DISPLACEMENT AT GIRDER END OF LONG-SPAN RAILWAY STEEL BRIDGES AND PERFORMANCE REQUIREMENTS FOR BRIDGE EXPANSION JOINT

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Abstract: In-depth understanding of spatial displacement at girder end of long-span railway steel bridges is vital to the design of bridge expansion joint (BEJ). And the performance requirements for BEJ are directly related to the displacement characteristics. In this paper, three different bridge types and corresponding structural restraint system are considered. Results show that the longitudinal displacement at girder end is mainly influenced by bridge types, structural restraint system and effective temperature. In some cases, train loads, longitudinal wind loads, and braking force also have obvious contributions especially for the semi-floating system. Vertical rotation angle at girder end is largely decided by train loads, uneven foundation settlement and temperature. It is also influenced by arrangement of auxiliary piers. Transverse movement and its rotation angle are the key factors deciding the safety and ride comfort of running train at the region of girder end. Two types of BEJs for railway bridges are introduced. Performance requirements for BEJ are proposed according to analysis results.

Keywords: Displacement; Girder end; Railway steel bridge; Bridge expansion joint (BEJ); Performance

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1 INTRODUCTION

Bridge expansion joints (BEJs) are key components at girder end for the accommodation of movements resulting from temperature effects, traffic loads, and natural hazards, to name a few [1, 2]. Many research achievements on BEJs in road bridges are obtained by inspection survey, model test, numerical simulation and long-term monitoring [3-8]. Compared to road bridges, performance requirements for BEJs of high-speed railway bridges are more critical due to the requirements of running safety and ride comfort of high-speed train [9-13]. WEI Y.H. pointed out that the rate of wheel load reduction increased gradually with the increase of vertical rotation angle at beam end under the train speed of 300km/h for simply supported beam bridge. The vertical fault in elevation and transverse displacement fault at girder end would cause geometrical irregularities [9]. LI Y.L. et al pointed out that the expansion joint had important effect on train running performance. Compared to the deflection of the expansion joint and its installation error, the vertical rotation angle at beam end had more obvious influence on vehicle responses [10]. GAO M.M. et al investigated dynamic performance of expansion joint at girder end of a long-span cable-stayed bridge by train-track-bridge coupling vibration analysis model. Results showed that the deformation of track structures at expansion joint and adjacent girder
end had differences. Such local irregularity caused impact to the train and expansion joint which caused excessive responses of the train under some load cases. Besides the longitudinal displacement, the vertical rotation angle, the transverse displacement and corresponding rotation angle shall be considered during the design of BEJs [11]. QUAN S. X. et al studied the influence of beam-end lateral expansion of steel truss girder on geometrical shape of track. Results indicated that lateral relative expansion between the steel truss girder and subgrade made larger lateral displacement of ballast track. Furthermore, the distance from lateral fixed support of steel truss girder to central line of the route was mainly responsible for variation of geometrical shape of track [12]. YANG Y. M. et al studied the effect of angular changes of bridge truss ends on train’s runnability by full scale modeling vehicles in the National Railway Test Center of China Academy of Railway Sciences. Test results showed that the transverse rotation angle and vertical rotation angle had obvious influences on wheel lateral force and transverse acceleration [13]. Analysis revealed that the vertical acceleration of car body and bogie undergone obvious fluctuations caused by the vertical fault in elevation at girder end and the peak value increased with the increase of vertical fault.

Therefore, detailed analysis on the displacement characteristics at girder end of long span railway steel bridges is essential to understand the mechanical behavior of this region. And those characteristics shall be considered in the preliminary design of BEJs. In this paper, three different bridge types, namely truss arch bridge, cable-stayed bridge and suspension bridge are compared on the displacement behavior at girder end. And performance requirements for BEJs are proposed according to displacement behavior at girder end and working conditions.

2 DISPLACEMENT AT GIRDER END OF DIFFERENT BRIDGE TYPES

Three different bridge types are considered. Dashengguan Bridge was a steel truss arch bridge in Beijing-Shanghai high-speed railway (HSR) line with a span arrangement (108+192+2×336+192+108) m, as shown in Figure 1(a). It supports a six-line railway, including two regular rails, two HSR with design speed 300km/h and two subway lines, as shown in Figure 2(a). Three truss planes in the longitudinal direction were used with a spacing of 15m [14, 15]. Spherical bearings were arranged under each main truss with a fixed bearing set under the mid-truss of pier 7 and a transversely-movable bearing under each side truss of pier 7. On other piers, the transversely-fixed bearings were used under mid-trusses and the multidirectionally movable bearings were set under side trusses.

