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Simulation Analysis of Continuously Welded Rail on Bridge— Longitudinal Force of Continuously Welded Rail on 48m Continuous Girder Bridge

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ABSTRACT: In many unfavourable condition, such as subgrade settlement and to save arable land , to protect the environment and cross obstacles such as rivers, gullies and mountains bridges are usually used to replace the subgrade which serves as a supporting structure for the railway track, resulting in a series of interaction problems between the CWR and the beam on the bridge which is one of the important issues in the design of high-speed railway bridges.

After the CWR is laid on the bridge, under the action of temperature, train braking force and vertical bending force, there will be relative interaction between the beams and rails due to the consequence's behaviour of one on the behaviour of the other. This interaction takes the form of force in the rail and in the deck and its bearing, as well as displacement of the various element of the bridge and track.

This paper establishes the models of standard simply supported beam of 50m span, continuous beam bridge of (32+48+32)m which is used for the studied of temperature force, vertical live load (bending force) and train braking force, analysis of the interaction between the beam and rail, discusses the influence of design parameters on the stress of beam rail system, summarizes the stress characteristics of beam rail system on simply supported beam, continuous beam bridge and puts forward design suggestions.

This paper mainly includes the following contents:

(1) The interaction between railway track and bridge beam

(2) Finite element analysis by a SAP2000 software of 50m simply supported beam, a simple supported beam track interaction model is established by SAP2000. According to the railway code, the temperature load, vertical live load (bending force) and braking force are loaded on it to observe the deformation behaviour of the track;

(3) Establishment of continuous bridge trackby SAP2000. Temperature load, vertical live load and braking force are loaded on the model to study the deformation law of track stress and the horizontal force of pier top;

(3) For the long-span continuous beam, a variety of small resistance fasteners and rail expansion regulator combined layout scheme are set for comparison and selection. According to the domestic and foreign standards, the limit temperature span length of the fixed area of the CWR and the limit value of the longitudinal stiffness of the brake pier of each span of the continuous beam bridge are deduced, and the impact of the collision effect on the CWR on the continuous beam is discussed.

KEYWORDS: Railway simply supported beam; track engineering; Continuous bridge; Beam-rail interaction; continuously welded rail CWR.

I. INTRODUCTION

In the process of high-speed railway construction, it is possible to cross many unfavourable terrains and avoid adverse factors such as subgrade settlement. In China, bridges are usually used to replace the subgrade as the supporting structure of the track. Now the proportion of bridge replacing Subgrade in China has reached 50%, which causes a series of interaction problems between CWR and bridge.

Laying CWR track on bridge can improve the operation status of the bridge and track which will further reduce the maintenance of labour and material consumption. In addition to the temperature force, the CWR on the bridge is also affected by the longitudinal additional force. The rail shrinks and deforms due to the change of temperature, flexures, action of the live load, and action of the train braking force. The bridge is connected to the track, making the bridge and the track interlinked, Therefore the deformation of the bridge is constrained to a certain extent making both the bridge and the track to form a mutually constrained.

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CWR is widely used in high-speed railway in China. Considering the need of crossing mountains and rivers and existing lines in a straight line, avoiding subgrade settlement, protecting the environment and saving land, in the construction of high-speed railway in China, bridges are often used to replace the subgrade as the supporting structure of the track. Taking Beijing Shanghai passenger dedicated line as an example, the bridge length accounts for 80.7% of the total length of the line, and most of the bridge forms are double track whole hole simply supported box girder, accounting for 90% of the total length of the bridge, of which the most common is 32m simply supported girder. Therefore, it is necessary to study the interaction between beam and rail of small and medium span simply supported beam and continuous beam [1].

II. THETRACK-BRIDGE INTERACTION

The interaction between the track and the bridge due to thermal stresses and traffic forces occurs because both are connected through the wheel-rail contact that the relative vertical movement between the two is not permitted. Building CWR track over a bridge involve the transfer of forces and displacements of the bridge deck due to thermal expansion and contraction of the rail, longitudinal forces of traction and braking forces of the trains and locomotives from rails to bridge deck and partly to rails themselves. When the CWR is connected to the sleepers with the aid of elastic fasteners, and rest on a bridge deck with or without a ballast cushion, interaction between the track and the bridge deck takes place as the two are not free to move with respect to the other. This results in setting up of additional horizontal forces in the rails as well as in the bridge girders, which in turn will affect the design of bearings and sub-structures as well [2].

Most of the tracks on high speed railways consists of continuous welded rail, this track structure provides favourable technical and economic effects, as well as a significant improvement in driving comfort and protection of the environment from noise and vibration. Cost efficiency of the CWR track is the most evident in reducing maintenance costs, extending the service life of the railway superstructure and substructure, as well as reducing traction costs and environmental protection costs [3].

