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Study on vibration isolation effect of different vibration isolation structures

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Abstract

This study investigates the effectiveness of open, EPS-filled, and sand-filled trenches in isolating ground vibrations using the finite element numerical sim-ulation method. A three-dimensional finite element model was established to analyze the attenuation of vibration acceleration induced by different barrier types. The isolation performance was evaluated based on the amplitude attenua-tion coefficient and the average amplitude attenuation coefficient. The results indicate that the vibration isolation effect of all three trench types decreases approximately linearly with increasing distance from the vibration source, with better performance observed in the near field compared to the far field. Under identical conditions, the open trench provides the best overall vibration isola-tion, followed by the EPS-filled trench, while the sand-filled trench performs the least effectively. The corresponding average amplitude attenuation coefficients are 0.823, 0.686, and 0.626, respectively. Further analysis reveals that filling material reduces the barrier's isolation efficiency, particularly in the far field, where vibration attenuation remains significant but the relative isolation effect is diminished.

Keywords

vibration isolation; open trench; filled trench; finite element method; ground vibration

1. Introduction

Environmental vibration, recognized as one of the seven major public nuisances, primarily originates from transportation, industrial production, and construction activities. Such vibrations propagate through surface media, leading to structural and cumulative damage in buildings, while seriously disrupting the normal operation of precision instruments. Moreover, long-term exposure to a vibratory environment adversely affects human health and significantly reduces quality of life. With the rapid expansion of high-density rail transit networks—such as high-speed railways and subways—in China, problems associated with large-scale and high-intensity vibration have become increasingly prominent, posing serious challenges to the vibration-sensitive environments along these corridors.

Numerous scholars have conducted research on vibration isolation barriers, employing field tests, model experiments, and numerical simulations for analysis . In field testing, Liu evaluated the vibration isolation effect by installing an open trench along a section of the Zhengzhou–Xi'an high-speed railway. When high-speed trains pass over the viaduct, the vibration exhibits uniform and stable surface-wave propagation characteristics. The installation of a vibration isolation trench significantly inhibits ground vibration behind the barrier, demonstrating a notable isolation effect. Similarly, Toygar performed a series of full-scale field tests to examine the influence of control parameters on isolation efficiency. Ground vibrations generated artificially in the field were measured using high-sensitivity accelerometers. Their results indicate that vibration frequency has a greater impact on the screening effectiveness than the actual depth of the barrier. Improved vibration isolation is achieved in areas close to the trench, whereas the effect diminishes with increasing distance. Alzawi conducted full-scale field tests to investigate the vibration isolation performance of both open trenches and geofoam-filled trenches, as well as the influence of trench geometry and source location on isolation effectiveness. Experimental results indicate that both open and geofoam-filled trenches can effectively reduce transmitted waves. With increasing normalized distance, the isolation performance of the open trench decreases, whereas that of the geofoam-filled trench remains relatively stable. In terms of model testing, Liu performed field experiments on Rayleigh wave isolation in a sandy foundation to examine the shallow vibration isolation effect of micro-trenches. The study analyzed how the geometric dimensions and position of such trenches affect isolation performance. Results show that trench depth has a significant influence on vibration reduction, while trench width and length have minor effects. The location of the micro-trench also plays a notable role in determining isolation effectiveness. To compare the performance of open trenches and pile rows under identical conditions in sandy soil, Liu carried out outdoor tests with controlled source distance and barrier depth. The findings demonstrate that open trenches provide significantly better vibration isolation than pile rows. When source distance and barrier depth are fixed, the isolation effect of both measures improves with increasing excitation frequency. Using centrifuge modeling, Baziar studied the propagation and mitigation of ground vibrations induced by high-speed railways. Geofoam barriers were tested in various configurations—single and double layers—at different locations. The results reveal that a single geofoam barrier can reduce ground vibration by up to 54.5%, while a double-layer configuration further reduces vibration by approximately 14–35% compared to a single layer and mitigates the poor performance observed at low input frequencies. In terms of numerical simulation, Li investigated environmental vibrations induced by subway train operations and corresponding mitigation measures. A finite element-infinite element coupled tunnel-soil model was established to analyze the vibration acceleration amplitudes at different locations on the ground surface. The study compared the vibration isolation effectiveness of open trenches and filled trenches under various conditions, including different train-load excitation frequencies, trench depths, distances from the source, and filling materials. To evaluate the isolation performance of open trenches and waste rubber tire-filled barriers in subway operational sections, Luo performed finite element numerical simulations of continuous barriers. Their analysis focused on the influence of trench depth, width, and different filling configurations using recycled rubber tires on the overall vibration isolation effect.