Hutong Bridge was a steel cable-stayed bridge that supported four-track traffic and a six-lane highway over the Yangtze River with a span arrangement (140+462+1092+462+140) m, as shown in Figure 1(b) and Figure 2(b). Three 16m uniform-depth truss planes in the longitudinal direction were also used, with a spacing of 17.5m [14, 15]. The railway bridge deck was an integral box structure combined with the main truss in order to improve the overall stiffness, as shown in Figure 2(b). Semi-floating structural system was adopted with spherical bearings erected under each main truss, damping devices and seismic-resistant bearings arranged between pylons and girders. Transversely-fixed bearings were installed under each mid-truss in order to resist the lateral wind loads. And multidirectionally movable bearings were adopted at two side trusses to release the thermal actions. Six damping devices at each pylon connected the girder and the lower beam of the pylon in the longitudinal direction with three on the same side. Bearings for seismic-resistance in transverse direction were arranged at two sides of the lower chord of the girders.

Wufengshan Bridge was a steel suspension bridge that supported four-track traffic and an eight-lane highway over the Yangtze River with a span arrangement (84+84+1092+84+84) m, as shown in Figure 1(c) and Figure 2(c). Different from above two bridges, two truss planes in
the longitudinal direction were used with the spacing of 30m [16]. Semi-floating structural system was adopted with multidirectionally movable spherical bearings under each main truss, and wind-resistant bearings in transverse direction located at outside of the lower chord at piers and pylons. Extra wind-resistant bearings in transverse direction were arranged outside the upper chord at the pylon. Four damping devices were at one side of lower beam of each pylon in the longitudinal direction, connecting with the stiffening girders. To decrease the vertical deformation, a multidirectionally movable bearing was set under mid-truss at girder end.

Figure 1: Layout of main bridge of representative long-span HSR steel bridges
2.1 Longitudinal displacement at girder ends

Longitudinal displacement (LD) at girder ends is the key factor for design of BEJs. Different design loads and influential factors shall be considered under most unfavorable conditions. Design value of LD at girder end of different bridges is shown in Figure 3. These values are contributed by temperature, vertical live load, braking force, longitudinal wind, and total values of the approach bridge. Comparisons tell us that effects of temperature are the major factors for longitudinal movement at girder end. Generally, temperature effects can be divided into effective temperature and the differential temperature [2]. The effective temperature refers to the overall temperature rise or fall of the whole bridge. Design value of effective temperature is ±40°C for Dashengguan Bridge, ±33°C/±21°C for steel/concrete structure of Hutong Bridge, and +25°C/-27°C for Wufengshan Bridge. From Figure 3, the LDs under effective temperature are 305mm, 440mm, and 233mm respectively for Dashengguan Bridge, Hutong Bridge and Wufengshan Bridge. Analyses show that such values are related to the value of effective temperature, the temperature span, and the structural system. Since the temperature span is 636m, 1148m, and 714m respectively for above bridges, the LD can be checked by formula method as the following.

\[ L_{ET1} = \alpha \cdot \Delta t_1 \cdot L_1 = 1.2 \times 10^{-5} \times 40 \times 636 = 305mm \]  
(1)

\[ L_{ET2} = \alpha \cdot \Delta t_2 \cdot L_2 = 1.2 \times 10^{-5} \times 33 \times 1148 = 455mm \]  
(2)

\[ L_{ET3} = \alpha \cdot \Delta t_3 \cdot L_3 = 1.2 \times 10^{-5} \times 27 \times 714 = 231mm \]  
(3)