Thus, interaction between the track and the bridge occurred because they interlinked (both the track and bridge are connected together) as it was earlier discussed, regardless of whether the railway track is directly fastened or a ballast track (has a ballast bed). This interaction takes the form of forces in the rails and in the deck and its bearings, as well as displacement of the various elements of the bridges.

If this interaction is under control, then the bridge will continue to fulfil its function i.e. supporting the track without the track being subject to any irregularities [4].

In summary, In the track-bridge interaction, there are two factors that have the greatest influence on the longitudinal force transfer: one is the longitudinal displacement resistance of the track bed and the other is the longitudinal horizontal stiffness of the bridge substructure. In the interaction between the line and the bridge, the rail transfers part of the stress to the lower structure through the ballast layer. The greater the longitudinal stiffness of the lower structure of the bridge, the better the transfer effect. On the contrary, it will lead to the increase of the rail stress. In order to meet the limitation of rail stress, the substructure must maintain a certain rigidity.

III. FACTORS AFFECTING TRACK-BRIDGE INTERACTION

The factors that could lead to interaction effects are those that cause relative displacement between the track and the deck.

The cases are listed below:

[1] The thermal expansion of the deck only, in the case of CWR, or the thermal expansion of the deck and the rail, whenever a rail expansion device is present.
[2] Deformation of the concrete structure due to creep and shrinkage
[3] Rotation of the deck on its supports as a result of the deck bending under vertical traffic loads.
[4] Longitudinal displacement of the supports under the influence of the thermal gradient
[5] Horizontal braking and acceleration forces.
[6] Deformation of the structure due to vertical temperature gradient.

IV. ESTABLISHMENT OF SIMPLY SUPPORTED BEAM BRIDGE MODEL

At present, analytical method and finite element method are generally used to study the mechanical characteristics of CWR bridge and track system. The finite element method is simple, practical and high-precision, so this paper uses the finite element method of 50m simply supported beam bridge for the research. Calculation of Track-Bridge Interaction based on finite element method by SAP 2000 is a complex task that has to do with the design and analysis of the consequence behaviourof the element frame i.e. the consequence of behaviour of the rail on the behaviour of the

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bridge and vice-visa which occur as an interlinked between the two structure (Bridge and Rail).

For the purpose of this calculation the model was taken as a case study for the analysis considering the temperature load (expansion force), vertical live load (bending force) and train braking force load. Through the analysis of the software model, the rail longitudinal force and the beam top horizontal force are obtained.

Therefore, in the modelling, the nonlinear member element is used to simulate the longitudinal resistance of the line, the member and steel arm are used to simulate the beam, and the vertical spring is used to simulate the vertical stiffness of the fastener [5] as shown in the figure below;

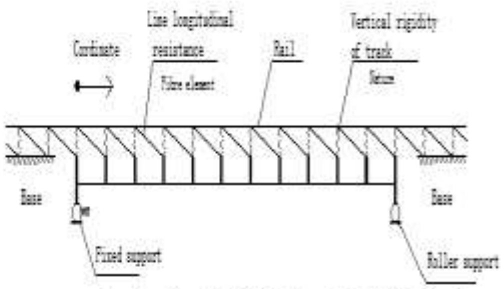

Figure 1: mechanical model of simply supported track-bridge interaction

The vertical connection stiffness between the track and the beam body is mainly provided by the fastener [M]. The vertical static stiffness of the fastener is usually 40-60mn / M and the dynamic stiffness of the fastener system is generally 1.5 times of the static stiffness, therefore for this paperit was taken as 60Mn /M [6] and the rigidity of substructure is 3000kN / cm.

V. MODEL PARAMETER

In this paper, 60kg/m rail (CHN60)is used as shown in the table below;

Table 1 parameters of CHN60 rail section

	Mass per meter (kg)	Cross sectional area (mm^2)	Section height (mm)	Distance between centre of gravity and bottom of orbit (mm)	Inertia moment to horizontal axis (mm^4)	Moment of inertia to vertical axis (mm^4)
CHN60	60.64	7745	176	81.2	32170000	5240000

According to UIC code, when the CWR is in a fixed area, the temperature change of the rail does not cause the displacement of the track, so in the calculation of the expansion force, only the temperature change of the beam itself needs to be considered. In the code for design of railway CWR track, the temperature change range of concrete bridge with ballast track is 15 ℃, 25 ℃ for steel beam and 20°C for concrete beam without ballast track [7,8].

