Applied Acoustics 116 (2017) 70–81

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Measuring, modelling and optimising an embedded rail track

Yue Zhao [a,c,*], Xusheng Li [b,c], Qiang Lv [c], Honglin Jiao [c], Xinbiao Xiao [a], Xuesong Jin [a]

[a] State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China
[b] School of Economics and Management, Southwest Jiaotong University, Chengdu 610031, China
[c] Chengdu Xinzhu Road & Bridge Machinery Co. Ltd., Chengdu 611430, China

ARTICLE INFO

Article history:
Received 23 September 2015
Received in revised form 19 July 2016
Accepted 22 July 2016

Keywords:
Embedded rail
Wheel/rail rolling noise
Decay rate
Tramway
Frequency response function

ABSTRACT

A finite element (FE) model and a boundary element (BE) model have been developed to predict the decay rate, vibration and noise responses of an embedded rail track. These models are validated using measured results. The optimisation of the embedded rail track is conducted using these calculated models. The results indicate that the optimised cross-section of the gutter for the embedding rail can significantly reduce the radiated noise of the embedded rail track. The embedded rail track using the I-shaped cross-section gutter reduces the radiated noise of the track by at least by 3 dB(A). Furthermore, combining the material parameter optimisation with the gutter cross-section optimisation can further reduce the radiated noise of the embedded rail track. Increasing the Young's modulus of the rail pad in the embedded rail track with the I-shaped cross-section gutter can result in a radiated noise reduction of 4 dB(A).

1. Introduction

With the rapid development of urbanisation, urban transport problems have become an increasingly important issue. Urban railway transit has been encouraged because it can effectively solve the congestion of road traffic and is environmentally-friendly. Tramway rail systems on the surface are cost-effective [1] and often used to facilitate street running [2]; therefore, they are still applied in urban transit.

An embedded rail track is a type of tramway rail system. In this type of structure, rails are embedded in an elastomeric material, which performs well in isolating rail vibrations and reducing the radiated noise of the track. Embedded rail tracks with continuously supported rails have better dynamic track responses, better damping characteristics and provide a more favourable vehicle-track interaction compared to classic ballasted tracks [3]. Furthermore, through an analysis using a waveguide finite element and boundary element approach, it can be determined that the embedded rail track can emit a considerably lower noise level if it is appropriately designed [4]. For example, an optimised embedded rail track with a small rail profile can emit between 4 and 6 dB(A) less noise than a ballasted track [5]. However, the vibration and radiated noise of an embedded rail track is not always desired; an embedded rail track without optimisation emits between 1.5 and 3 dB(A) more noise than the ballasted track [5].

In recent years, an increasing number of embedded rail tracks have appeared in China. In this report, based on the vibration and noise measurements conducted on an embedded rail track in the Xinzhu rail transit industrial park located in Xinjin, Chengdu suburb, FE and BE models are developed to calculate the vibration and noise characteristics of the embedded rail track. Using these models, material parameters and a gutter cross-section of the embedded rail track are optimised with respect to its vibration and radiated noise.

2. Embedded rail track

For traditional ballasted tracks and slab tracks, the rails are discontinuously supported by rail fasteners whereas for embedded rail tracks, a pair of rails are continuously supported. As indicated in Fig. 1, the 59R2 groove rails are placed in two longitudinal rectangular gutters created in the slab, and the rails are embedded with a type of elastomer consisting of rubber crumbs and polyurethane. PVC tubes placed on both sides of the rail web are used to reduce the amount of embedding elastomer material. Tube holders and elastic wedges on the two sides of the rail bottom at discontinuous equidistant points are used to hold the tubes and adjust the rail gauge.

* Corresponding author at: State Key Laboratory of Traction Power, Southwest Jiaotong University, Chengdu 610031, China.
E-mail address: zhaoyue@my.swjtu.edu.cn (Y. Zhao).

http://dx.doi.org/10.1016/j.apacoust.2016.07.021

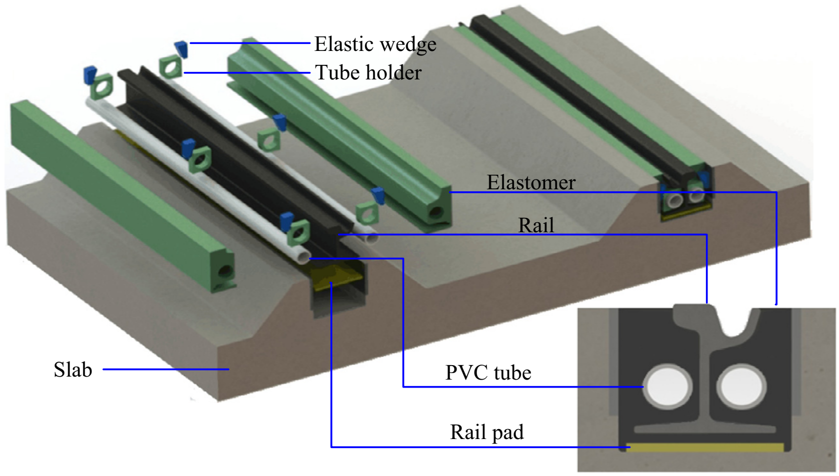

Fig. 1. Embedded rail track.

