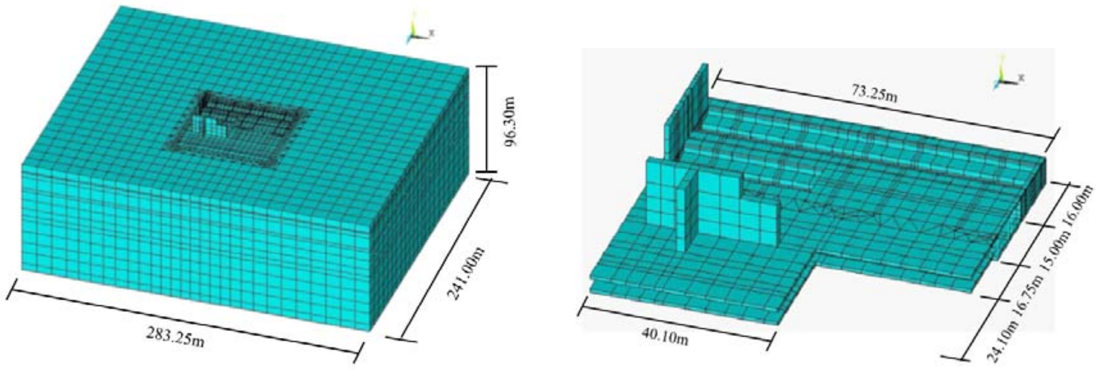

Figure 6: Finite element model and details of the concrete part

By mode analysis, the first natural frequency is 0.668Hz, which is corresponding to the vibration of the soil and is very close to the dominant frequency in power spectral density function in Figure 3 and 5. For the large amount of element number and the difficulty of calculation by the restriction of computer, it is not easy to distinguish the natural mode of only concrete foundation clearly. The vertical, transverse and longitudinal frequency is about 7.3Hz, 21.7Hz and 40.3Hz.

The transverse and longitudinal response should be analyzed in two directions by transient dynamic method individually. Comparative analysis for the test condition of random excitation is done and the main result is listed in Table 1. The finite element model is verified to be reasonable.

Table 1: Peak acceleration of test points in site test and numerical analysis (unit: m/s^2)

	Site test		Numerical analysis	
Test point	Longitudinal	Transverse	Longitudinal	Transverse
T2	0.2740	0.2729	0.2850	0.2645
T3	0.0502	0.0391	0.0474	0.0337
T4	0.0065	0.0018	0.0082	0.0027
T5	0.0147	0.0353	0.0130	0.0258
T6	0.0055	0.0099	0.0067	0.0113

4. NUMERICAL ANALYSIS

In order to evaluate the influence of vibration induced by the shaking table array, 4 worse conditions in the future use, as shown in Figure 7 are chosen for numerical analysis.

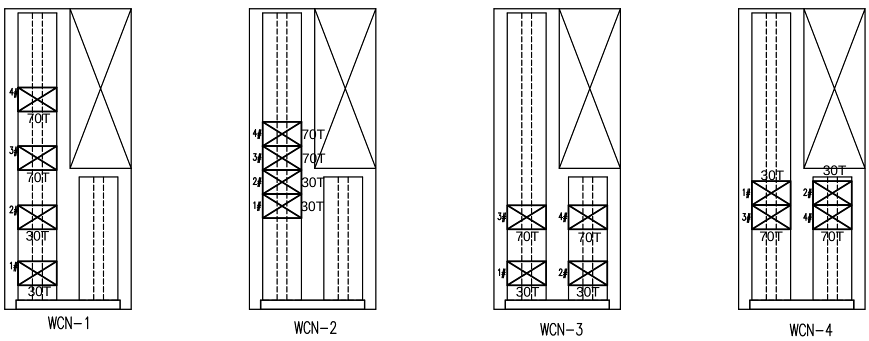

Figure 7:4 Worse conditions for analysis

The time history as shown in Figure 4 with peak value 1.5g is set as the input excitation. And the maximum total mass is 200T for 4 tables. Figure 8 and 9 demonstrate the vibration attenuation of peak acceleration on line A and B on the concrete foundation and the soil under condition WCN-2. On the concrete part, the vibration will reduce by half and more in a distance of about 20 meters away and can be attenuated effectively by the concrete foundation. In the soil region, which is 30m outside the concrete part, the vibration level is lower than the level of ground borne vibration.

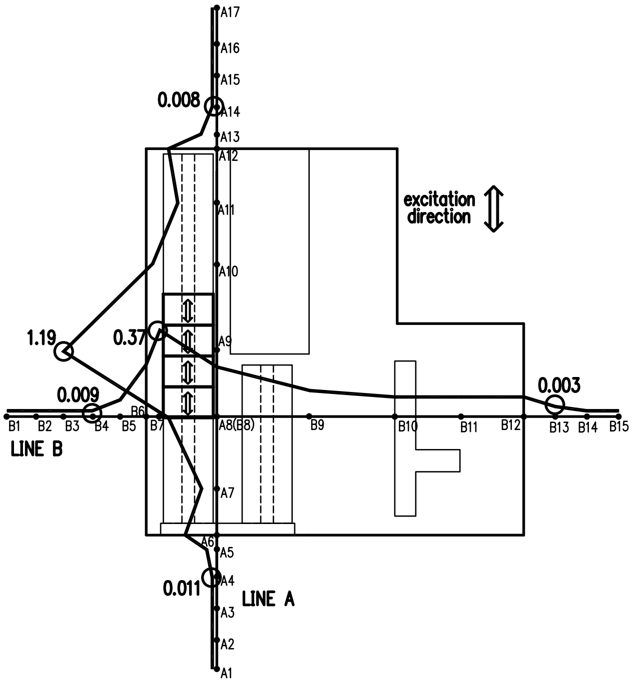

Figure 8: Peak longitudinal acceleration along line A and B for condition WCN-2(unit:m/s^2)