Where \( L_{ET} \) refers to LDs of above three bridges, \( \alpha \) denotes the coefficient of thermal expansion coefficient, and \( L \) is the temperature span. Results of the formula method are similar to the numerical values in Figure 3. In formula (1), the longitudinal displacement under effective temperature of Dashengguan Bridge is the same as numerical value in Figure 3(a). In formula (2), the value of Hutong Bridge is a little larger than numerical value in Figure 3(b) with relative error 3.4%. The reason is that the formula only gives the free movement of temperature span of the cable-stayed bridge under effective temperature without considering the restraint effects on girders from stayed cables. But the accuracy of the formula method can be accepted. The accuracy of formula method in Wufengshan Bridge can also be verified by numerical result with very close values of 231mm and 233mm.
The influence of differential temperature on longitudinal displacement at girder end is much more complicated compared to the effective temperature. For steel truss arch bridge, differential temperature refers to temperature differences between top surface and other levels in the bridge deck cross section. It accounts for 19.3% of longitudinal displacement contributed by temperature of Dashengguan Bridge at its girder end. For cable-stayed bridge and suspension bridge, differential temperature includes temperature differences between cables and girders, different surfaces of concrete pylon and surfaces in the bridge deck cross section. For temperature differences between cables and girders, additional effective temperature on girders due to wrong temperature settings shall be avoided. For temperature differences between different surfaces of pylon, the surface in the longitudinal direction shall be selected for LD.

![Figure 3: Numerical results of longitudinal displacement at girder end of different bridges](image)

LDs at girder end caused by the vertical live load are influenced by the structural system and the position of live load. Taking Dashengguan Bridge for instance, the LD at girder end under vertical live load is much less than Hutong Bridge and Wufengshan Bridge due to its longitudinal fixed restraint system. For cable-stayed bridges with semi-floating system, the restraint of stay cables influences the longitudinal movement of girders. The height of pylon also plays roles together with the cables on the longitudinal stiffness. For Wufengshan Bridge, the influence line of LD at girder end under unit vertical load is shown in Figure 4. It can be clearly concluded that the maximum value of LD at girder end occurs when the vertical live load distributes exactly half of the bridge mid-span. Such characteristics of LD is in accordance
with other suspension bridges [17]. For Wufengshan Bridge, maximum value of 261mm is much larger than Dashengguan Bridge (23mm) and Hutong Bridge (103mm).

Figure 4: Influence line of LD at girder end under unit vertical load of Wufengshan Bridge

LD caused by braking force shall also be considered especially for long-span bridges with semi-floating system. The design value is 74mm and 77mm for Hutong Bridge and Wufengshan Bridge respectively, which is more than 15mm of Dashengguan Bridge. The longitudinal wind has influences on longitudinal movement at girder end. For Dashengguan Bridge, longitudinal wind is not considered since the extreme effects of temperature and wind are supposed not to appear simultaneously [18]. While in Hutong Bridge and Wufengshan Bridge, effects of longitudinal wind are both considered due to its obvious influences with 134mm and 129mm respectively for LD at girder end.

Influences of the approach bridge adjacent to the major bridge on displacement at girder end shall be considered when the girder end of the approach bridge is longitudinally movable. The design value of LD for the approach bridge is 60mm, 60mm and 90mm under effects of different design loads for Dashengguan Bridge, Hutong Bridge and Wufengshan Bridge respectively.

The total value of LD at girder end can be obtained by summation of each value. 476mm, 877mm and 904mm are for Dashengguan Bridge, Hutong Bridge and Wufengshan Bridge, respectively. The final design values for BEJs of above three bridges are ±600mm, ±900mm and ±940mm/-820mm, respectively. The final design value shall be greater than the total value due to the safety margin and the product model of BEJs.

2.2 Transverse displacement at girder ends

To satisfy the requirements for safety and comfort of running trains, strict limit values are considered for transverse displacement (TD) at girder end. For BEJ itself, the transverse deformation shall be less than 1mm under lateral swaying force of train. For bridge structure at girder end, requirements on transverse displacement or deformation are related to the difference between main bridge and the approach bridge. TD can then be transformed into transverse rotation angle after considering the bridge gap between main and the approach bridge. Such requirements are often fulfilled by proper restraint system. For instance, three truss planes in the longitudinal direction are used in Dashengguan Bridge. It facilitates the arrangement of transversely-fixed bearings under the mid-truss to resist the lateral wind loads at side piers and auxiliary piers, and the fixed bearing under mid-truss of main pier 7. While for Hutong Bridge, transversely-fixed restraints are installed under mid-truss at side-piers and auxiliary piers with slide bearings under mid-truss at pylons. Wind-resistant bearings are then arranged at lower and upper chord of main girder at bridge pylon. For Wufengshan Bridge, transversely-fixed bearings are not used due to two truss planes. Wind-resistant bearings are set at outside of the lower chord of stiffening girders at piers and pylons together with wind-resistant bearings at upper chord of girders at the pylon to resist the lateral movement under wind loads. Above
restraint systems endured the expansion and contraction in the transverse direction caused by the temperature variation and the characteristics are similar for effective temperature. The TDs at girder end of Wufengshan Bridge under temperature effects are given in Figure 5. Under effective temperature, the TD increases as the distance to the mid-truss increases which conforms to the linear law. Such an increase can also be expressed by the formula $a \cdot \Delta \cdot L$ as depicted in Formula (3). And the length $L$ refers to the half span of the end beam, i.e. 15m. Under differential temperature, TDs are much evener as shown in Figure 5. The magnitude is less than the value of effective temperature.

