RESEARCH ON ISOLATION EFFECT OF VIBRATION ISOLATION TRENCH IN SOIL MEDIUM BY 1:50 MODEL TEST

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Vibration isolation barrier is a common method for impeding vibration generated by rail transit in soil medium. This research using the method of model test, detailed studied vibration isolation effect of trench in soil medium.

The scaling scale of 1:50 was adopted, and a model box of 2.1 × 1.8 × 1.5m was built up, filled with geotechnical medium prepared with proportional Beijing silty clay and sawdust. The surface hammer shock excitement point was set in the centre of model box, the vibration isolation trench was set on one side, and the vibration acceleration sensors were symmetrically arranged within a certain area on both sides (with or without the vibration isolation trench). Hammer shock excitation was used in this study, surface vibration acceleration on both sides of excitement point was recorded and compared, and the vibration isolation effect of trench in protected zone with various lengths could be analysed.

The results showed that, vibration isolation trench have soil surface vibration amplified in front of barrier (near the source point), away from the source side (in the protected zones) there is a certain range of vibration isolation effect, and the effective isolation frequency was observed ranging in 40-300Hz., in which high-frequency wave (100-150Hz) was isolated more efficient than low-frequency peak (75Hz). Furthermore, the increase of trench length (shield scope) would help to improve the isolation effect, but for the specific frequency wave, the attenuation ratio would not increase monotonically with the trench length.

Keywords: vibration isolation trench, model test, vibration isolation effect, soil medium

1. Introduction

Nowadays the environmental vibration problem caused by power machine, blasting and urban rail transit is becoming increasingly prominent. Vibration isolation barrier in the transmission route has been considered a common and efficient solution. Since the 1960s, many researchers at home and abroad have contributed mountains of meaningful exploration for isolation mechanism and effect of open or in-filled trench.

For better understanding the soil vibration isolation mechanism and more efficient barrier designing, the former scholars conducted in situ tests[1-2], or use theoretical methods[3-4] such as one-dimensional wave theory, beam deflection or the Kirchhoff diffraction theory to observe or calculate the vibration wave diffraction near the trench. Other researchers calculate the damping ratio behind the trenches with the use of finite element numerical simulation method [5-8].

However, given the inhomogeneity and anisotropy of geomaterials and complexity of the construction site, the theoretical and numerical simulation solution might not accurately present the true propagation law of vibration wave in soil. And the in situ experiments are both time consuming and labor intensive. Using model test method to explore the vibration isolation mechanism and design isolation barrier for specific project has the advantages of high efficiency and intuition, but research of soil vibration isolating on the small scale model test has been rarely reported. In this study, a 1:50 scale model was established to study the vibration isolation effect of open trench with various lengths, which hopes to bring some reference for other researchers.

2. Model test design

2.1 Model Test Box

Previous studies have shown that, when the width ratio of the free surface plane to the structural plan is greater than 5, the dynamic calculated results are stable and the boundary effect could be negligible. Considering the range of vibration isolation and other factors, the geometric similarity ratio between the model and its prototype was designed 1/50, and the model box was designed 2.1m (length) × 1.8m (width) × 1.5m (height). The model box frame was composed of angle steel, with steel diagonal braces strengthening the structure. The four sides were inserted bamboo veneer, and the bottom with steel plate.

In order to prevent the vibrating wave reflection effect produced near the boundary of the model box, four sides and the bottom were covered a layer of polyethylene foam veneer with side thickness of 5cm and bottom of 10cm.

Gravity similarity was not considered in this test as elastic similarity should be adopted. The similarity between the model and the prototype is designed taking several factors into account, including the geometric shape, the material property, the external influence (load) and the vibration response. The mass density similarity of the test model was determined C_ρ=1/2, and the similarity coefficient of elastic modulus was C_E=1/10. Then the remaining quantities could be derived according to Bockingham π theorem, as shown in Table **1**.

Table 1: Similarity of the model test

Category	Quantities	Similarity	
Geometric characteristic	length	Cl	0.02
Material characteristics	strain	$C\varepsilon$	0.02
	stress	$C\sigma$	0.1
	elastic modulus	C_E	0.1
	mass density	$C\rho$	0.5
Dynamic characteristics	time	$Ct=1/ C\omega$	0.06
	frequency	$C\omega=(C_E/C\rho)^{1/2}/Cl$	17.8
	velocity	Cv	0.4
	accelerated velocity	$Ca=C_E/(C_lC\rho)$	10.0

According to the similarity ratio, the geomaterials filled in the model box were sawdust soil (sawdust: Beijing soil: water = 1.0: 3.5: 3.0) through trial and error as Beijing silty clay was taken as the prototype. The geomaterals were layered filled and compacted with an expected mess density of 1200kg/m^3 and an elastic modulus of about 4.6MPa.