This study employs numerical simulation to systematically examine the vibration isolation performance of open trenches, sand-filled trenches, and expanded polystyrene (EPS)-filled trenches on ground surface vibrations.

2. Model establishment

A three-dimensional finite-element model was developed in ABAQUS to examine the vibration-isolation performance and surface-amplitude attenuation of open-, sand-, and expanded polystyrene (EPS)-filled trenches under external vibration (Fig. 1). The model measures 2.0 m (length) × 1.5 m (width) × 1.5 m (height). The soil was treated as a linear elastic material under small-strain assumptions; its parameters are listed in Table 1. A fixed boundary was applied at the bottom, and infinite elements were assigned to the lateral boundaries to minimise wave reflection and ensure reliable simulation results.

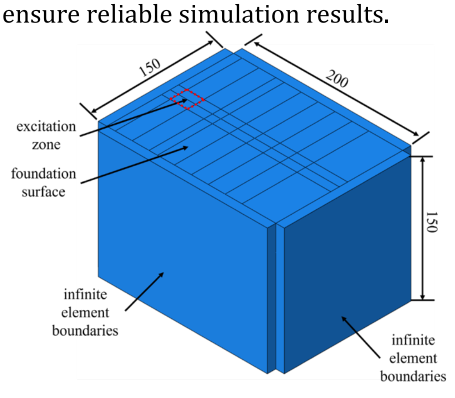
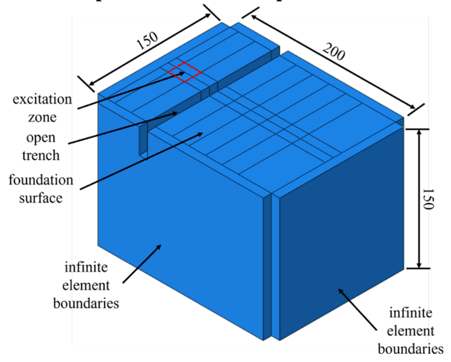


Figure 1. Measurement point diagram

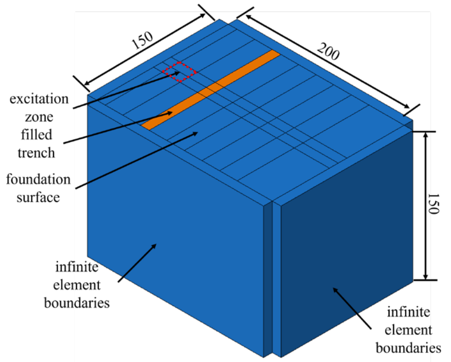
Table 1. Filler material constitutive model parameters

parameter	values
density，ρ（kg/m3）	1850
elastic modulus，E（MPa）	40
Poisson 's ratio，ν	0.35

The isolation trench was positioned 0.2 m from the vibration source, with dimensions of 1.5 m (length) × 0.1 m (width) × 0.3 m (depth), as illustrated in Figure 2. Three filling conditions were considered: an open trench, a sand-filled trench, and a trench filled with expanded polystyrene (EPS) geofoam. The corresponding material parameters are provided in Table 2.



(a) Empty trench model diagram



(b) Filled trench model diagram

Figure 2. Measurement point diagram

Table 2. Filler material constitutive model parameters

Filled material	density /kg·m-3	elastic modulus /MPa	Poisson 's ratio
EPS	18.4	4	0.05
sand	1840	20	0.2

Five measurement points were positioned at distances of 0.5 m, 0.7 m, 0.9 m, 1.1 m, and 1.3 m from the vibration source (as shown in Fig. 3) to evaluate the vibration isolation performance of the barrier structure.

