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Experimental Study on the Model of Separated Vibration-Isolation Foundation under Impact Loading

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Abstract

This study aims to investigate the vibration response of the foundation soil under impact loading through model experiments and to analyze the influence of the rubber vibration-isolation layer on the dynamic response of the soil. Based on actual engineering conditions as the reference prototype for the experiments, a concrete foundation model was designed, and accelerometers were reasonably arranged. Impact loading was applied by dropping a weight from a certain height. By comparing the data from two sets of experiments with and without the vibration-isolation layer, the influence of the vibration-isolation layer on the vibration response of the soil was revealed.

Keywords

Impact Loading; Foundation Vibration; Vibration Isolation.

1. Introduction

With the rapid development of China's economic construction and the accelerated urbanization process, various types of ultra-large, specialized, and high-precision novel machinery and equipment have been growing rapidly. The project under discussion is a foundation engineering for a certain project, which falls under the infrastructure construction of a large-scale precision laboratory. The equipment within the laboratory often involves high-precision measurements, high-speed rotating machinery, or conditions subjected to impact loading; therefore, the foundation may be subjected to significant dynamic loads. Given that the laboratory houses a variety of precision instruments, the mutual vibration influence among them cannot be ignored, especially under strong impact loading. The vibration of the foundation may propagate outward through the foundation soil, potentially affecting the surrounding environment. The installation of vibration-isolation bearings or flexible cushion layers can achieve effective vibration isolation and damping effects[1][2]. Song Xiangrui[3] et al., based on engineering case studies, found that laying vibration-isolation pads at the base and installing steel spring supports both offer good vibration isolation effects, and they concluded that laying vibration-isolation pads at the base is more suitable for general engineering applications. Ye Jun[4]et al. observed a significant reduction in the vertical vibration of the self-compacting layer and the base after adding a vibration-isolation layer beneath the prefabricated track slab, which effectively mitigated the propagation of wheel-rail vibrations to the surrounding environment. For this foundation engineering under impact loading, a vibration-isolation layer is applied at the base of the foundation to reduce the vibration impact caused by the dynamic loads on the surrounding environment.

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2. Experimental Program

2.1 Similarity Relationships of the Model

2.1.1 Similarity Theory

Since real-world engineering projects are typically large-scale and impractical for direct experimental data acquisition, model tests are necessary for experimental research. Similarity theory, as one of the essential theoretical foundations for structural dynamics model tests, plays an irreplaceable role in model testing. Its core objective is to construct scaled-down models that satisfy specific similarity relationships to replace the prototype for experimentation. According to the first, second (π theorem), and third theorems of similarity in model test design[5][6], when all these similarity conditions are met, the results obtained from model tests, when multiplied by the similarity constants, can reflect the dynamic response of the prototype structure.

2.1.2 Similarity Relationships

When determining the geometric similarity ratio for the model tests, it is necessary to consider factors such as the dimensions of the prototype and select appropriate similar materials based on the similarity relationship of the elastic modulus. However, in practice, it is extremely difficult to ensure that every parameter of the model perfectly meets the required similarity relationship with the actual prototype. Therefore, in the process of this model test study, some non-critical factors were intentionally downplayed. The relevant physical parameters of the model and the prototype need to satisfy the similarity relationships. After a comprehensive consideration of all factors, geometric dimensions, density, and elastic modulus were determined as the primary control variables, while other physical quantities were derived using similarity theory and dimensional analysis. The similarity relationships for the model tests are shown in Table 1 below.