2.2 Vibration Isolation Trench

In order to compare the surface vibration response with and without the isolation measure as well as in front and behind the trench, the excitation position was set in the centre of the surface of the model box with the isolation trench on one side, and the vibration acceleration sensors were symmetrically arranged within a certain area on both sides of the vibration source (Figure **1**).

The open trench was set 20mm in width (1m in prototype), 260mm in depth, and 255mm away from the vibration source. The measuring point 1(P1) was located at 10mm in front of the trench wall (240mm from the excitation set), and point 2/4/6 (P2/4/6) were at 10mm, 260mm and 520mm behind the trench wall (270mm, 520mm and 780mm respectively from the vibrating source), which could present the attenuation right behind the isolation measure. Point 3 was 150mm from point 4, which could be used to observe the screening area after trench length varied.

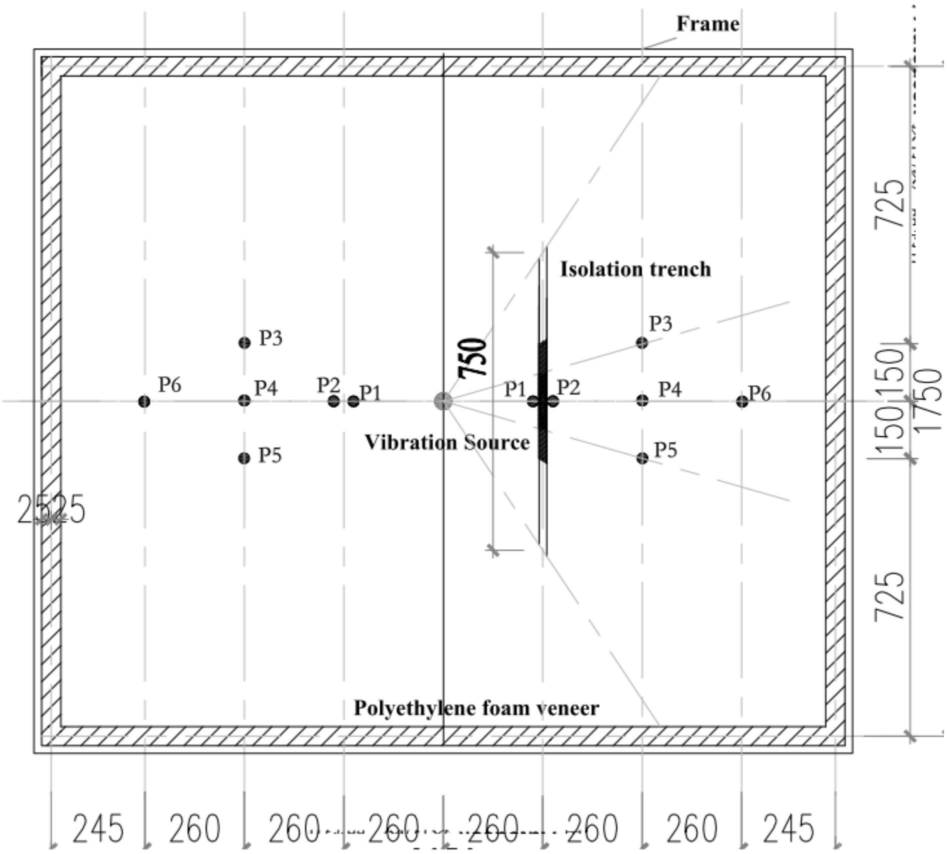

Figure 1: Position of measure points

The trench length perpendicular to the wave propagate were varied to observe the influence of the physical dimension of isolation trench on the vibration isolation effect. The adopted lengths were 150mm, 300mm, 520mm, 600mm and 750mm.

