Experimental Research on the Vibration Absorption Performance of Medium Damping Fasteners in Metro Shield Tunnel

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Abstract. Medium damping fasteners have the advantages of low cost, easy maintenance, and convenient in gauge adjustment, etc., which are gradually and widely used in metro construction. In order to study the performance of medium damping fasteners in a driving environment, we performed measurement on site about the vertical and lateral displacement of the rail, as well as the vertical acceleration of the rail and the tunnel wall on a straight and curved metro cross-section with medium damping fasteners. By comparing with the results of ordinary fasteners, it can be seen that: (1) The medium damping fastener has a vibration reduction effect on the vertical acceleration level of the tunnel wall in the frequency range of 6.3~31.5Hz and 50~80Hz; moreover, it has a vibration reduction effect on the lateral acceleration of the tunnel wall in the frequency range of 5~31.5 Hz and 50~80 Hz. (2) The vertical and lateral displacement of the rail and the gauge change with the medium damping fasteners are larger than those of the ordinary fasteners. (3) The maximum Z vibration level measured from the tunnel wall is most suitable for evaluating the source strength of the metro, wherein the source strength of this metro line is 88.42 dB.

Keywords. Metro shield tunnel, vibration test, medium damping fastener, maximum z-vibration level, dynamic displacement of rail.

1. Introduction
In order to overcome the problems caused by metro vibration, civil engineers around the world found a variety of ways to achieve vibration absorption in metro, mainly including steel spring floating slab, vibration isolation cushion floating slab, ladder sleepers, etc. [1-3]. However, those mentioned above are often costly and is inconvenient to be maintained. As such, for cities with weak economic power or for lines with low-speed it is less cost-effective in using of the above measures. In this context, medium damping fasteners have the advantages of low cost, easy maintenance, convenient in gauge adjustment, etc., which is suitable for metro lines with medium speed or with low vibration damping requirements, and have good economic and technical effects.

Medium damping fasteners often have a form of double-layer structure, which has less rigidity and greater mass than ordinary fasteners, so as to achieve excellent damping effects [4-5]. Figure 1 is a diagram of the comparison of the two types of fasteners. Therefore, carrying out such field test is of great significance for comprehensive evaluation of the performance of the medium damping fasteners.
and design optimization thereof.

![Figure 1. Double-rubber layers of a medium damping fastener.](image)

### 2. Test Condition

#### 2.1. Metro Line Information

In order to study the rail displacement and vibration effects of medium damping fasteners under driving environment, the field tests on cross-section of a medium damping fastener and the cross-section of an ordinary fastener of a certain metro were conducted. Selecting a test cross-section in where medium damping fasteners were laying, and a test cross-section in where ordinary fasteners were laying. In both cases the cross-sections were all selected as curved sections with a curve radius of 350 m and the maximum superelevation of 120 mm. Moreover, the speed of the metro vehicle is 57km/h. Both cross-sections were in good condition to conduct such test.

#### 2.2. Arrangement of the Measuring Points

Spring-type displacement sensor was used to measure the vertical displacement of the rail, the lateral displacement of the rail head and the lateral displacement of the rail bottom. The schematic diagram of the measuring points is shown in figure 2.

![Figure 2. Arrangement of the displacement measuring points.](image)

(a) Measuring points of the rail.  
(b) Measuring points of the track slab.  
(c) Measuring points of the tunnel wall.  

![Figure 3. Layout of measuring points of the acceleration test.](image)

Meanwhile, the piezoelectric accelerometer was used to measure the vertical and lateral acceleration of the rail and of the track slab as well as to measure the vertical and lateral acceleration
of the tunnel wall. The accelerometer layout is shown in figure 3. The site layout is shown in the figure 4.

3. Data Analysis

3.1. Z-vibration Level (VLZ) and Insertion Loss

Based on the requirements in Reference [6], the vertical (Z-direction) weighting method (1~80Hz) in Reference [7] was used to analyze data related to the tunnel wall vibration. In which, the Z-vibration level (VLZ), which is currently the most commonly used evaluation index, refers to the Z-vibration level measured when a train passes through the measurement section.

Vehicle speed has a certain influence on environmental vibration. Reference [8] gives the correction formula for environmental vibration caused by different speeds:

$$C_v = 20 \log \frac{v}{v_0}$$

In which:

- $v_0$—Reference speed of a source, in km/h;
- $v$—Running speed of a train, in km/h.

Take the measurements gathered when twenty trains passed the section as the measured data, and analyze the data gathered to obtain the VLZ of the measuring points of the tunnel wall for relevant sections under both fasteners as well as the vibration difference DVLZ thereof, as shown in table 1.

**Table 1.** VLZ and DVLZ of a tunnel wall cross-section of medium damping fasteners and ordinary fasteners

| Fastener form | Damping fastener | Ordinary fastener |
|---------------|------------------|-------------------|
| VLZmax(dB)    | 80.02            | 88.26             |
| Speed(km/h)   | 57.74            | 56.69             |
| Corrected value after speed unification(dB) | 0                | 0.16              |
| Speed corrected VLZmax(dB) | 80.02            | 88.42             |
| Insertion loss DVLZmax(dB) | 8.4              |                   |

It can be seen from table 1 that after the vehicle speed is corrected to the same speed, the VLZ of the section of the medium damping fastener is significantly smaller than that of the ordinary fastener. The difference between the two is as high as 8.40 dB, which can meet the requirements of vibration reduction requirements in most area.

3.2. 1/3 Octave Analysis

Performing 1/3 octave analysis on the measuring points of the vibration damping fastener. As a result, the acceleration level in the range of 1~3000 Hz was obtained, as shown in figure 5(a). Did the same for ordinary fasteners and acceleration level was obtained, as shown in figure 5(b).

