INFLUENCES OF LOCAL THICKENING TOP PLATE OF HIGH-SPEED RAILWAY BOX GIRDER BRIDGE ON STRUCTURE NOISE

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The noise induced by the operation of high-speed railway is increasingly severe. It’s very difficult and expensive to reduce the noise, so it is universally accepted as an international problem. The noise radiated by the high-speed railway bridge concentrates in the low-frequency domain. This paper proposes a design scheme for box girder shape, in order to reduce the low-frequency structure noise of the high-speed railway bridge using theory of train-track-bridge dynamic interaction, acoustic BEM and acoustic principles. The mechanisms of noise reduction are also deeply studied. The result can provide a theoretical guide for the shape design and engineering applications of the low structure noise box girder.

Keywords: shape design, vibration and noise reduction, structure noise, box-girder bridge, high-speed railway.

1. Introduction

High-speed railway improving the national economy and facilitating people's travel, however, many problems have exposed with this rail transit mode rapid developing. Zhai Wanming pointed out in the review article of modern rail transit engineering [1]: For high-speed railway, the environmental protection is getting worse. Among, the noise is particularly serious that noise reduction is difficult and costly. Thus, this problem has become a recognized international engineering challenge. The attention of the environmental vibration and noise in urban rail transit are becoming more and more important that the demanding measures and design of vibration and noise reduction become a major challenge to the development.

Due to the bridge vibration radiates structure noise, the noise level of elevated line obviously increase. Moreover, bridge structure accounts for a high proportion in high-speed railway. Therefore, the theory research of bridge structure noise has practical significance. The research methods of bridge structure noise mainly include FEM-BEM, statistical energy analysis method, model acoustic transfer vector method and 2.5D method [2-5]. In the world, vibration and noise reduction measures of railway are often concentrated on track system. Many damping track have been designed that the purpose is reduce the energy transmitted to the bridge, such as the trapezoidal sleeper track and the floating slab track. Gao Fei et al.[6] analyzed the radiated noise from elevated structure with trapezoidal track installed on the Beijing Metro Line 5 and verified by experiment. The results pointed out that the trapezoidal track has a good vibration and noise reduction effect that the
maximum reduction of low frequency vibration velocity can be more than 70% and the maximum structure noise can be decreased 24dB(A). For the noise control of Hong Kong West Rail Line [7], the mathematical model of train-track-elevated structure was established by Wilson Ihrig, and pointed out the high-elasticity fasteners cooperate with the floating plate track can effectively solve the structural noise radiation. However, the literature [1] pointed out the damping track is not a panacea that it may cause new problems, such as abnormal wavy wear on the rail. For the bridge design, Janssens et al. [8-10] developed a low-noise bridge with integrated embedded rails by various parameters of the top, web, bottom thickness and total height that the bridge noise was reduced 5-7dB. Moreover, the 1: 4 ratio models of main girder of three bridges were established and the calculation models were verified by measuring. Han Jianglong et al. [11] studied the structure noise influence of plate thickness and addition transverse ribs in a U-beam bridge. Zhang Xun et al. [12] analysed the structure noise influence of plate thickness and dip angle of web plate in a 32 m simply-supported concrete box girder bridge, and the top plate thickness was increased that can effectively reduce the bridge structure noise. It is necessary to point out that the acoustic principle is more complicated and difficult than the vibration principle, and it is difficult for both to achieve desired results at the same time.

In order to achieve the aim of reducing vibration and noise for a 32m double-line simply-supported concrete box girder bridge, a new bridge shape is designed in this paper that based on the train-track-bridge interaction theory, the acoustic boundary element method and combined with the structure noise radiation principle. Moreover, the noise reduction mechanism of the design scheme is analysed in further.