Table 1. Similarity Ratios of Physical Quantities for the Scaled Model

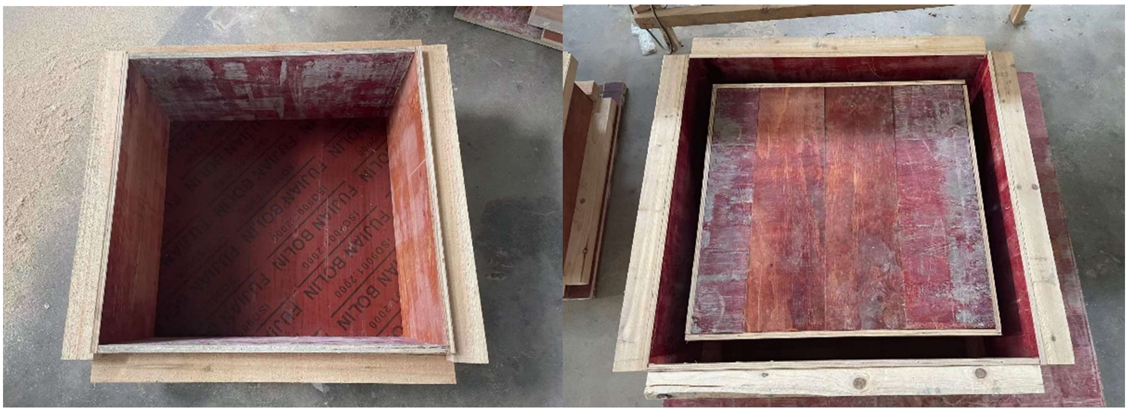
Physical Quantity	Similarity Relationship	Similarity Ratio
Elastic Modulus (E)	C_E	1
Density (ρ)	C_ρ	1
Geometric Dimension (l)	C_l	25
Load (F)	$C_F=C_EC_l^2$	625
Mass (m)	$C_m=C_EC_l^2$	625
Structural Vibration Frequency (f)	$C_f=C_L^{-1/2}$	0.2
Time (t)	$C_t=C_l^{1/2}$	5
Strain (ε)	$C_\varepsilon=1$	1
Stiffness (k)	$C_k=C_EC_l$	25
Damping (c)	$C_c=C_EC_l^{2/3}$	8.55
Displacement (u)	$C_u=C_l$	25
Velocity (v)	$C_v=C_l^{1/2}$	5

2.2 Model Design and Fabrication

The scaled model was fabricated based on the design parameters, and the main process was divided into four stages:

(1) Fabrication of Structural Formwork

Appropriate wooden formwork was selected and cut into side panels and base panels using a saw. The edges were then smoothed. Wooden beams were used to fix around the formwork to provide stable support and reinforcement, preventing damage to the mold during concrete pouring. The dimensions of the foundation mold were 0.6 m × 0.6 m × 0.3 m. The excavation mold was fixed in an inverted position, with a base plate thickness of 0.05 m and a wall thickness of 0.05 m, as shown in Figure 1.



(a) Photographs of the Foundation Formwork (b) Photographs of the Excavation Formwork

Figure 1. Fabrication of Wooden Formwork

(2) Mixture Proportion Design for Structural Concrete

In accordance with the "Code for Design of Ordinary Concrete Mix Proportions"[7], and considering the required workability, the design mix proportion for the foundation concrete (Grade C40) was determined as: cement:sand:gravel:water = 1:1.224:2.276:0.4. For the excavation concrete (Grade C30), the design mix proportion was determined as: cement:sand:gravel:water = 1:1.07:2.04:0.5.

(3) Concrete Pouring and Curing

After determining the mix proportions, the required quantities of cement, sand, gravel, and water for pouring the structure were calculated. The materials were mixed using a concrete mixer. Before pouring, the formwork was moistened with water to prevent adhesion between the concrete and the mold, which could lead to difficulties in demolding. The freshly mixed concrete was then poured into the mold and compacted using a vibrator to achieve the desired shape. Following the pouring process, the test foundation and excavation were cured for 28 days using the natural curing method, with plastic film wrapped around the structure to maintain moisture. The formwork was removed after 48 hours of curing.

(4) Soil Excavation and Structure Placement

In the experiment, if the model box test method is adopted, the limited size of the model box inevitably leads to the reflection of vibration waves as they propagate towards the surrounding and bottom boundaries. These reflected waves, when returning to the model soil layer, will interact with the original vibration waves in complex ways, either superimposing or interfering with them. This phenomenon undoubtedly affects the accuracy and reliability of the experimental results to some extent. In comparison, conducting the test in an open area can reduce the interference caused by boundary-reflected waves and accurately capture the acceleration of the foundation soil under impact loading. Given these considerations, the current experiment ultimately opted for an outdoor test. The

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well-cured concrete structure was placed at the designated location, as shown in Figure 2. After the structure was placed, excess soil and debris generated during excavation were removed to ensure the site was clean. The area was then leveled and compacted using a shovel.

