Prediction of Isolation Effect on the Environment along Fuzhou Metro Using Infilled Barriers

YOU Wen-cong, XU Hang-li, ZHENG Guo-chen

***Abstract*— The typical sites along Fuzhou metro are summarized, the train-track vertical coupling numerical model is used to calculate the vibration source acceleration, and the tunnel-soil finite element model is established. The finite element model is used to predict the seismic isolation effect of the sites at different distances after different parameters are set on the transmission path.The results show that the sites along the Fuzhou metro are mainly III sites. For the typical sites along the Fuzhou Metro, the effective vibration isolation frequency bands of the rigid and flexible filling barriers are within 25Hz and greater than 50Hz respectively. 6m, the higher the height of the barrier, the better the isolation effect, but the barrier width has no obvious effect; With different filling materials, when the wave impedance ratio is far away from 1, the better the isolation effect of the barrier in the effective frequency band is. The distance between rigid packed barriers must be no less than the buried depth of the vibration source, and it is suitable for long distance isolation. The flexible packed barriers are more suitable for short distance isolation.**

***Index Terms*— Fuzhou metro，rigid filling barrier，flexible filling barrier，effective frequency band，effect of vibration isolation**

I. Introduction

Since the regular operation mode of metro and excessive environmental vibration have a great impact on the structural safety of buildings, residents' work and life, and the normal operation of precision instruments in neighboring areas, if a metro traffic network is formed in the city, the influence trend may be further enhanced [1-4]. By 2022, Fuzhou, the capital of Fujian province, has opened four subway lines, and many more are under construction and will be put into operation in the future. The environmental vibration caused by Fuzhou subway should be paid attention to.

If the vibration isolation measures are taken between the subway vibration source and the control area, the transmission of subway vibration can be cut off or the intensity of subway vibration can be reduced. At present, engineers, experts and scholars at home and abroad have studied this problem. Literature [5] concludes through numerical calculation that the low-frequency vibration attenuation of subway vibration waves below 12.5Hz is small in the soft soil layer, while the mid-high-frequency vibration attenuation above 40Hz is large. According to the transmission law of subway vibration under different site conditions, literature [6] concluded that the type of site has a significant influence on vibration wave attenuation. In literature [7], finite element method was used to block subway excitation waves by vibration barrier in adjacent areas of subway. The results showed that the vibration barrier could effectively reduce the vibration intensity, but it was significantly related to the location and material properties of the barrier. In literature [8], waste tires are filled with barriers for vibration isolation, and the results show that this material can provide high-quality vibration isolation effect within a certain frequency range. In literature [9], three-dimensional finite element model was used to analyze the vibration isolation effect of empty gully on environmental vibration induced by subway, and the relationship between the characteristics of empty gully and the interface of layered foundation was also analyzed. The above research results show that different site conditions need different vibration isolation barriers to adapt; Although the vibration gully has been proved to have the ideal effect of vibration isolation, the structural conditions are not easy to meet in the concrete project, and the cost of support and maintenance is high. Therefore, it is necessary to carry out control prediction based on vibration isolation barrier along Fuzhou Metro with specific site conditions. It is discovered by consulting great deal of documents that the research achievements on environmental vibration control of Fuzhou Metro are rare.

In view of this, this paper summarized the typical sites along the Fuzhou Metro, selected the mature and cheap rigid and flexible materials as the filling material, and predicted the influence of environmental vibration isolation effect along the Fuzhou Metro through numerical calculation by using the filling barrier with different parameters, and obtained some useful conclusions. It can provide guidance and reference for further design and control of subway operating environment.

II. Modeling

2.1 Vehicle-Track Coupled Model

Rolling effect along longitudinal axis of track can be regarded as quasi-static, so vertical and transverse vibration of vehicle-track are the main research contents of dynamics, and base on existing research literatures, vertical excitation of the metro is greatly stronger than transverse excitation[10]. In order to stress the key points, simplify the calculation, vehicle track vertical coupled model of vibration is established for numerical analysis in this paper.

In reference [11], the train model was simplified into a 4-axis passenger car with two bogies, which was decomposed into car body, bogie and wheelset, without considering the vibration in the longitudinal axis direction of the three. The car body and bogie consider the two degrees of freedom of

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ups and downs and nod, each wheelset only considers the one degree of freedom of ups and downs, the total calculated freedom is 10. The vertical motion of subway trains can be considered as a multi-rigid system. The system equation can be obtained by applying D 'Alembert's principle to each rigid body one by one. The rail was simulated by Euler beam, the concrete supporting block was simplified into mass block element, and the rubber pads and rubber boots under the rail and supporting block were respectively simplified into spring damping element [11].