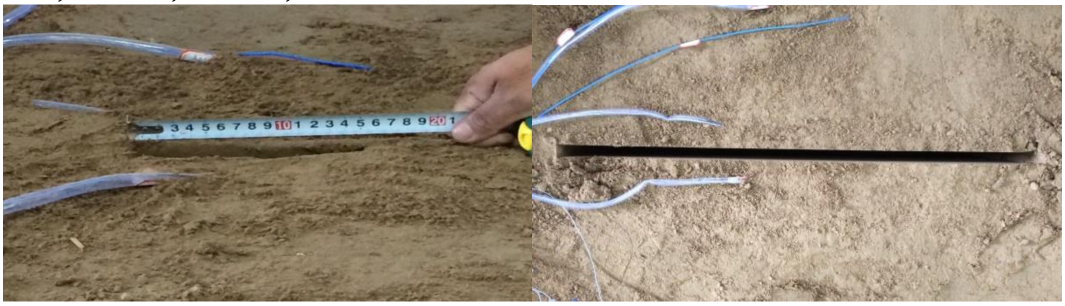

Figure 2: Photo of the open isolation trench

The surface hammering method was adopted, and an iron pad was set at the hammer point to prevent surface destruction. A hammer of PCB 086C01 was used with iron head to ensure the excitation of high frequency vibration. Lightweight vibrating acceleration sensors of PCB 352C22 with were used with waterproof treatment.

3. Experimental results and analysis

3.1 Surface vibration attenuation without isolation trench

Figure **3** showed the vibration frequency response curve of points on the side without isolation measure. The points from the vibration source 240mm and 270mm presented vibration energy concentrated in the range of 40-300Hz, and peaks appeared in 60-180Hz. The points from the vibration source 520mm and 780mm presented higher vibration frequency response in the range of 50-180Hz.

The vibration response of the points showed a relatively uniform and gentle variation with the increase of the distance from the vibration source, which reflected the natural attenuation characteristic of the vibration wave in soil.

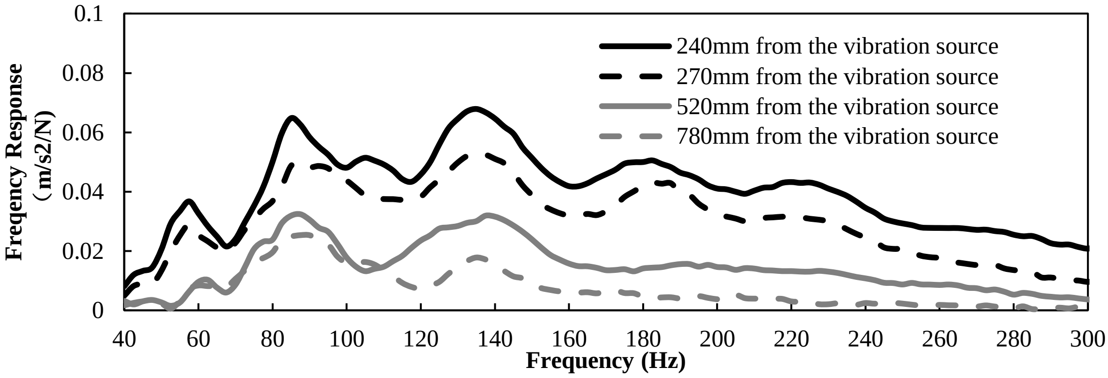

Figure 3: Vibration frequency response curve of measuring points on the side of no trench

3.2 Surface vibration attenuation with isolation trench

Figure **4** showed surface vibration frequency response curve with and without isolation trench, in which the dashed line represented the side with trench and the full line stood for the side without. For the position 240mm from the vibration source, compared to the point without isolation measure, amplification at 40-95Hz could be observed. For the position 520mm from the vibration source, the isolation trench significantly lowered the peak value of 0.031m/s^2/N to 0.012m/s^2/N at 70-160Hz, and the isolated vibration energy remained almost zero above 160Hz.