Figure 2. Placement of the Model

2.3 Arrangement of Testing Equipment and Sensors

(1) Testing Equipment

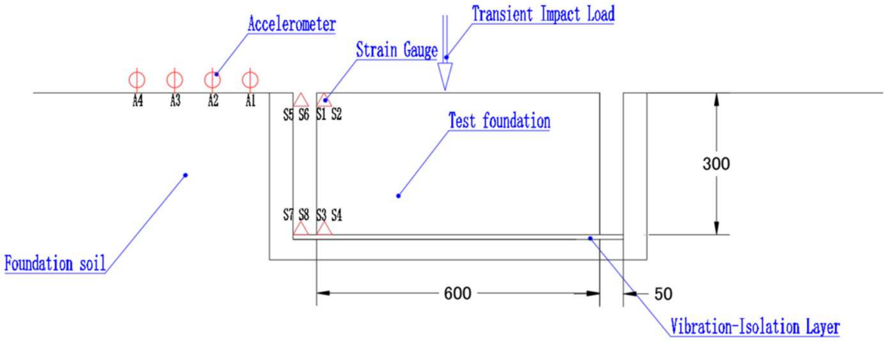
Strain gauges of model BFH120-50AA-R1-P300 were used, with dimensions of 55.5 mm × 5.5 mm for the gauge body and 50 mm × 4 mm for the grid size, and a sensitivity of 2.0. These gauges were employed to measure the strain in the foundation and excavation. A 941B-type geophone was used to capture the vibration acceleration of the foundation soil.

In the simulation tests, a 63.5 kg drop hammer from a dynamic probe was used to freely fall from a specific height. According to the principle of conservation of momentum (Ft = mv), the magnitude of the impact force can be adjusted by controlling the falling height of the hammer. In this study, the similarity theory was applied to derive the scaling constants for the model, and the impact load was calculated to be approximately 10 kN. The DH5922N dynamic signal testing system was used to measure the scaled specimens.

(2) Sensor Arrangement

To capture the strain response characteristics of the foundation and excavation under impact loading, strain gauges were installed at eight locations: the upper and lower middle sections of the foundation and excavation, and the upper and lower sections of the side walls. The strain gauges were labeled as S1 to S8. To determine the maximum principal strain in the foundation and excavation, the strain gauges were arranged in a 45° triaxial rosette configuration.

In the model test, to obtain the acceleration response characteristics of the foundation soil, four acceleration measurement points were set along the horizontal direction of the soil layer, labeled as A1 to A4. The arrangement of the measurement points in the model test is shown in Figure 3.



(a) Cross-Sectional View of Measurement Points

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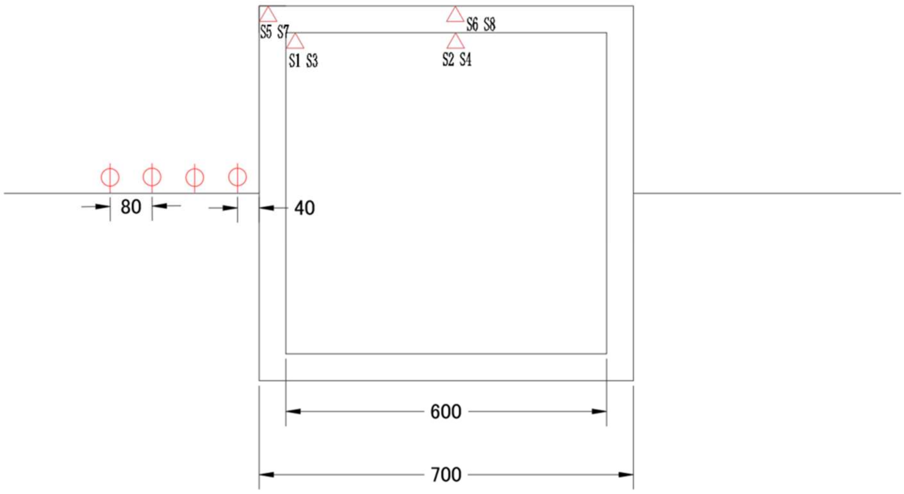

(b) Plan View of Measurement Points

Figure 3. Layout of Measurement Points

3. Analysis of Test Results

3.1 Propagation and Attenuation Characteristics of Vibration Waves

To verify the propagation characteristics of vibration waves in foundation soil and investigate the vibration response of foundation soil under impact loading on the foundation, the acceleration data from measurement points A1, A2, A3, and A4 along the central axis of the foundation soil were selected for analysis. The acceleration response time-history curves for each measurement point are shown in Figure 4.