Another key problem arises for Wufengshan Bridge that the transverse displacement is only restricted by wind-resistant bearings. Numerical results show that the overall transverse displacement at girder end is close to 10mm under the extreme wind loads without running train when the allowed elastic deformation of the wind-resistant bearing is 10mm. It will make the BEJs under bad mechanical status. And the allowed elastic deformation value is then restricted to 5mm at side and auxiliary piers, a value that satisfies the free expansion and contraction under temperature effect (maximum 4.5mm). And wind-resistant bearings shall also recover to normal state and original position after the wind loads disappear as a performance requirement.

![Figure 5: Transverse displacements at girder end of Wufengshan Bridge under temperature effects](image)

**2.3 Rotation angle at girder ends**

Vertical rotation angle (VRA) and transverse rotation angle (TRA) are also important parameters. Firstly, the rail’s uplift and pressure are mainly controlled by the VRA at girder end, the rail supporting structure and the rail fastening performance [19]. Under ZK static live load, the proposed limit values of vertical rotation angle are listed in Table 1 for passenger dedicated line (PDL) bridges in China. It shows that the limiting VRAs are related to several parameters including track type on bridge, girder end location and girder end overhang length. And stricter values of VRA are proposed for ballastless track due to lack of adjustment of ballast.

Taking Dashengguan Bridge for instance, the VRA at girder end under ZK static live load is 1.93‰rad [20]. And the VRA for the approach bridge is -1.0‰rad [15]. The total rotation angle is 2.93‰rad which satisfies the requirement of limit value 4.0‰rad (ballasted). Under temperature effects, VRA at girder end of main bridge is 1.8‰rad and -1.4‰rad at girder end of the approach bridge. And the braking force of train has little effects on the VRA. Hence the maximum value of VRA at girder end of Dashengguan Bridge under design loads is 6.13‰rad.

For Hutong Bridge, several design loads are considered for calculation of VRA including uneven settlement of bridge foundation, temperature effects, wind loads and vertical live loads. The maximum VRA at girder end of main bridge caused by each design load is 0.36‰rad,
0.62‰rad, 0.2‰rad, 1.29‰rad, respectively. So the major influential factors on VRA are live load and temperature effects. Arrangement of auxiliary piers improve the overall structural stiffness obviously and decrease the VRA of live load at girder end [21]. The total VRA at girder end of main bridge is 2.47‰rad.

Taking Wufengshan Bridge as another example, design loads are also considered like Hutong Bridge for calculation of VRA. The maximum VRA of each design load is 0.58‰rad by uneven settlement of foundation, 0.12‰rad by temperature effects, 0.2‰rad by lateral extreme wind loads (longitudinal wind effects can be omitted), and 0.9‰rad by ZK static live load. The total VRA at girder end of main bridge is 1.8‰rad. VRA at girder end of the approach bridge is -0.93‰rad. The total value of VRA is 2.73‰rad. The reason for less VRA under live load is also the arrangement of auxiliary piers with two continuous span of 84m.

### Table 1: Limit value of vertical rotation angle under ZK static live load at the girder end in China

<table>
<thead>
<tr>
<th>Track type on bridge</th>
<th>Location</th>
<th>Limit value (rad)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballasted</td>
<td>At abutment</td>
<td>$\theta \leq 2.0%$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>At piers</td>
<td>$\theta_1 + \theta_2 \leq 4.0%$</td>
<td></td>
</tr>
<tr>
<td>Ballastless</td>
<td>At abutment</td>
<td>$\theta \leq 1.5%$</td>
<td>Girder end overhang length $L_e \leq 0.55m$</td>
</tr>
<tr>
<td></td>
<td>At piers</td>
<td>$\theta_1 + \theta_2 \leq 3.0%$</td>
<td>$0.55m \leq L_e \leq 0.75m$</td>
</tr>
</tbody>
</table>