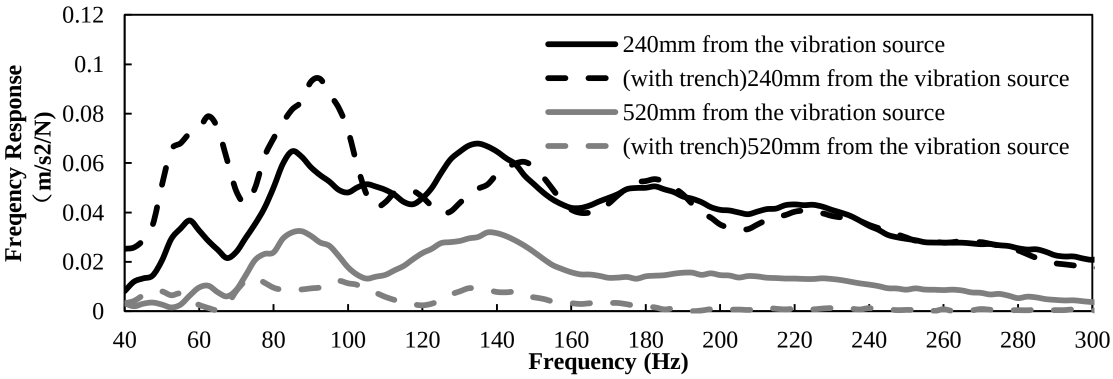

Figure 4: Vibration frequency response curve with and without isolation trench

3.3 Influence of trench length variation on the isolation effect

3.3.1 Amplification effect in front of trench

Figure **5** showed the vibration frequency response variation in front of the open trench with different lengths. At 50-100Hz, amplification in vibration response could be observed in front of trench with all lengths of 150mm-750mm. At 100-160Hz, the amplified amplitude seemed to be related with trench length. Curves of shorter trenches of 150mm and 300mm showed marked enhancement, while results at trench of 520mm and longer showed almost none increasement.

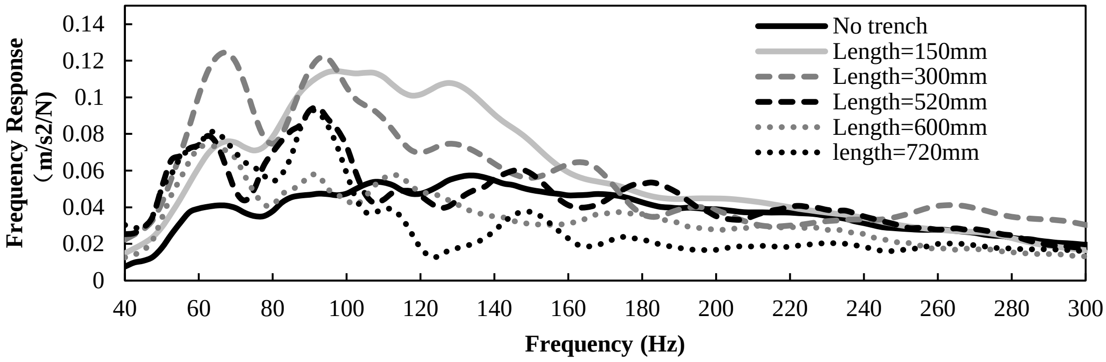

Figure 5: Vibration frequency response curve of point 1 under different lengths of trench

3.3.2 Isolation effect of point 2, 4 and 6

Figure **6** presented the vibration frequency response attenuation curves with distance at 75/100/125/150Hz with various trench length conditions, in which the vertical grey line marked the location of isolation trench.

Compared with no trench side condition, at 75Hz the vibration frequency response showed great increase at 240mm point, and the curve behind the trench seems similar under all trench conditions. While at 125Hz and 150Hz, decrease in vibration response appeared in almost all the post-trench points and the decrement showed a tendency to increase with longer trench.