The numerical calculation model was established by Hertz nonlinear elastic contact theory, and the longitudinal coupled random vibration analysis program of rail system was compiled by MATLAB software using the six level of American irregularity spectrum. The acceleration time history response of the track bed was fitted as the subway excitation wave.

2.2 Finite Element Model of Tunnel-Soil

When the metro runs, vibration waves excited by the wheel-track cross the ballast towards the tunnel and adjacent soil. The vibration wave superposition is generated during its propagation process because different vehicle bodies go through the points in turn with metro marshalling, and that are equivalent to transient wave motion in a semi-infinite medium. So finite elements of tunnel-soil are established through adopting arbitrary 8 nodes hexahedron elements, and the layered medium model is presented to reflect the inhomogeneity along the depth of the adjacent soil. The model range, the size of finite element, the damping characteristic and the time step for integration are determined by literature [12], and the 3D consistent viscous-spring artificial boundaries are applied to model boundaries.

III. PARAMETER SETTING

3.1 PARAMETER OF VEHICLE-TRACK

According to the feasibility study report of Fuzhou Metro line 1, line 2 and line 6, the results show that in train system, B-type vehicle body is selected, the speed restricted to 80 km/h, and the train is marshalled by six vehicle bodies, and in the track structures, 60kg/m grade rail applied for the metro track, 1600 bearing blocks are laid in quota per kilometer, elastic supporting block ballastless track and DTVI2 type fasteners are also selected. The parameters of track and vehicle are shown in table 1 and table 2.

Table 1. Parameters of track

Steel rail			**Bearing block**	
Elastic modulus /Pa	Inertial moment /m^4	Mass /kg/m	Mass /kg	Spacing /m
2.1×10^{11}	3.04×10^{-5}	60	100	0.625

Table 2. Parameters of train model

vehicle		**bogie**			**Suspension stiffness**		**Suspension damping**		**Wheel set**		**Length between bogie**
mass /kg	Pitching inertia /kg·m^2	mass /kg	Pitching inertia / kg·m^2	Fixed axle spacing /m	primary /N/m	secondary / N/	primary / N·s/m	secondary / N·s/m	mass /kg	radi /	/m
4.7×10^4	1.7×10	2200	1600	2.2	0.87×10^6	0.41×10^6	6×10^4	2.2×10^5	1900	0.4	12.6

3.2 Parameter of Typical Soil

According to geological prospecting information of Fuzhou Metro line 1, line 2 and line 6,the geological conditions of the region along Fuzhou Metro are complex, where the proportion of alluvial plain(type III sites) is more than 75%. In order to describe the soil along Fuzhou Metro accurately, the most representative of typical stratum is selected with conditions of Fuzhou geologic unit, geotechnical engineering investigation reports and average depth (12m) of tunnel. The soil material properties are shown in table 3, and the distribution of site soil is shown in table 4.It is assumed that every layer of soil is homogeneous and continuous, soil layered face and bed rock surface are considered as horizontal planes, and damping ratio of the soil is 0.05.

Table 3. Material properties of soil

Soil type	**Elastic modulus /MPa**	**Passion ratio**	**density /(t/m^3)**	**Internal Friction angle/°**	**Cohesion /kPa**
Miscellaneous fill	10	0.3	1.65	10	10
silt	7.3	0.42	1.55	6.5	11.1

Silty clay	18	0.38	1.9	14	34
Medium sand	35	0.25	1.9	28	0.5
pebble	150	0.2	2.1	38	0
Strong-weathered rock	200	0.2	2.2	30	35
Bed rock	5000	0.15	2.6	45	220

Table 4. Distribution of site soil (III)

Soil layer	**Thickness /m**	**Shear Wave velocity /(m/s)**
Miscellaneous fill	2.0	124
Silty clay	4.0	156
silt	14.0	111
Medium sand	2.0	227
pebble	8.3	358
Strong-weathered rock	15.0	443
Bed rock	1.0	710

3.3 Parameter of In-filled Barriers

Flexible materials, such as flyash, foam plastic and rigid materials, such as sand gravel, concrete, are selected as Infilled Materials for barriers. Physical Properties of In-filled Materials are shown in table 5.