Transverse rotation angle (TRA) is another essential factor at girder end which influences the running safety of trains. Since the bridge gap changes with temperature, live load, wind loads, to name a few, TRA changes according to the following formula.

$$ TRA = \left( \frac{D_m - D_a}{L_{gap}} \right) \text{ (rad)} \quad (4) $$

Where $D_m$ denotes the deformation or displacement at girder end of the main bridge, $D_a$ refers to the deformation or displacement at girder end of the approach bridge, $L_{gap}$ is the length of bridge gap, rad is the unit of TRA. When $L_{gap}$ decreases, TRA will increase obviously with big difference of deformation or displacement between the main bridge and the approach bridge. Limit values for TRA of track surface at girder end are listed in Table 2 [22]. It is observed that such values are not directly related to the bridge structure. Since ballasted track is usually adopted in long-span railway steel bridges, these values cannot be used directly for limit value of TRA at bridge girder end. But they are close to each other. As depicted in Table 2, the limit value of TRA is related to train’s operating speed and the span of girder end. The limit values are stricter under higher running speed. Another limit value for TRA of bridge at girder end is 1.0‰rad caused by the transverse displacement of adjacent piers under ZK live load, lateral swaying force of train, centrifugal force, wind loads and temperature [19].

TRA can be restricted effectively by proper design of structural system and arrangement of bearings. For example, three-truss planes in the longitudinal direction of bridge girders are often used to facilitate the arrangement of transversely-fixed bearings under the mid-truss. Three-truss planes not only play an important role in improving the rigidity of railway bridge deck, but also restrict the overall lateral movements at girder end under extreme lateral wind loads. Such a design idea is used in Dashengguan Bridge, Tongling Bridge and Hutong Bridge, etc. However, the expansion and contraction of steel girder cannot omitted in the lateral direction.
due to the influence of temperature. Generally, TRA has a larger value when the effective temperature rises because the width of bridge gap decreases. Taking Wufengshan Bridge as an example, the value of TRA is 1.95‰rad considering the effective temperature rise of 25°C. The result can be obtained by following equation.

\[ TRA = \frac{(3.1 - 1.31)}{(700 + 220)} = 1.95 \% \text{rad} \]  

Where 3.1 mm refers to the transverse deformation at the outer rail line of the girder end of main bridge under effective temperature rise of 25°C, 1.31 mm refers to the corresponding value of the approach bridge. And 700mm is the minimum bridge gap when the bridge expands under temperature rise. 220mm is the top width of steel sleeper. Compared to the result of Table 2, only Japanese design standard can be satisfied under the design effective temperature rise. Different from Wufengshan Bridge, the situation for Hutong Bridge would be more optimistic because the approach bridge is a simply supported steel girder bridge with three main truss planes and the same arrangement of bearings like main bridge at girder end. So the difference of transverse deformation and TRA would be minor and can be omitted.

<table>
<thead>
<tr>
<th>Technical specifications</th>
<th>Maximum speed (km/h)</th>
<th>TRA of track surface at girder end (%rad)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L&lt;30m</td>
<td>L≥30m</td>
</tr>
<tr>
<td>Design standards for railway structures. (in Japanese)</td>
<td>70</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>110</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>3.5</td>
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<td></td>
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<td></td>
<td>260</td>
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<td>Temporary provisions of China</td>
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</tr>
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</table>

### 3 PERFORMANCE REQUIREMENTS FOR BRIDGE EXPANSION JOINTS

#### 3.1 Major types of BEJs for long-span railway steel bridges in China

When the spacing of adjacent fastener linking the rail and sleeper exceeds by 650mm, BEJs shall be installed at the girder end to provide extra support at the bridge gap and satisfy the mechanical requirement of the track structure. In this section, major types of BEJs used in long-span railway steel bridges in China are introduced firstly. Then performance requirements for BEJs are proposed according to the displacement at girder end and working conditions.