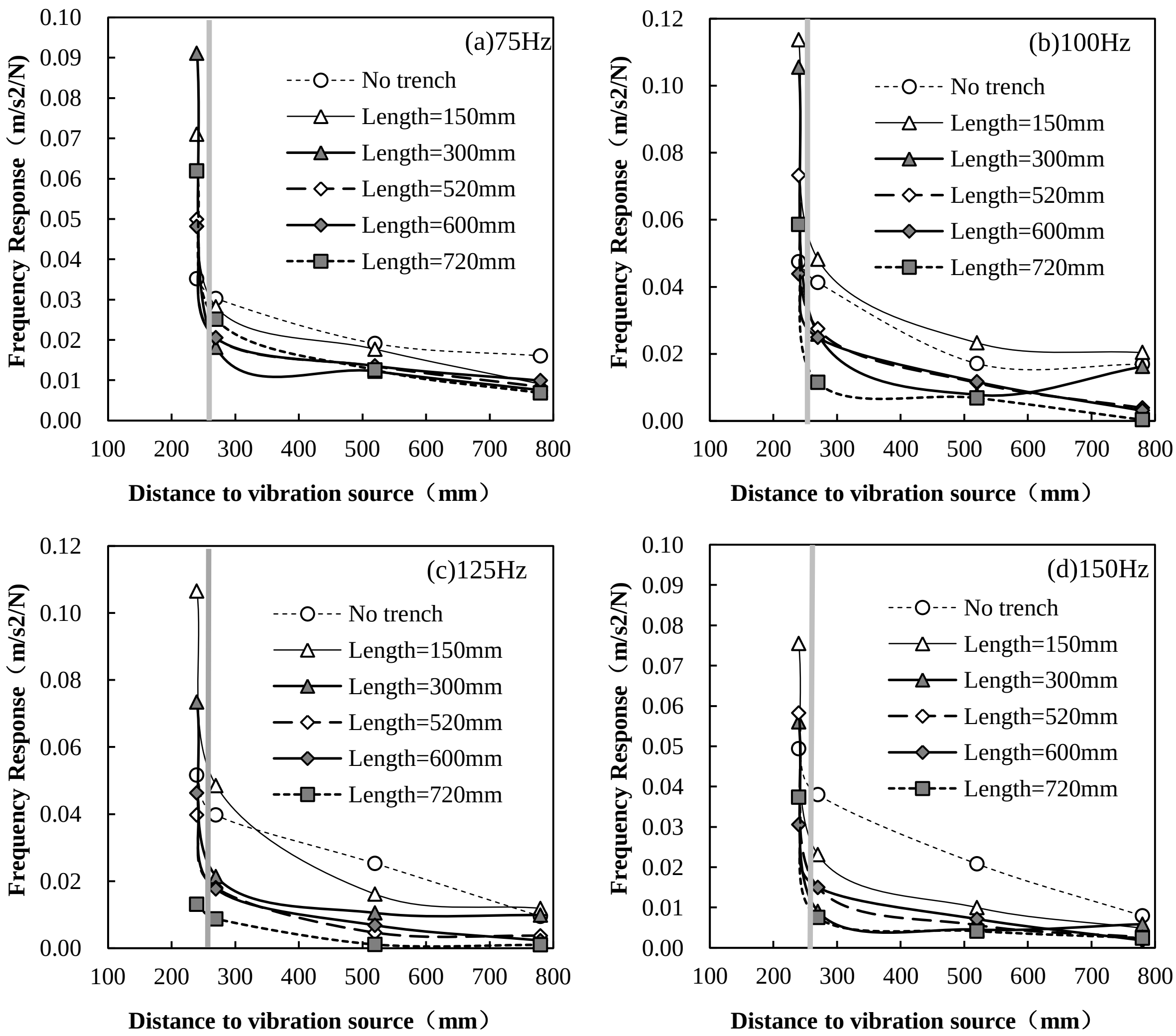

Figure 6: Vibration frequency response attenuation curve with distance from source

For better describing the isolation effect of trench, attenuation ratio was calculated as vibration frequency response of points behind the trench/vibration frequency response of symmetrical points at no trench side. Figure **7** showed the attenuation ratio variation of points right behind the trench with trench length at 75/100/125/150Hz. It seemed that at all locations, attenuation ratio of 75Hz vibration wave did not show a regular fluctuation as the trench was prolonged. At the same time, a tendency to decline with larger trench length could be observed in the attenuation ratio of vibration wave at 100Hz, 125Hz and 150Hz.