Table 5. Physical Properties of In-filled Materials

Material	density /kg/m^3	Elastic modulus /MPa	Passion ratio	Shear Wave velocity /m/s	Shear Wave velocity contrast	Wave impedance ratio
Fly ash	500	25	0.35	136	0.59	0.15
foam plastic	80	11.8	0.40	230	0.10	0.04
sand gravel	2100	500	0.24	310	1.35	1.44
concrete	1800	14000	0.20	1800	9.97	11.97

Note：when wave impedance ratio below 1, the material is flexible, and otherwise material is rigid.

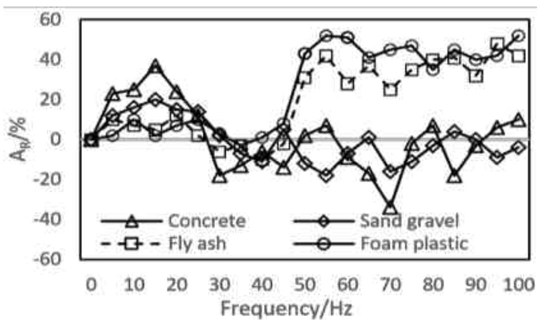
I. Analysis of Isolation Effect

To analyze the vibration isolation effect behind the barrier, AR is introduced, and the ambient acceleration of unisolated and isolated environments is defined as σ and σ ', then AR=(σ-σ ')/σ.

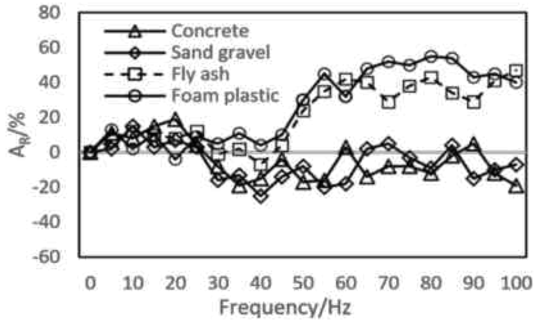
With the barrier height H, barrier width B, barrier distance L (horizontal distance from the barrier to the tunnel center) and the filling material as the influencing parameters, the above model is used to select the most unfavorable condition of 80km/h two-way passage and adjust the four parameters respectively to predict and analyze the influence of the vibration isolation effect along the Fuzhou Metro.

4.1 Filler Material

The barrier parameters are assumed, that H is 2m, B is 1m, and L is 15m, and flexible materials of flyash, foam plastic and rigid materials of sand gravel, concrete are selected as fillers for in-filled barriers. Figure 1 shows the changing curve of surface isolation effect where are behind the in-filled barrier at 2m or 10m away.



(a) 2m behind barrier



(b)10m behind barrier

Figure 1. Isolation Effects Comparison of Different Materials

From figure 1, it shows that,

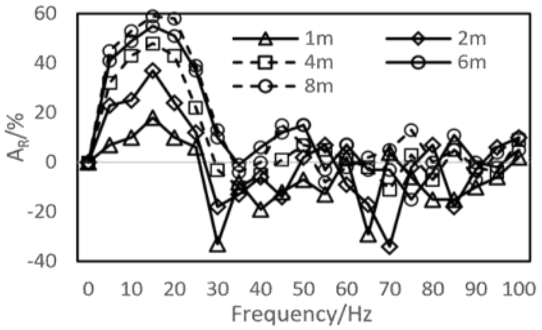
1. when the surface point is close to the barrier (2m behind barrier), the effective isolated frequency range is within 25Hz by using two rigid materials, but outside of this frequency range, in-filled barriers of rigid materials fail to cut vibration level of the surface point, even are strengthened as a trend. The effective isolated frequency range extends above 50 Hz by using two flexible materials, and the isolation effects are not obvious in the low-frequency band.

2. when the surface point is far from the barrier (10m behind barrier), by using two rigid materials, the effective isolated frequency range is in conformance with the surface point nearby, but the isolation effects significantly reduce by 90%. By using two flexible materials, the effective isolated frequency range and the isolation effects are independent on the distances between the surface point and barrier.