There are mainly two types of BEJs used in long-span railway steel bridges, through-type BEJ and deck-type BEJ, as shown in Figure 6 and 7. These two types of BEJ are distinguished by the position of support girder which accommodate the longitudinal movement of bridges and provides the vertical support at the gap. In Figure 6, the support girder moves directionally and freely in the box at free side to accommodate the displacement at the girder end. Guided by the support bearing and compact bearing, the support girder can move freely with the sliding surfaces in the same longitudinal direction. And it is fixed by lateral blocks in the box at the fixed side. I-section is often used as the cross section of the support girder. Scissors system is at two sides of the steel sleepers to guarantee uniform distance between sleepers during movement of bridges. Furthermore, the outside guide rail parallel to the rail provides the lateral stiffness together with the block in the box to limit the lateral deformation. Boxes are firmly connected with the main bridge and the approach bridge to provide supports. The number of
movable steel sleepers has the modular characteristic which is related to the design value of displacement at girder end. The more the movable steel sleeper, the larger expansion or contraction the device will have. This type of the device currently used in China is classified by the displacement from 300mm (±150mm) to 1000mm (±500mm) according to investigation. BEJ with 2000mm-scale of displacement has been designed in Hutong Bridge and Wufengshan Bridge with total expansion and contraction of 1800mm and 1760mm.

Another type of BEJ is called deck-type since movable steel sleepers are suspended by the support girder. Such type of BEJ is composed of movable steel sleeper, support girder, scissors system, and fasteners, as shown in Figure 7. Integrated design is adopted since the BEJ is incorporated with the rail expansion joint (REJ). Both devices are on the track. This type of product is used in HSR long-span steel bridges with design value 1200mm (±600mm) and 2 movable steel sleepers. When displacement increases, the number of movable steel sleepers needs to increase. Then the stiffness would be a challenge for the support girder due to its height limit. For this case, the height of girder top shall not exceed by 25mm above the rail surface.
3.2 Performance requirements for BEJs

Performance requirements for BEJs of long-span railway steel bridges are proposed as follows according to the displacement characteristics and working conditions.

1. BEJs shall have the ability to accommodate the longitudinal displacement at girder end. Meanwhile, the distance of fixed sleeper at two ends of the bridge gap shall be generally less than 2500mm to reduce the dynamic effects of running PDL train due to bogie wheelbase.

2. During the expansion and contraction of BEJ, transverse rotation angle at girder end shall be restricted in proper limit value such as 1.0‰rad~2.5‰rad. And vertical rotation angle shall be less than 2‰rad. Lateral stiffness of BEJ shall be guaranteed with the transverse deformation less than 1mm under lateral swaying force of train. Proper arrangement of restraint system shall be considered dealing with the transverse displacement caused by strong lateral wind loads.

3. The vertical deformation of support girder of BEJ under ZK live load considering dynamic coefficient shall be less than 1mm for general case. Deflection-to-span ratio shall be considered for the long-span steel railway bridge when such a requirement can not be fulfilled.

4. The highest elevation of scissors system shall be less than 25mm of structure gauge.

5. The maximum center distance of adjacent steel sleeper shall generally be less than 650mm. And the minimum clear distance shall be more than 20mm. The width of steel sleeper shall satisfy the fasteners’ installation requirements.

6. Longitudinal displacement under train load has different characteristics compared to the temperature effects. Performance of durability such as the sliding parts of BEJs and its accumulative displacement shall be paid enough attention especially for the HSR suspension bridge. Period of replacement for sliding parts shall be not less than 5 years or more.

7. Requirements on waterproof, dustproof, easy maintenance etc. shall also be fulfilled.

4 CONCLUSIONS

In this paper, displacement at girder end of different bridge types is analyzed. Then the performance of bridge expansion joint for HSR long-span bridges is proposed according to the result of displacement and working conditions. This paper can be regarded as a reference for the optimal design of BEJs. Early in the preliminary design of long-span railway steel bridges, the performance requirements of BEJs shall be incorporated into the overall design scheme such as the optimal arrangement of structural system, the bearings and other restraints, and the design of approach bridges, etc. The proper design of main bridge and the approach bridges can facilitate the design of BEJs. Detailed analysis on the displacement characteristics at girder end of long-span railway bridges shall be carried out in structural analysis, including longitudinal and transverse displacement, vertical and transverse rotation angle under different design loads. Performance requirements for BEJs shall be fulfilled because those indexes influence the running safety and ride comfort of high speed train. Because of the complexity of structural and train response at the girder end region of long-span railway bridges, on-site test and model test shall be done continuously to find out the interaction mechanism of the coupling system of bridge, railway track, movable BEJ and running train.

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