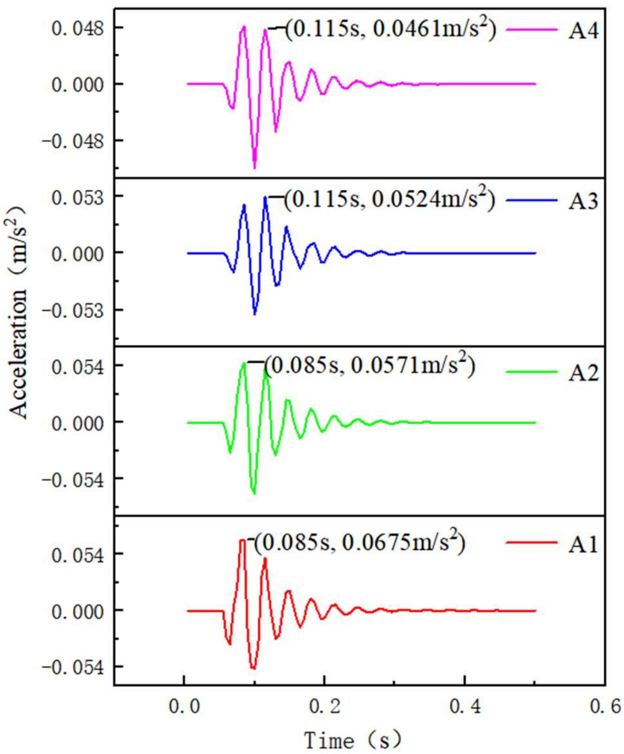

Figure 4. Acceleration Time-History Curves of Each Measurement Point

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Analysis of the above figure leads to the following conclusions regarding the characteristics of vibration propagation:

1) Under impact loading, although the magnitude and arrival time of the peak acceleration differ among different measurement points, the acceleration time-history curves for each point exhibit similar waveforms. For measurement points along the same horizontal line, the vibration waves induced by the impact loading undergo multiple oscillations within a very short time, with acceleration quickly reaching its peak and then gradually stabilizing.

2) The peak acceleration at A1 is 0.0675 m/s², occurring at 0.085 s. The peak acceleration at A2 is 0.0571 m/s², also occurring at 0.085 s. The peak acceleration at A3 is 0.0524 m/s², occurring at 0.115 s. The peak acceleration at A4 is 0.0461 m/s², occurring at 0.115 s. For measurement points along the same horizontal line, the further the distance from the vibration source, the longer the time it takes for the acceleration to reach its peak, and the smaller the peak acceleration. After 0.2 s, all acceleration waveforms show a trend of gradual attenuation. This indicates that the energy of the impact loading in the foundation soil dissipates over time. This variation in acceleration demonstrates that the energy of the vibration waves attenuates gradually within the soil, which is attributed to the presence of soil damping.

Since the impact loading on the foundation generates vibration waves that propagate through the foundation soil with characteristics similar to those of ground vibration attenuation caused by dynamic compaction, the research findings on ground vibration attenuation due to dynamic compaction[8]can be applied. The following formula can be used:

$$A = kR^{-\alpha}\alpha$$

In the formula:A represents the peak acceleration;k is the equivalent coefficient, which is related to the site conditions and the compaction energy;R is the distance from the vibration source;α (alpha) is the attenuation coefficient.

This formula effectively fits the attenuation characteristics of the vibration waves generated by impact loading in the foundation soil.

The peak acceleration data were fitted using the above formula, and the results are shown in Figure 5, with the detailed regression curve parameters listed in Table 2.