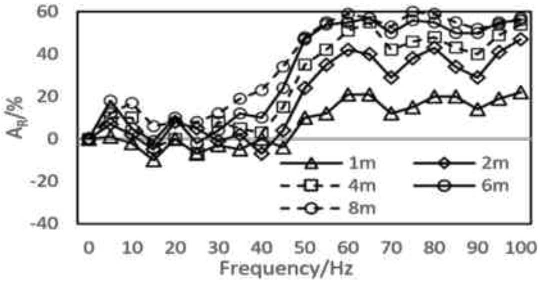
3. the isolation effects of filled concrete are superior to that of filled sand gravel, it shows that with filled rigid materials, the lower the wave impedance, the worse the isolation effect, and the isolation effects of filled foam plastic are superior to that of filled fly ash, it shows that with filled flexible materials, the higher the wave impedance, the worse the isolation effect.

4.2 Height of Vibration Isolation Barrier

The in-filled barrier parameters are assumed, that B is 1m, and L is 15m, flexible materials of fly ash and rigid materials of concrete are selected as fillers for in-filled barriers. H is between 1~ 8m. Figure 2 shows the changing curve of surface isolation effect with different depths(H) where are behind in-filled barrier at 2m away.



(a) concrete filling



(b) fly ash filling

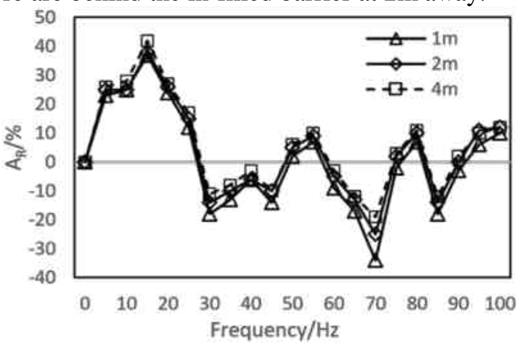
Figure 2. Isolation Effects Comparison at Different Depths of In-filled Barriers

From figure 2, it shows that,

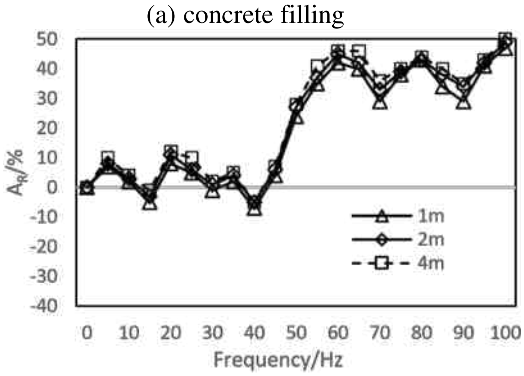
In different filling effective vibration isolation frequency bands, when the height of the isolation barrier ranges from 2m to 4m, 4m to 6m and 6m to 8m, if the isolation barrier is rigid concrete, its isolation effect increases by 89.6%, 37.8% and 4.2% on average, respectively. If the vibration isolation barrier is flexible fly ash, its vibration isolation effect increases by 84.3%, 29.7% and 3.6% respectively on average, indicating that with the increase of the height of the vibration isolation barrier, the vibration isolation effect becomes stronger, but the increase rate is slow. When the height of the barrier exceeds 6m, the increase of the vibration isolation effect is less than 5%. Therefore, it can be considered that the barrier height suitable for Fuzhou site conditions is 6m. In the other frequency bands, the increase of depth has no obvious effect on the isolation effect.

4.3 Width of Vibration Isolation Barrier

The in-filled barrier parameters are assumed, that H is 2m, and L is 15m, flexible materials of fly ash and rigid materials of concrete are selected as fillers for in-filled barriers. B is between 1~ 4m. Figure 3 shows the changing curve of surface isolation effect with different widths(B) where are behind the in-filled barrier at 2m away.



(a) concrete filling



(b)fly ash filling

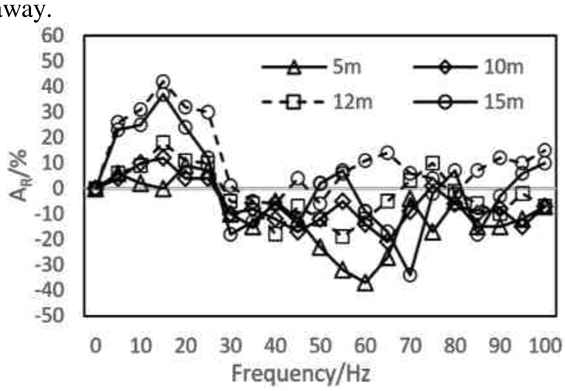
Figure 3. Isolation Effects Comparison at Different Widths of In-filled Barriers