Vertical live loadadopts for the train is the uniformly distributed in accordance with the German code and European code in which the uniformly load is 64Kn/m.

Braking force increases with the deceleration of the train. When the train stops running, the braking force reaches the maximum value. In this paper, on the basis of UIC code, the load range is 300m according to 16kn /m/ line [7,9].

The bridge beams are of a concrete grade of C50 used to casted the beam of the bridge which was defined to be of a rectangular frame section whose section parameter was set from default as depth (length) 3500mm and the width (breadth) is 4000mm.

A 50m long beam section model is established. Each beam section unit is 1m long, the elastic modulus of beam unit material (E) is 3.45 × 105N/mm^2, the coefficient of thermal expansion of the beam (A) is 1.0 × 10-5, the concrete strength grade is 50000 which C50 in which the shape of the beam is rectangular section.

The upper flange rigid arm is established by setting the coordinate system of Y axis node at the corresponding position of 1.765m above the beam nodes, and these nodes are connected with the beam nodes through the steel arm.

The lower rigid arm such as the fixed and roller support are established by setting the joint established at the corresponding position of 1.984m under the joint at both ends of the beam element, and the two joints are connected with the beam element above them by the steel arm.

The rail was Set up at the joint corresponding position of 1.865m above the beam joint, and extend the rail on the beam to 116 joints on both sides respectively, connect these joints with the frame of rail attribute to establish the unit, and the connected section is the rail. The elastic modulus (E) of rail is 2 × 106 N /mm^2, Poisson (U) ratio is 0.3, coefficient of thermal expansion (A) is 1.2 × 10-5 ℃, and bulk density is 7.85N//mm^3.

The rail joint is connected with the joint at the corresponding position 0.1M below it through

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connection. The property of the connection is that the vertical resistance is elastic and its rigidity is 600000N/mm. The longitudinal resistance of the line is a nonlinear broken line. Its value is selected base on the specification shown below.

$$r=\begin{cases} 12.0u & \leq 2mm \\ 24, u & > 2mm \end{cases}$$

Whereu is the relative displacement of track-bridge.

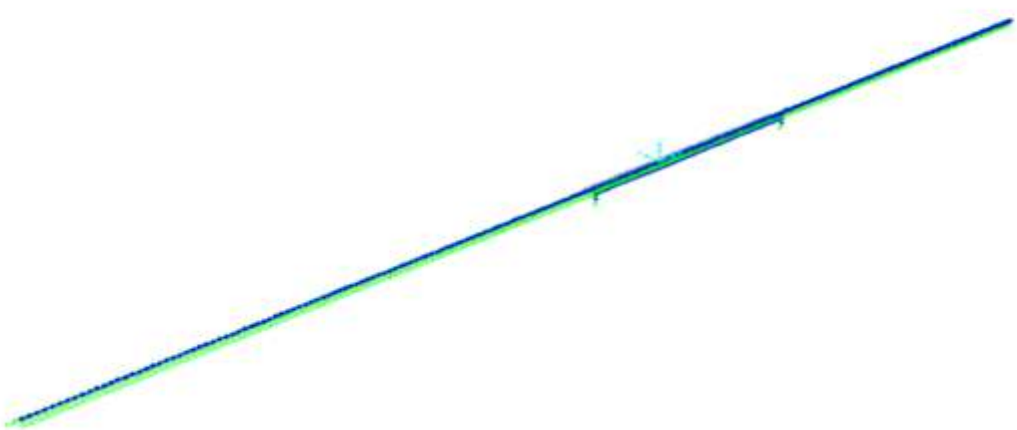

Figure 2: finite element model of 50m simply supported beam

VI. DISTRIBUTION RULE OF LONGITUDINAL FORCE ON THE SIMPLY SUPPORTED BRIDGE BEAM

[1] Expansion Force

The temperature load is applied on the beam element on the finite element model, and 15 ℃ is adopted according to Chinese code [8]. During the application of the temperature load the aspect of the temperature variation should be considered which will result in the differences in temperature between the deck and the rail and also causes a change in length in a free moving structure.
The calculation results are shown in Figure below

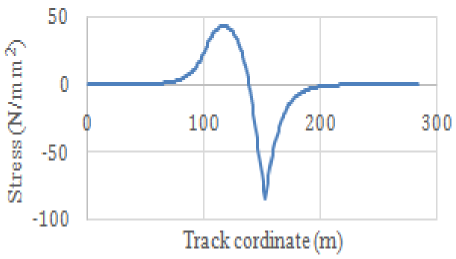

Figure 3: Rail axial stress (expansion force)

It can be seen from the figure above that the axial stress of the rail near the beam end of the beam body reaches the maximum value of 43.2 MPa and -82.3MPa respectively (a positive value indicates tensile stress and a negative value indicates compressive stress).