2. Prediction model of bridge structural noise

In order to predict the bridge structure noise, it is necessary to solve the bridge dynamic response and the references [13-15] give a detailed theoretical derivation and verification. The train-track-bridge coupling dynamic model is established and adopt the hybrid explicit-implicit numerical integral method by Zhai method and Newmak-β method to solve the system dynamic response. Using the bridge dynamic response as the acoustic boundary condition, the low-frequency bridge structure noise is predicted by acoustic BEM. The reference [16] gave a theoretical model of low-frequency bridge structure noise. The detailed theoretical derivation and difficulty of acoustic BEM can be found in reference [17].

In this paper, the 32 m simply-supported concrete box girder bridge is researched object that laying CRTSI slab ballastless track. A new bridge shape of low structure noise is designed which the local thickened top plate of the box girder bridge under track. Among, the bridge concrete grade is C80, the thickness of top, web and bottom plates are 0.315m, 0.48m and 0.3m respectively. The excitation adopted is the China high-speed ballastless track spectrum.

3. Vibration and noise reduction design

3.1 Structure low noise bridge design

The energy from the wheel-rail interaction is transmitted to the bridge through the track that causing the bridge vibration and to radiate the structure noise. The vibration response, vibration distribution and radiation efficiency of the bridge structure are all factors that affect the structural noise radiation. Therefore, it is necessary to consider above factors when design the new bridge shape of low structure noise in this paper and the design premises have the following three points:

(1) The top plate local thickening of the box girder bridge under the track can reduce the transmission energy to the whole bridge structure and weaken the vibration response.

(2) For box girder bridge, the top plate local vibration is the mainly vibration characteristics and top plate is the most important structure noise contributor. The top plate local thickening can change
the overall vibration distribution of bridge and it can reduce the structural noise radiation by change
the vibration mode.

(3) The self-vibration characteristics and the sound radiation efficiency can be changed of the
box girder bridge by amending the bridge shape. Therefore, the bridge structure acoustical radiation
mechanism is changed and the radiation ability can be weakened.

To sum up, Fig.1 shows a schematic of improving the bridge design and the thickened region
thickness is twice the original thickness.

![Design sketches of box girder bridge](image)

Figure 1 Design sketches of box girder bridge (Initial model 1-left, Improve model 2-right).

3.2 Effect of vibration and noise reduction

Firstly, the vibration response and the structural radiation noise of two type bridges are predicted
and the results are compared that evaluate the effect of vibration and noise reduction

The transverse 50m of box girder bridge at middle-span of the train running side is selected the
main research area. The bridge structure noise radiation characteristics and mechanism are re-
searched in this paper. If considering the ground reflection, it is difficult to effective evaluate the
structure noise radiation of bridge itself. Therefore, the ground reflection effect is neglected. Sketch
of sound field distribution is shown in Figure 2.

![Sketch of sound field distribution](image)

Figure 2. Sketch of sound field distribution.
Figure 3. Comparison of bridge vibration response.

It can be seen from Fig.3 that the box girder bridge vibration is concentrated in 0-200Hz, and 80-100Hz is the mainly severe vibration frequency range. By comparing the vibration responses of two models, the vibration reduction effective of improve model is very obviously, especially the vibration response of top plate in 0-50Hz which include the infrasound frequency range. Compared with the vibration reduction effect of the top plate, the other plates are weaker.

Figure 4. Comparison of bridge structure noise.

Fig.4 shows that the radiation noise of the improved box girder bridge is obviously reduced. In 80-100Hz and 0-50Hz, the reduction noise effect at the bridge below area and the all area is obvi-
ously respectively. In conclusion, the noise radiation ability of the improved bridge is effective weakened, which is a good bridge shape of low structure noise.