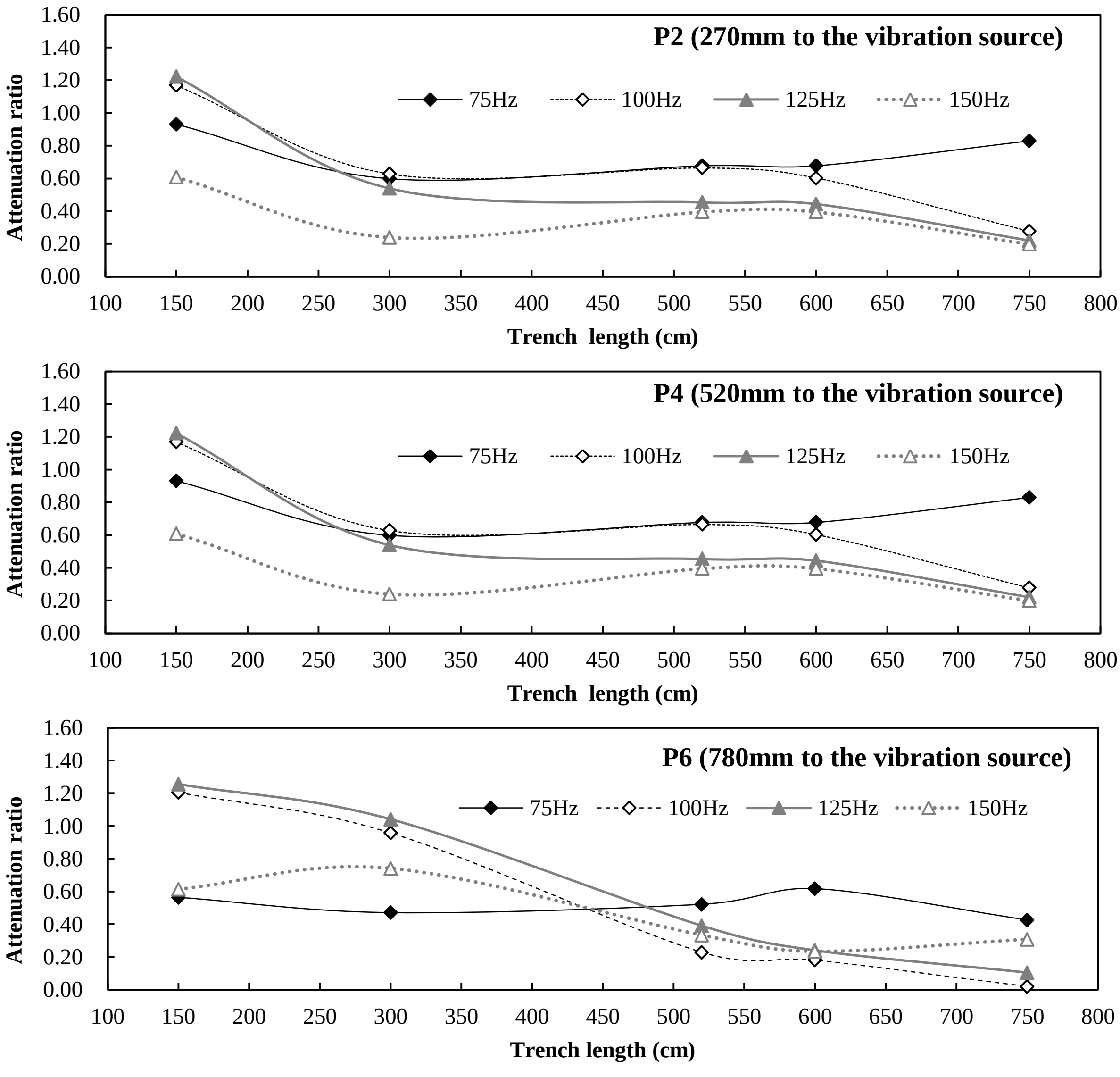

Figure 7: Variation of attenuation ration with trench length at 270/520/780mm from the vibration source

3.3.3 *Isolation effect of point 3*

Figure **8** illustrated the vibration frequency of point 3 at various trench conditions. The vibration wave at 110-300Hz could be mostly isolated under all trench lengths. When the trench was prolonged to 520mm, the 100Hz peak began to be significantly cut down. And with the trench length further increased, the 75Hz peak gradually lowered.