[2] Bending Force

Vertical traffic load which is uniformly distributed loads cause the beam of the bridge (deck) to bend in which end up causing rotation of end of the section and displacement of the upper edge of the beam. Applied 64KN/m vertical uniform load [10,11] above the bridge.
The calculation result is shown below

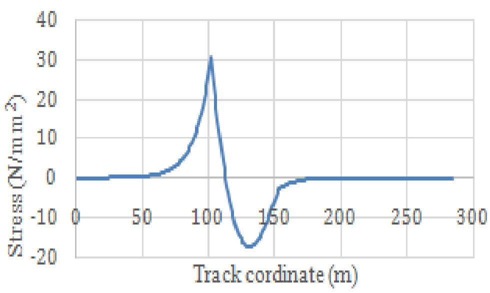

Figure 4: Rail axial stress (deflection force)

It can be seen from figure 4 that the maximum axial stress of the rail at the support at the left end of the beam is 31.6MPa, and the minimum axial stress of the rail in the simple supported beam span is - 18.6MPa.

[3] Braking Force

The braking force is added to the rail at the right end of the beam from the left Subgrade of the built finite element model, which is 16KN/m [12].
The calculation result is shown below

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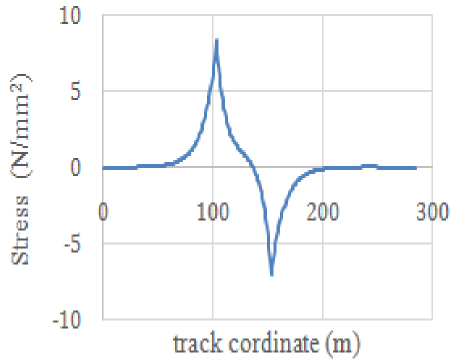

Figure 5 Rail axial stress (braking force)

It can be seen from Fig. 5 that under the braking force, the rail stress at both ends of the simply supported beam has an extreme value of 8.6MPa and -7.3MPa as maximum and minimum axial stress respectively.

VII. THE MODEL TRACK OF CONTINUOUS BEAM BRIDGE

Same as the simply supported beam model, for the continuous beam bridge of (32+48+32) m, the following assumptions were made:

[1] The lateral effect of each component and constraint is ignored;

[2] No structural weight.

Since the modelling is based on the same Material and has the same structure composition and the same length of roadbed section. Therefore, the same simplified mechanical calculation model is adopted, as shown in the figure below:

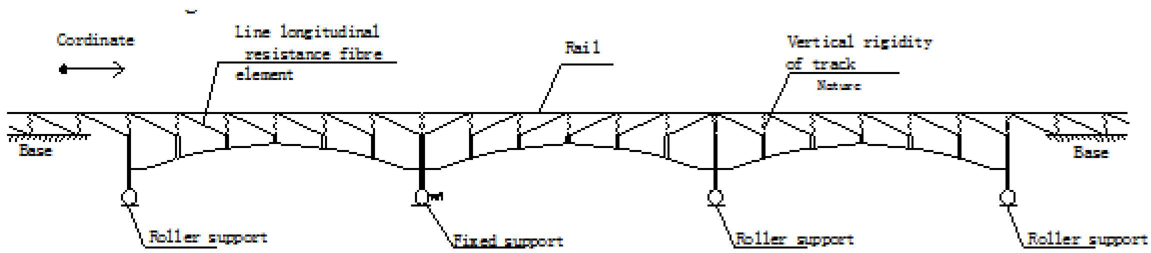

Figure 6 schematic diagram of mechanical calculation model of continuous beam bridge of span (32+48+32) m

Compared with the simply supported beam model, the physical model, the beam body simulation by the entity unit, the base plate and the track plate and subgrade section bearing layer of the surface in the shell element simulation, rail used in the beam element (that is, the framework of SAP2000 unit) simulation, the corresponding position of connecting links has the similar properties, but because the number of connection Settings and set up different parameters, to ensure that the simulation model parameters are the same.

For the simulated length of subgrade section, the German specification requires that it must have the necessary length of $l \geq l + 40$m, where l refers to the average single-span length of each span of the bridge [13,14]. According to UIC specification, the model of 100m roadbed section is built at each end of the bridge [4,13]. Considering the safety, the length of roadbed section is 100m.