3.3 Mechanism of noise reduction

In order to research the bridge structure noise radiation mechanism, the acoustic radiation characteristics are analyzed firstly. Fig. 5 shows the sound radiation efficiency and sound power comparison of the two type bridges. As can be seen from the Fig. 5, the overall sound power of the improved model has been reduced in full frequency range, especially in 0-50Hz. The mechanism mainly includes the following three points:

![Figure 5. Comparison of bridge sound radiation characteristics.](image)

Table 1: The sound pressure value of each field points at 23.7 Hz

<table>
<thead>
<tr>
<th>Sound pressure(dB)</th>
<th>Field points</th>
<th>SF1</th>
<th>SF2</th>
<th>SF3</th>
<th>SF4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model 1</td>
<td></td>
<td>43.8</td>
<td>74.5</td>
<td>74.1</td>
<td>65.5</td>
</tr>
<tr>
<td>Model 2</td>
<td></td>
<td>50.3</td>
<td>53.3</td>
<td>49.5</td>
<td>62.3</td>
</tr>
</tbody>
</table>

(1) The resonance phenomenon of the box girder bridge is avoided.
At 23.7Hz, it is very close to the vibration distributions of two type bridges. Although the vibration response of the original bridge is slightly larger than the improved bridge, but top plate of former has obvious local resonance phenomenon at the bridge end, which can effectively cause radiation structural noise of box girder bridge.
Although the vibration responses of the two type bridges mainly show the top plate local vibration at the bridge end, but the other plates are also vibrated. The model shape of improved mode is the bottom plate local vibration, and the certain resonance phenomenon also exists that resulting in the sound pressure is increased in below sound area SF1 of bridge because the bottom plate radiates a greater structural noise (see Tab. 1).

(2) The vibration distribution of the box girder bridge is changed.
At 27.1Hz, the vibration distribution of two type bridges is the top local vibration and the bridge whole vibration respectively that resulting in the sound radiation efficiency is obvious reduced, which together with the vibration reduction affects the structural noise radiation.

(3) The sound radiation efficiency of the box girder bridge is suppressed in 0-50Hz.
The top plate is the main contributor of structural noise. The acoustic radiation efficiency is effectively suppressed, indicating that vibration model of new bridge shape is changed and weakens the ability of radiation sound wave. At 23.7Hz, the natural vibration characteristics of two type bridges show the local vibration of top and bottom plates respectively. The sound radiation efficiency of the former is better than the latter.
To sum up, there is a certain relationship between the above issues. For box girder bridge, the vibration mode, response and distribution of new bridge shape are changed that influence resonance region and reduce the sound radiation efficiency.

(a) The 12th model shape of initial bridge (mm)-23.7Hz (left)

The 10th model shape of improve bridge (mm)-23.8Hz (right)

(b) Vibration acceleration (m/s²)-23.7Hz

(c) Vibration acceleration (m/s²)-27.1Hz

Figure 6. Comparison of two kinds bridge vibration characteristics (Initial bridge-left, Improve bridge-right).

3.4 Comparison of the noise reduction effect of the local and overall thickened top plate of box girder bridge

Comparing the sound radiation characteristics of the whole and local thickened top plate of the box girder bridge, in the same case, the sound power and sound radiation efficiency are very close. Two design schemes have a good noise reduction effect. However, the paper proposes the design scheme of local thickened top plate under the track can not only achieve the noise reduction effect similar to the overall thickening, but also reduce the construction cost and the bridge self-weight. Therefore, the new bridge shape is a better design scheme of low noise bridge structure, but the vibration reduction effect of the overall thickened top plate is better.
4. Conclusion

In this paper, firstly, for initial and improved bridge, the vibration response and sound pressure are compared. Secondly, the mechanism of noise reduction is analyzed in further. Finally, the vibration and noise reduction effect of local and whole thickened top plate are compared. Some conclusions have been reached:

(1) For box girder bridge, the local thickened top plate under track of train running is obviously effective of vibration and noise reduction, which is a good low structure noise bridge shape design.

(2) The new bridge shape can weaken the overall vibration response and change vibration distribution of box girder bridge. Moreover, the sound radiation efficiency is effectively suppressed that reduce the ability of structure noise radiation.

(3) For the overall and local thickened top plate, two design schemes have a good noise reduction effect. Although the vibration reduction effect of the overall thickened top plate is better, but the local thickened top plate under track reduce the construction cost and the bridge self-weight.

REFERENCES