From figure 3, it shows that,

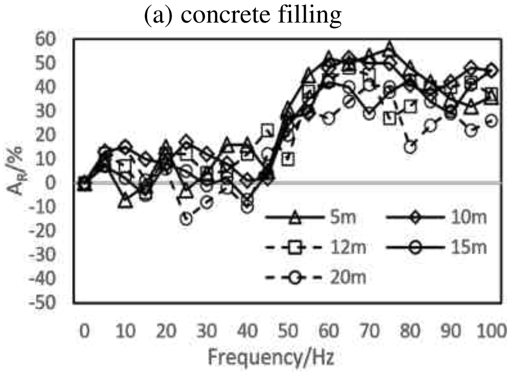
When the width of the isolation barrier varies from 1m to 2m and 2m to 4m, if the isolation barrier is rigid concrete, its isolation effect increases by 2.1% and 1.6% on average, respectively. If the vibration isolation barrier is flexible fly ash, the vibration isolation effect increases by 1.8% and 2.4% on average, respectively, indicating that when the width of the vibration isolation barrier increases, the vibration isolation effect is slightly improved, but not significantly. It can be seen that the change of the width of the vibration isolation barrier has little influence on the vibration isolation effect.

4.3 Distance between Vibration Isolation Barriers

The in-filled barrier parameters are assumed, that H is 2m, and B is 1m, flexible materials of fly ash and rigid materials of concrete are selected as fillers for in-filled barriers. L is between 5~ 30m. Figure 4 shows the changing curve of surface isolation effect with different horizontal distances (L) where are behind the in-filled barrier at 2m away.



(a) concrete filling



(b) fly ash filling

Figure 4. Isolation Effects Comparison at Different Distances of In-filled Barriers

From figure 4, it shows that,

1.For the rigid packed barrier, when the distance is less than 12m, the average vibration isolation effect is less than 10%; when the frequency is more than 25Hz, there is basically no vibration isolation effect, and there is even significant amplification. The amplification amplitude can exceed 40% near 60Hz; When the distance is greater than 12m, the vibration isolation effect is better within 25Hz, and the average vibration isolation effect can reach more than 25%, and the vibration isolation effect becomes better with the increase of the distance. However, after 25H, there is basically no vibration isolation effect, and there is an obvious amplification near the middle and high frequency. Therefore, it is more suitable for long-distance vibration isolation. According to the above calculation and analysis results, under the condition of specific site in Fuzhou, the critical distance of the rigid packed barrier is about 12m, which is also the buried depth of subway tunnel. It can be considered that the distance of the isolation barrier should be basically the same as the buried depth of the subway tunnel.

2.For the flexible packed barrier, the vibration isolation effect is more obvious when the frequency exceeds 55Hz, and the closer the barrier is, the better the vibration isolation effect is. When the distance exceeds 15m, the vibration isolation effect decreases significantly. Therefore, the flexible packed barrier is more suitable for short distance vibration isolation.

II. CONCLUSION

In this paper, the train-track vertical coupling numerical model is used to calculate the vibration source acceleration, summarize the typical sites in Fuzhou metro traversing area, establish the tunder-soil finite element model, and predict the seismic isolation effect of the sites at different distances after filling barriers with different parameters are set on the propagation path. The following conclusions are drawn:

1The site soil along Fuzhou Metro is mainly alluvial plain (type III sites).

2 The effective vibration isolation frequency bands of rigid packed barrier and flexible packed barrier are within 25Hz and greater than 50Hz respectively; For rigid and flexible filling materials, the more the wave impedance ratio is away from 1, the better the isolation effect of the barrier in the effective frequency band.

3 For typical sites along Fuzhou Metro, when the barrier height is within 6m, the higher the barrier height, the more obvious the isolation effect; Beyond 6m, the barrier height has little effect.

4 No matter what kind of filling material, the barrier width has no obvious influence on the vibration isolation effect.

5For typical sites along Fuzhou Metro, the setting distance of rigid filling barrier should not be less than the buried depth of vibration source, and only within a certain distance behind the barrier can there be ideal vibration isolation effect, which is suitable for long-distance vibration isolation; The more effective the distance of the flexible packed barrier is, the better the vibration isolation effect is. Moreover, the vibration isolation effect behind the barrier is independent of the distance, so it is more suitable for short-distance vibration isolation.

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