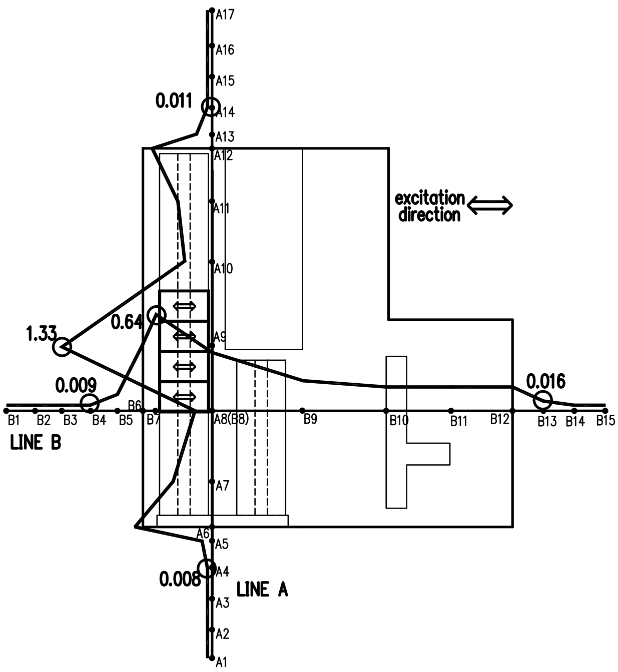

Figure 9: Peak transverse acceleration along line A and B for condition WCN-2 (unit:m/s^2)

In Figure 10, the peak acceleration in transverse and longitudinal direction on some key points on the edge of concrete part and the soil nearby for different conditions are labeled. The west region of the long trench is the area of concrete foundation with large vibration influence on it as it is near the acting points of the shaking tables. Despite the relative large excitation level comparing with the site test condition, the attenuation of vibration on the concrete base is still significant as the possible peak acceleration on the edge is less than 10% of the peak value of the input excitation. And the peak acceleration of the soil in the outside 10 meters from the concrete part is reduced to the level of 0.1-0.2m/s^2. This means very little influence of vibration induced by shaking table array on the surrounding environment.

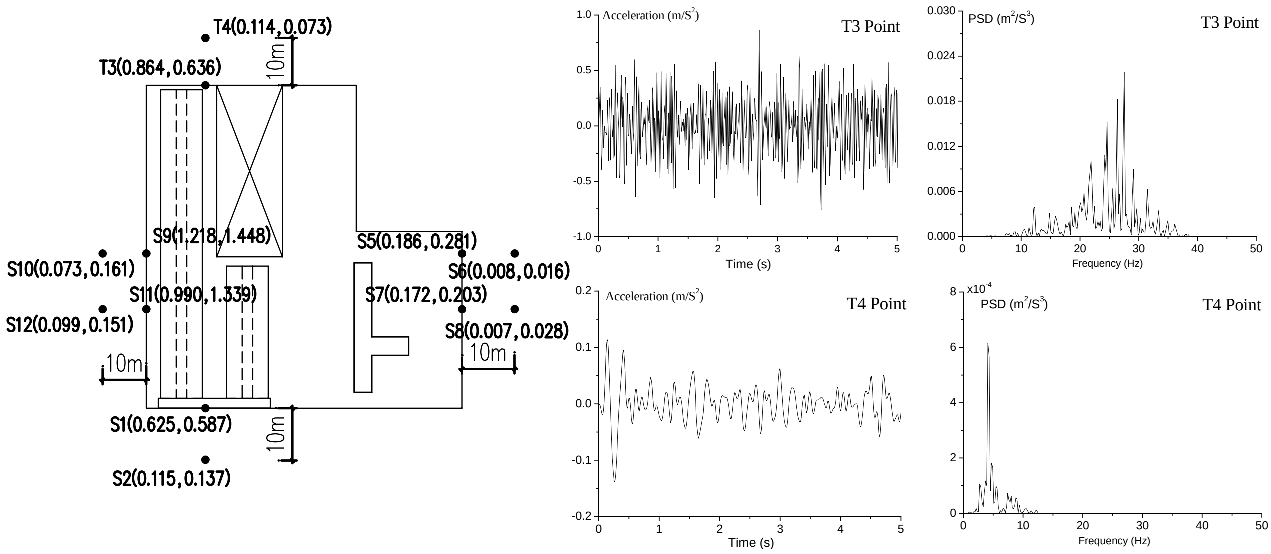

Figure 10: Peak acceleration and transverse acceleration of T3 and T4 (unit:m/s^2)

(Figures in brackets denote the peak acceleration in transverse and longitudinal direction.)

5. CONCLUSION

Vibration induced by the shaking table array is studied in this paper. Both the ground borne vibration and the vibration excited by a small table are tested in site. And the finite element method is used for further analysis of vibration excited by the shaking table array in different conditions of normal service. It is seen that the vibration can be attenuated effectively on the concrete part and the level of acceleration in the soil region about 30m away from the concrete part can be neglected. The scheme of large mass foundation for vibration reduction is proved to be effective and the design requirement is satisfactory met.

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