3. Experimental analysis of the embedded rail track

3.1. Vibration characteristics of the track

Measurements of the embedded rail track were conducted on the Xinzhu rail transit industrial park located in Xinjin in the Chengdu suburb. According to the standard ISO 7626-5 [6], the frequency response functions (FRFs) of the track were measured using a hammer excitation. As indicated in Fig. 2, accelerometers were fixed on the rail head, elastomer and slab surface using AB glue in the vertical direction. Therefore, the response of the elastomer at higher frequencies can be attenuated by the mounting. Additionally, the accelerometer mass is 180 g so that the accelerometer resonance with respect to the elastomer affects the accuracy of the measurement to a certain extent. The FRFs of the rail head, elastomer and slab surface were measured when the hammer was used to knock on the rail head in the vertical direction.

Additionally, according to the European standard EN 15461 [7], the vertical FRFs of the rail head along the longitudinal direction of the track were measured to assess the vibration decay rates of the embedded rail track. The decay rate influences the decay of vibration along the track and determines the length of the excited track; as the length of the vibrating track increases, more noise is radiated [2].

As indicated in Fig. 3, the thick black line represents the rail, the rectangular shaded blocks under the thick black line represent the slabs, and the red circle represents the measuring point of the accelerometer. The black arrows in Fig. 3 represent the positions of the hammer impacting on the rail. The accelerometer was fixed on the rail head to measure the vertical acceleration. The distribution of the hammer hitting points has three categories: the spot, the near field and the far field. Their intervals are indicated by the blue numbers above the arrows.

The measured FRFs were expressed in the form of a one-third octave band spectra, and the decay rates in each one-third octave band can be evaluated using the formula [8] as follows:

$$DR = \frac{4.343}{\sum_{i=0}^{i=29} \frac{|A(x_i)|^2}{|A(x_0)|^2} \Delta x_i} \qquad (1)$$

where DR is the decay rate, which is measured in dB/m; $A(x_i)$ is the measured FRF when the hammer is applied at the position of arrow i; and Δx_i is the distance between adjacent forcing points associated with position i, which is measured in m. Fig. 4 depicts the measured FRFs of the embedded rail track. It can be seen that the measured rail FRF (black solid line) above 100 Hz increases to more than 0.1 m/s^2/N, and it has the highest amplitude in this frequency range. The first two resonances occur at approximately 160 Hz and 630 Hz. Additionally, the measured elastomer FRF (red[1] dashed line) has two peaks at approximately 160 Hz and 630 Hz. The peak at 160 Hz of the elastomer reaches more than 0.6 m/s^2/N, and it is more significant than that of the rail, which is partly due to the resonance of the accelerometer with respect to the elastomer, as indicated in Fig. 5. The modal analysis results of the FE model for the track, including the accelerometer, indicate that the accelerometer and the elastomer have resonant frequencies in the frequency range from 160 Hz to 230 Hz. However, the elastomer peak at 630 Hz and the elastomer FRF amplitude in the higher frequency range are smaller than those of the rail. At approximately 630 Hz, the local elastomer vibration slightly increases along with the rail head. The vibration response of the elastomer after 160 Hz has a tendency to decline because of the damping effect of the elastomer in the higher frequency range. Additionally, the amplitude of the elastomer can largely isolate the vibration propagation from the rail to the slab.

Fig. 6 illustrates the measured decay rate of the embedded rail. It can be seen that the decay rate of the embedded rail is relatively higher in the frequency bands below 100 Hz and above 1000 Hz whereas it drops to less than 1 dB/m in the range from 100 Hz to 1000 Hz. The vibration decays rapidly along the track longitudinal direction in the frequency bands below 100 Hz and above 1000 Hz whereas the vibration propagates freely along the track longitudinal direction in the frequency range from 100 Hz to 1000 Hz; therefore, this embedded rail track vibrates and radiates noise easily in the frequency range from 100 Hz to 1000 Hz.

3.2. Vibration and noise characteristics during tram running

Furthermore, when a tram was running on an embedded rail track, the accelerations of the embedded rail track and wheel/rail rolling noise were measured. The accelerometers were fixed on a side of the rail head along with the elastomer and the slab surface using AB glue to measure the vertical responses. The accelerometer mass is 60 g (lighter than that used in the FRF measurements), which results in a higher resonance frequency of the accelerometer with respect to the elastomer, i.e., approximately 300 Hz. Additionally, a microphone was placed in the centre of the tram bogie area to measure the wheel/rail rolling noise when the tram was run-

[1] For interpretation of colour in Figs. 4, 27–30, the reader is referred to the web version of this article.