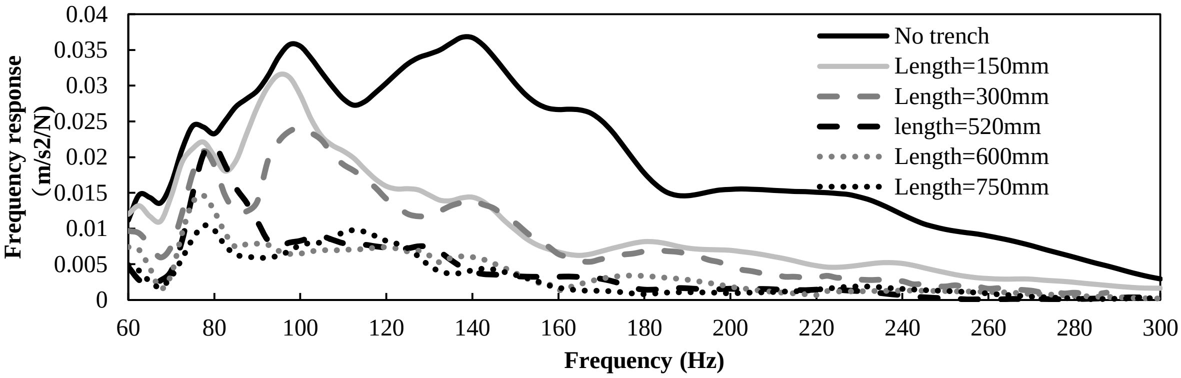

Figure 8: Variation frequency response of point3

Figure **9** illustrated the attenuation ratio variation of point 3 with trench length at 75 /100 /125 /150Hz. The result was 0.35-0.87 at 75Hz, and 0.11-0.36 at 150Hz. The trend of decrease with longer trench could be illustrated in attenuation ratio at all the frequency, but the decrease degree varied. It should be noted that the ratio was no longer reduced at 100-150Hz when the 520mm trench was prolonged to 750mm, which indicates the isolation effect might not be continually improved as shield scope enlarged.

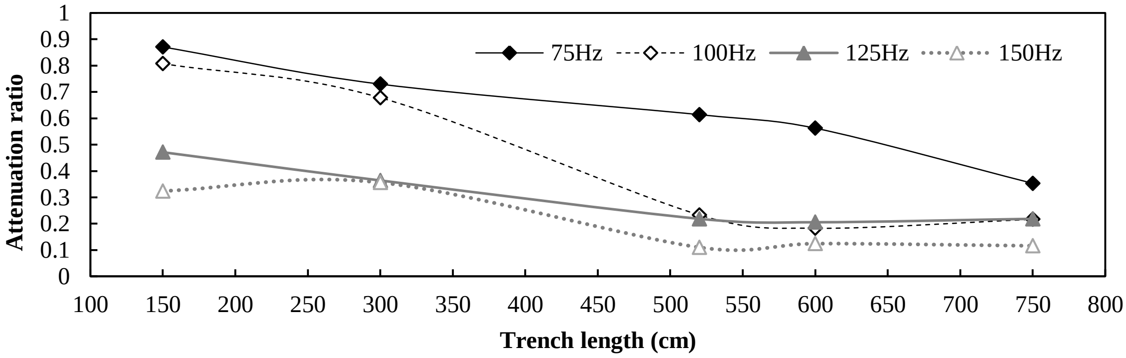

Figure 9 Variation of attenuation ratio with trench length at point 3

In this study, enhanced vibration response near the isolation trench was widely observed in various trench conditions, and the enhancement seemed more obvious near short trenches (in this study, <520mm). This phenomenon was also recorded by many other researchers, such as Lu Wen[9], Deng Yahong [8] etc., and it was generally assumed to be induced by superposition of incident wave and reflected waves in the vicinity of the trench wall.

It was also observed that the trenches has better isolation effect in high-frequency wave(100-150Hz) than low-frequency peak (75Hz) in the range of 40-300Hz in this experiment. Similar "low-pass filter" phenomenon was also observed in situ by Mao Kunming [2]. The vibration of short wavelength (high frequency) is less likely to be diffracted than long wavelength (low frequency), and could be more easily isolated by trenches and other barrier. At the same time, in this study, the isolation effect was not continually improved as shield scope enlarged, which was also consistent with large number of practical experience along the Japanese high speed rail.

Furthermore, the observed phenomenon in this model test was consistent with previous filed measurement or numerical simulation, indicating that small scale model test such as 1:50 is feasible in the study of vibration isolation mechanism. However, the calibration in quantitative relationship between model test and prototype still remains to be studied.

4. Conclusions

In this study, a 1:50 scale model test was established, and the trench isolation effect on the surface vibration wave in soil was analysed. The following conclusions could be obtained:

1. The vibration response is enhanced in front of the isolation trench, and the enhancement effect seems more obvious with shorter trenches. The isolation effect is achieved behind the isolation trench, and the ground vibration attenuation could be accelerated.
2. Behind the isolation trench, certain isolation effect could be observed in the range of 40-300Hz, in which high-frequency wave (100-150Hz) was isolated more efficient than low-frequency peak (75Hz) in this study.
3. On the whole, the increase of trench length (shield scope) would help to improve the isolation effect, but for the specific frequency wave, the isolation would not increase monotonically with the trench length.

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