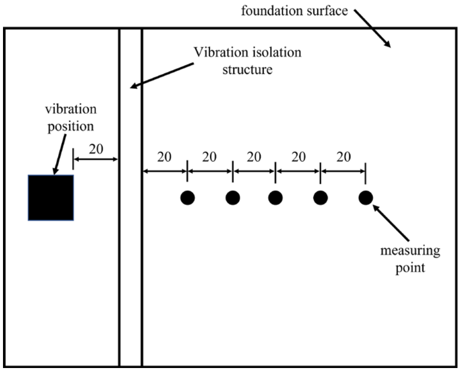


Figure 3. Measurement point diagram

3. Analysis of Effect

In order to quantify the vibration isolation effect of different vibration isolation barriers, the amplitude attenuation coefficient and the average amplitude attenuation coefficient are used to calculate. The amplitude attenuation coefficient is as follows :

$$A_r = \frac{a_1}{a_0}$$

A_r -amplitude attenuation coefficient ; a_1-Vibration acceleration when setting vibration isolation measures ; a_0-Vibration acceleration without vibration isolation measures.

The average amplitude attenuation coefficient is as follows :

$$A_R = \frac{\bar{a}_1}{\bar{a}_0}$$

A_R-average amplitude attenuation coefficient ; $\bar{a}_1$ - vibration acceleration when vibration isolation measures are set ; $\bar{a}_0$ - Vibration acceleration without vibration isolation measures.

3.1. Isolation Efficiency of Open Trench

As shown by the amplitude attenuation coefficient curve of the open trench, the coefficient remains at a high level of approximately 0.91 (ranging from 0.913 to 0.916) within the near-field region of 0.5 m to 0.7 m from the source, indicating effective vibration isolation in this zone. When the distance increases from 0.7 m to 1.3 m, the attenuation coefficient decreases linearly from 0.916 to 0.672. This trend demonstrates that the isolation performance of the open trench gradually diminishes with increasing distance from the vibration source.

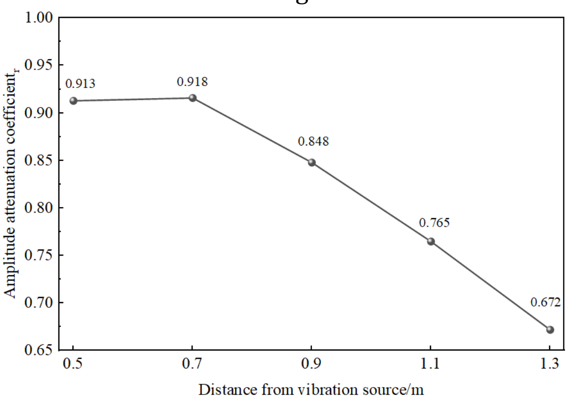


Figure 4. Amplitude attenuation coefficient curve for the open trench

3.2. Vibration Isolation Effect of the EPS-filled Trench

The attenuation coefficient curve for the EPS-filled trench indicates effective iso-lation near the source, with a value of 0.879 at 0.5 m. As the distance increases from 0.5 m to 1.3 m, the coefficient exhibits a nearly linear decline, successively measuring 0.832, 0.721, 0.542, and finally 0.454 at 1.3 m. These results demon-strate that the vibration isolation effect of the EPS-filled trench weakens with in-creasing distance, while the degree of vibration attenuation becomes progressive-ly more pronounced.

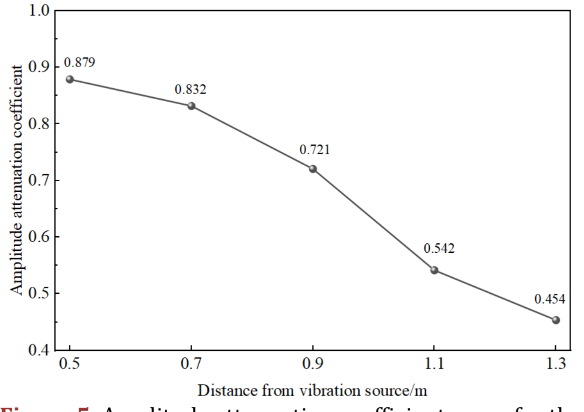


Figure 5. Amplitude attenuation coefficient curve for the EPS-filled trench

3.3. Vibration Isolation Effect of the Sand-filled Trench

The amplitude attenuation coefficient of the sand-filled trench exhibits a clear de-creasing trend with distance from the vibration source. Near the source at 0.5 m, the coefficient is 0.863, indicating effective vibration isolation at this proximal lo-cation. As the distance increases, the coefficient declines linearly to 0.781, 0.654, 0.510, and finally to 0.320 at 1.3 m. These results demonstrate that the vibration isolation performance of the sand-filled trench deteriorates significantly with in-creasing distance.