Comparing the figure 5(a) with the figure 5(b), it can be seen that the medium damping fastener has amplifying effect on the low-frequency (1-50Hz) vibration, while has little effect on the high-frequency vibration. The 1/3 octave curve of medium damping fasteners has the form of fluctuation rises from low frequency to high frequency; the 1/3 octave curve of ordinary fasteners suddenly increased in range of 31.5-50 Hz. Generally speaking, curve for medium damping fasteners is smoother.
Performing 1/3 octave analysis on the measuring points of the track slab of the vibration damping fastener and get the acceleration level in the range of 1~80Hz, as shown in figure 6(a). Did the same for ordinary fasteners, and also get the acceleration level shown in figure 6(b).

Comparing the figure 6(a) with the figure 6(b), it can be seen that the vertical vibration on track slab is damped in the 6.3~80 Hz frequency band, while the lateral acceleration of the track slab is damped in frequency bands of 1~31.5 Hz and 50~80 Hz.

Performing 1/3 octave analysis on the vertical measuring points and the lateral measurement points of the tunnel walls with the damping fastener section and the ordinary section, respectively. As a result, the acceleration level in the range of 1~80 Hz was obtained as shown in figure 7.

It can be seen from the figure 7(a) that the damping fastener has a damping effect on the vertical
acceleration level of the tunnel wall in the frequency bands of 6.3~31.5 Hz and 50~80 Hz. Meanwhile, it can be seen from the figure 7(b) that the damping fastener has a damping effect on the transverse acceleration of the tunnel wall in the frequency bands of 5~31.5 Hz and 50~80 Hz.

3.3. Test Results on Dynamic Deformation of the Rail

3.3.1. Section of the Medium Damping Fastener. As the train passes the test section, typical plot of measured data of the rail displacement relative to the track slab which tested according to medium damping fastener is shown in figure 8.

Count the test data of 20 trains, it can be seen that the both of the rails at the section of the TSF vibration damping fastener are sinking relative to the track slab in the vertical direction, in which the maximum sinking distance is between 1.149 mm and 1.699 mm. The average values of the maximum sinking distance on both sides of the rails relative to the track slab for these twenty trains are 1.323 mm and 1.499 mm, respectively, and the vertical displacement of the inner rail is slightly larger than that of the outer rail. The lateral displacement of the rail head on both sides of the rail relative to the track bed are positive, indicating that the rail moves out when a train passes.

3.3.2. Section of an Ordinary Fastener. As the train passes the test section, typical plot of measured data of the rail displacement relative to the track slab which tested according to ordinary fastener is shown in figure 9.

Count the test data of 20 trains, it can be seen that the both of the rails at the section of the ordinary fastener are sinking relative to the track slab in the vertical direction, in which the maximum sinking distance is between 0.692 mm and 1.102 mm. The average values of the maximum sinking distance on both sides of the rails relative to the track slab for these twenty trains are 0.787 mm and 0.995 mm, respectively, and the vertical displacement of the inner rail is slightly larger than that of the outer rail. The lateral displacement of the rail head on both sides of the rail relative to the track bed are positive, indicating that the rail moves out when a train passes.

3.3.3. Comparative Analysis. The statistical results are based on the average value of the maximum dynamic deformation of the two types of the fastener sections at the rail measuring points when 10 trains pass by. Then, take the average value plus 2.5 times the standard deviation as the maximum possible value to perform calculation. The comparative analysis results are shown in table 2.

It can be seen from the table 2 that the vertical displacement of the rail relative to the track slab, the
lateral displacement of the rail head and the gauge change in rails with vibration damping fastener are all increased compared with that of the ordinary fasteners. The maximum possible values of gauge change for vibration-damping fasteners and ordinary fasteners are 2.986 mm and 2.519 mm, respectively; the maximum possible values of rail lateral displacement for vibration-damping fasteners and ordinary fasteners are 1.830 mm and 1.563 mm respectively; and the maximum possible values of the vertical displacement for vibration-damping fasteners and ordinary fasteners are 1.724 mm and 1.162 mm, respectively.

Table 2. Comparison of the maximum possible value of the rail dynamic deformation with the two fasteners (unit: mm).

| Type                              | Section of TSF Vibration Damping Fastener | Section of ordinary ZX-2 fastener |
|----------------------------------|------------------------------------------|-----------------------------------|
|                                  | Outer rail | Inner rail | Average value | Outer rail | Inner rail | Average value |
| Maximum possible value of vertical displacement of rail | -1.537 | -1.724 | -1.630 | -0.915 | -1.162 | -1.039 |
| Maximum possible value of lateral displacement of rail head | 1.805 | 1.830 | 1.817 | 1.430 | 1.563 | 1.496 |
| Maximum possible value of gauge change                       | 2.986 |         |          | 2.519 |         |          |

4. Conclusion

(1) The medium damping fastener can effectively reduce the vibration of the tunnel wall; (2) The medium damping fastener has a vibration reduction effect on the vertical acceleration level of the tunnel wall in the frequency range of 6.3~31.5Hz and 50~80Hz; moreover, it has a vibration reduction effect on the lateral acceleration of the tunnel wall in the frequency range of 5~31.5 Hz and 50~80Hz. (3) When a train passes, the vertical displacement of the rail, the lateral displacement of the rail head and the gauge change with the medium damping fasteners are larger than those of the ordinary fasteners. (4) The maximum Z vibration level measured from the tunnel wall is most suitable for evaluating the source strength of the metro, wherein the measured source strength of this metro line is 88.42dB. (5) The medium vibration damping fastener has a good vibration damping effect, and the measured displacement value is less than the limit value of the code, so it has better safety and economic benefits. It is suitable for laying and using in subway tunnel sections with low vibration damping requirements.

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