The distance of 1.77m between the track plate and the bridge is reserved. The track plate in the roadbed section is 99.9m long, at the same height as the track plate on the bridge and corresponding to the transverse position, with the same width. The Links connection is bound in 6 directions, namely U1, U2, U3, R1, R2 and R3. The connection is U1 linear, U2 polyline, R3 direction is not constrained. The stiffness of U1 is 600000N/mm. The longitudinal resistance of the line is a nonlinear broken line.

Its value is selected base on the specification shown below

$$r=\begin{cases}12.0u & \leq 2mm\\ 24, u & > 2mm\end{cases}$$

Where u is the relative displacement of track-bridge.

VIII. DISTRIBUTION RULE OF LONGITUDINAL FORCE ON THE CONTINUOUS BRIDGE BEAM

In order to verify the correctness of the model, the analysis and calculation of the telescopic, flexural force (bending force) and braking force of the rail are carried out on the model, just like the simply supported beam model. By applying the temperature load of overall temperature rise of 15oc to the beam body, 64KN/m frame distributed load for the flexural force and 16KN/m frame distributed load for the braking force.

[1] Expansion Force

The temperature load is applied on the beam element on the finite element model, and 15 ℃ is adopted according to Chinese code[8].During the application of the temperature load the aspect of the temperature variation should be considered which will result in the differences in temperature between the beam and the rail and also causes a change in length in a free moving structure.

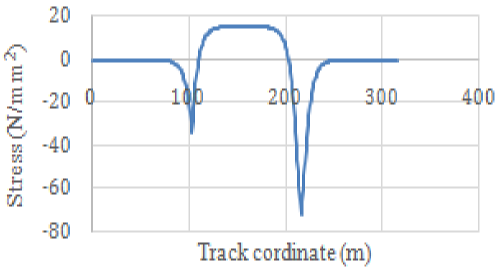

Figure 7 Rail axial stress (expansion force)

It can be seen from the figure above that the axial stress of the rail reaches the maximum value of 16 MPa and -72.3MPa respectively (a positive value indicates tensile stress and a negative value indicates compressive stress).

[2] Bending Force

When calculating the rail longitudinal force, the continuous beam is exerted of vertical live load of 64KN/m, the direction of vertical live load is downward which is determined by the entity node position, equal longitudinal spacing, the vertical position of the beam body surface, and the cross-sectional shape of the beam

The vertical live load is uniformly distributed loads and cause the continuous beam to bend in which end up causing rotation of end of the section and displacement of the upper edge of the eam.

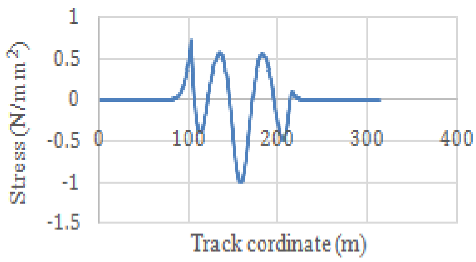

Figure 8 Rail axial stress (Flexural force)

The maximum axial stress of the is 0.78MPa, and the minimum axial stress of the rail in the simple supported beam span is – 0.98MPa.

[3] Braking Force

The braking force is added to the rail at the length equal to the total span of the bridge and opposite to the rail of the built finite element model, which is 16KN/m.

The calculation of the braking force is shown below;

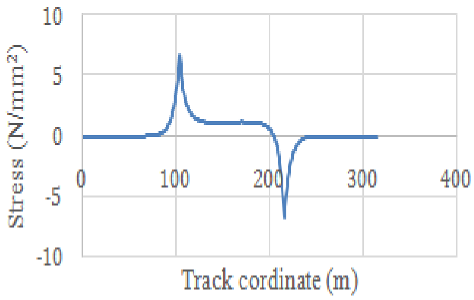

Figure 9 Rail axial stress (braking force)

From the figure above, it can be seen that under the braking force, the rail stress at both ends of the simply supported beam has an extreme value of 6.9MPa and -6.5MPa as maximum and minimum axial stress respectively.

IX. CONCLUSION

[1] This Paper introduced the principleof interaction between rail and beam both in china and other countries using a simply supported beam model and a continuous beam model of (32 + 48 +32)m span as a case study which was built and analysed by sap2000 by adopting an expansion force of 15oc, bending force of 64kN/m and train braking force of 16kN/m according to Chinese code.

[2] Through the establishment and analysis of the bridge track interaction of the simply supported beam model, it is found that under the action of temperature, vertical live load and braking force, this force reached the maximum value at both end of the simply supported beam model. The maximum tensile stress occur at the fixed support and the maximum compressive stress occurs at the movable support.

[3] We got to know that when temperature load, vertical live load or train braking force act on the continuous beam model, the extreme value of the rail axial stress appears near the sliding support at the left and right end of the continuous beam model or near its mid span position.

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