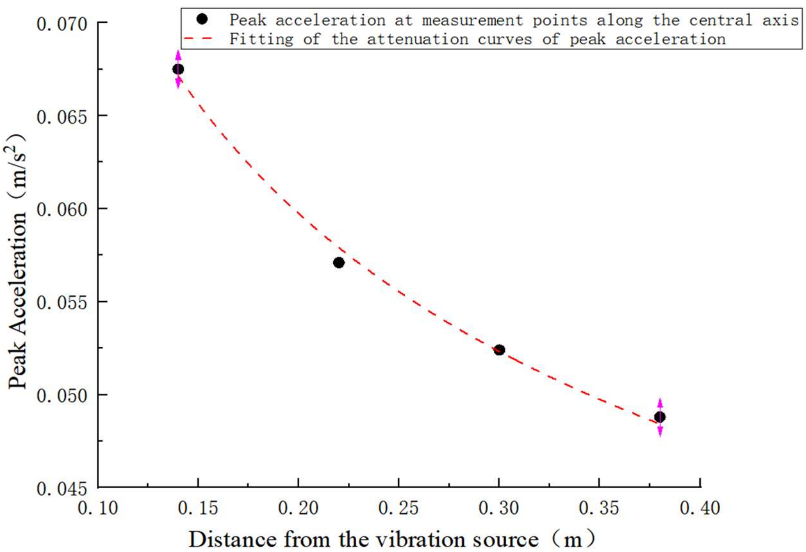

Figure 5. Attenuation Curves of Peak Acceleration at Measurement Points

Table 2. Parameters of the Regression Curves

k	α	Correlation Coefficient
0.108	0.327	0.99

The results show that Equation (3.1) provides a good fit to the experimental data. Under impact loading, the peak acceleration at each measurement point decreases with increasing distance from the vibration source, and the correlation coefficient reaches 0.99. This indicates that the curve obtained through data fitting essentially conforms to the power-law attenuation rule. Additionally, the following conclusions can be drawn from the fitted curve: within the region close to the vibration source, the decline in peak acceleration is relatively large; however, beyond a certain range, the decrease in peak acceleration becomes more gradual.

3.2 Analysis of the Vibration-Isolation Effectiveness of the Vibration-Isolation Layer

As shown in Table 3, the implementation of a vibration-isolation layer significantly reduces the vertical peak acceleration of the foundation soil. The calculation results indicate that the peak acceleration at all measurement points decreases markedly when a vibration-isolation layer is present, with reductions ranging from 54.12% to 64.64%. This demonstrates the highly effective role of the vibration-isolation layer. Among them, the measurement point A1, which is closest to the vibration source, exhibits the largest reduction of 58%, indicating a significant vibration isolation effect. The closer the location is to the vibration source, the better the vibration isolation effect of the layer, and the greater the reduction in peak acceleration. Conversely, at locations farther from the vibration source, the vibration energy induced by the impact loading has already been significantly attenuated due to soil damping, resulting in less noticeable vibration isolation effects.

Vibration-isolation layers are typically composed of materials with high damping characteristics. When an impact load is applied to the structure, the layer can absorb and dissipate energy through internal friction and deformation within the material. This energy dissipation mechanism reduces the amount of energy transmitted to the internal measurement points of the structure, thereby lowering the peak acceleration. The vibration-isolation layer acts like a buffer, converting the energy generated by the impact load into other forms (such as heat) to prevent it from being directly transferred to the foundation soil. This ultimately protects the surrounding foundation soil and adjacent structures from excessive dynamic responses.

Table 3. Summary of Peak Acceleration Values

Measurement Point	A1	A2	A3	A4
Without Vibration-Isolation Layer(m/s^2)	0.0675	0.0571	0.0524	0.0461
With Vibration-Isolation Layer(m/s^2)	0.0282	0.0262	0.0251	0.0238
Reduction	58%	54%	52%	48%

4. Conclusion

Based on the dynamic model test data, the dynamic response characteristics of the foundation soil surrounding the foundation with a rubber vibration-isolation layer were analyzed. It was concluded that under impact loading, the implementation of a vibration-isolation layer can effectively reduce the acceleration of the surrounding foundation soil, thereby providing significant protection to the surrounding environment.

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References

[1] Pan,P,Shen,S.,Shen,Z,Gong,R.(2020).Experimental vestigation on the effectiveness of laminated rubber bearings to isolate metro generated vibration. Measurement, (in press).

[2] Xu,Y.L.,Li,B.(2010).Hybrid platform for high-tech equipment protection against earthquake and microvibration. Earthquake Engineering and Structural Dynamics, 37(5), 747-767.

[3] Song Ruixiang, Zhang Xuegang, Sun Guodong, et al. Application of two types of vibration isolation foundations in property development along the subway line. Noise and Vibration Control, 2018, 38(05): 156-161+172.

[4] Tan Hanhua, Sun Jinzhong, Qi Shengwen. Study on the attenuation law of dynamic compaction vibration. Engineering Investigation, 2001 (05): 11-14.

[5] Chen Zhe. Dynamic Response Analysis of Structures Based on Similarity Theory and Model Testing [D]. Jiangsu: Nanjing University of Aeronautics and Astronautics, 2012.

[6] Wu Tian. Research on Similarity and Scaled-Model Design Methods in Impact Dynamics [D]. Jiangsu: Nanjing University of Aeronautics and Astronautics, 2019.

[7] JGJ 55-2000, Code for Design of Ordinary Concrete Mix Proportions [S].

[8] Tan Hanhua, Sun Jinzhong, Qi Shengwen. Study on the attenuation law of dynamic compaction vibration. Engineering Investigation, 2001 (5): 11-14.