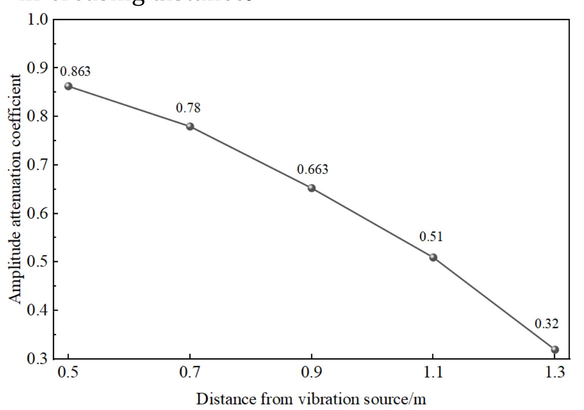


Figure 6. Amplitude attenuation coefficient curve for the sand-filled trench

3.4. Comparative Analysis

Regarding the variation in isolation performance, the amplitude attenuation coef-ficients for the open trench, EPS-filled trench, and sand-filled trench all decrease with increasing distance from the vibration source. This indicates that the vibra-tion isolation performance of all three trench types is more effective in the near-field region than in the far-field region.

A comparison among the different trench types, as shown by the attenuation coef-ficient curves, reveals that the open trench consistently exhibits the highest values, followed by the EPS-filled trench, with the sand-filled trench showing the lowest attenuation. This trend is corroborated by the calculated average amplitude at-tenuation coefficients (open trench: 0.823; EPS-filled trench: 0.686; sand-filled trench: 0.626), demonstrating that the open trench provides the best overall isola-tion, the EPS-filled trench offers intermediate performance, and the sand-filled trench is the least effective.

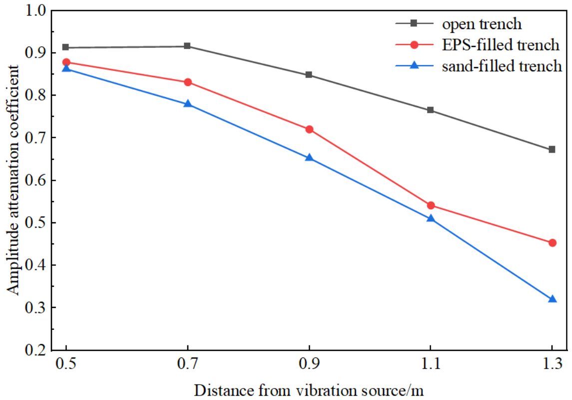


Figure 7. Amplitude attenuation coefficient (different barriers)

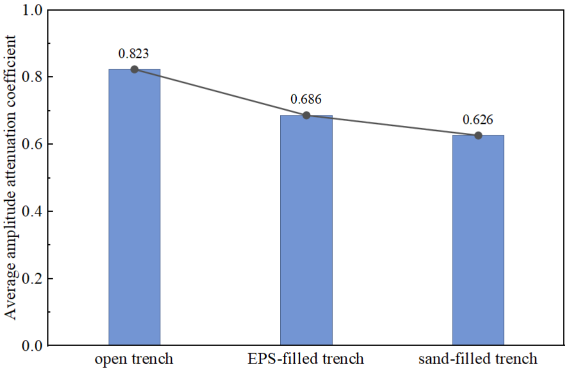


Figure 8. Average amplitude attenuation coefficient for different barrier types

4. Conclusion

Based on the variation trends and comparative analysis of the amplitude attenuation coefficient, the following main conclusions are drawn regarding the vibration isolation effectiveness of the open, EPS-filled, and sand-filled trenches:

(1) The amplitude attenuation coefficient for all three trench types decreases approximately linearly with increasing distance from the source, confirming that isolation performance is superior in the near field (0.5–0.7 m) compared to the far field (up to 1.3 m).

(2) Under identical distance conditions, the open trench consistently yields the highest attenuation coefficient, with an average value of 0.823, indicating the best overall isolation performance. The EPS-filled trench ranks second (average: 0.686), while the sand-filled trench performs the worst (average: 0.626).
(3) The filling material significantly influences the isolation efficiency. Compared to the open trench, both filled trenches show a more pronounced reduction in attenuation coefficient. Notably, in the far field (e.g., at 1.3 m), the sand-filled trench exhibits the lowest coefficient (0.320), reflecting its strong wave-attenuation capability but relatively weaker overall isolation effect in the studied configuration.

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