Influence of Near-field Pulse-like Ground Motion on Seismic Response of Steel-concrete Plate Composite Beam Bridges with Seismic Isolation

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Abstract: For steel-concrete composite bridges, different seismic excitations are selected, and nonlinear time-history analysis method is used to study the influence of near-field seismic impulse effect on seismic response of steel-concrete plate composite beam bridges and damping effect of steel-concrete plate composite beam bridges. Under Near-Field Seismic excitation, cable-stayed seismic isolation bearings are used. The seismic responses of main girder displacement, bearing deformation, shear force and pier seismic force are compared and analysed through two directions of input. The influence of impulse earthquake on seismic response of steel-concrete composite beams with isolation bearings is studied. The seismic response of steel plate composite beam bridges is basically smaller than that of non-isolation girder bridge after the isolation bearings are laid out, and the response decreases by more than 40%. The isolation bearings have good damping effect. Therefore, under the action of impulsive ground motion, it is suggested to adopt isolation bearings, such as Cable-sliding Friction Aseismic Bearing.

1. Introduction
Near-field ground motions are more complex than far-field ground motions. The important characteristics of near-field ground motions, such as rupture directivity effect, hanging wall and hanging wall effect, basin effect and impulse effect, are the main causes of serious damage to engineering structures. The main characteristics of near-fault ground motions are pulse-like ground motions caused by forward directivity effect and sliding impact effect. Compared with the traditional bridge structure, adding isolation device between pier top and beam body can prolong the period of structure and enhance the hysteretic energy dissipation capacity of structure, so as to effectively reduce the damage caused by earthquake. In this regard, considerable research [1-3] has been done at home and abroad. For near-field ground motions, due to their different seismic action mechanism, impulse shock releases a large amount of seismic energy in a short time. It is necessary to study the effectiveness of seismic isolation devices under near-field earthquake. Seismic response of isolated bridges subjected to near-field long-period impulsive ground motions has also become an urgent issue [4-5]. Li Xuehong et al [6] found that the impulse characteristics of long-period ground motions are disadvantageous to the performance of bearing isolation.

As steel-concrete composite structure bridge has better structural performance, it is now widely used. Liu Yang et al [8] evaluated the seismic performance of small and medium-span steel-concrete composite bridges under near-field seismic excitation, but little research has been done on the impact...
of near-field seismic impulse effect on steel plate composite beam bridges. Therefore, this paper selects eight near-field ground motions as seismic input to study the effect of near-field ground motions on seismic reduction effect of steel-concrete plate composite beam bridges with seismic isolation, and the seismic response characteristics of continuous girder bridges with non-seismic isolation composite bridges are compared.

2. Relying on Engineering and Establishment of Finite Element Method

Taking a steel-concrete composite continuous girder bridge as an engineering background, a 4*35m continuous girder bridge is selected for analysis. The composite girder takes I-shaped steel girder as the main girder, and forms a steel skeleton by welding with end cross girder, middle cross girder and other steel cross girders. The prefabricated bridge deck is connected into a whole by shear nail steel main girder. The standard cross section of main girder is shown in Fig.1. The width of the deck is 13.025 m and the height of the I-shaped steel girder is 1.75 m. The ML15 shear nails with diameter of 22 mm and nail length of 190 mm are arranged along the main girder and the upper flange of the cross girder.

![Fig.1. Standard cross section of main girder](image)

When establishing the seismic finite element model of the composite girder, the along-bridge direction is X-axis, the cross-bridge direction is Y-axis, and the vertical is Z-axis. In order to improve the accuracy of model simulation, thick shell element is used to discretize prefabricated concrete bridge deck into space structure; steel girder, cross girder and pier are simulated by space frame girder element; shear nail and support are simulated by LINK element; pier base is simulated by mass point and pile foundation is simulated by 6*6 concentrated soil spring. The finite element dynamic calculation model of the composite girder is shown in Fig.2.

![Fig.2 Seismic finite element model of steel-concrete plate composite beam bridges](image)

3. Near-field ground motion input

In order to compare and analyze the influence of impulse characteristics of near-field ground motions on seismic response of steel-concrete plate composite beam bridges, four forward-directional impulse-effect ground motions TCU051-EW, TCU054-EW, TCU082-EW, TCU102-EW and four non-impulse-effect ground motions TCU071-EW, TCU072-EW, TCU078-EW and TCU079-EW are selected as earthquake input. The specific information of ground motions is shown in Table 1.

| Name of ground motion | PGA/g | PGV/cm | PGA/PGV/s |
|-----------------------|-------|---------|-----------|
| TCU051-EW             | 0.16  | 53.84   | 0.34      |
| TCU054-EW             | 0.15  | 46.02   | 0.31      |
| TCU082-EW             | 0.23  | 54.93   | 0.24      |
| TCU102-EW             | 0.30  | 91.70   | 0.31      |
4. The influence of impulse characteristics of ground motion on the response of bridge with isolation bearing

Under the action of near-field earthquake, the cable-stayed seismic isolation bearing is used. At the same time, the impulsive earthquake motion is used as the excitation. Through two directions of input, the seismic responses of the main girder displacement, bearing deformation and shear force, as well as pier seismic force are compared and analyzed, and the influence of the pulse seismic on the seismic response of the steel-mixed composite girder with the seismic isolation bearing is studied.

The cable-stayed seismic isolation bearing is a kind of seismic isolation bearing, which can balance the force and displacement of the structure under earthquake, reduce the seismic action of the structure, effectively limit the maximum relative displacement of pier and girder, and prevent the occurrence of girder falling disaster. The mechanical model of cable bearing is shown in Fig. 3. The parameters of cable bearing in this paper are as follows: the free travel is 0.1m, and the horizontal stiffness of cable member of cable bearing is 11670kN/m.

![Restoring force model](image)

In the picture: $u_0$——free travel of cable shock absorption bearing, $K_H$——horizontal stiffness of cable members with cable shock absorption bearings: $K_H = 4 \cdot \cos^2 \alpha \cdot K_s$, $K_s = EA / L$

4.1. Displacement of main girder end

Table 2 lists the displacements of the end of the main girder with different supports under near-field impulsive ground motion. It can be seen that the longitudinal and transverse displacement of the main girder decreases when the cable-stayed bearing is used. The longitudinal displacement of the main girder decreases from 569.79 mm to 345.67 mm, with a decrease of 39.33%, and the transverse displacement of the main girder decreases from 441.83 mm to 250.45 mm, with a decrease of 43.32%. It shows that the isolation bearing can limit the displacement of the girder end, and greatly reduce the possibility of the main girder sliding along the longitudinal and transverse directions and the longitudinal girder collision.

### Tab.2 Comparison of effect of seismic isolation bearing on displacement of girder end

| Ground motion | Plate bearing | Isolation bearing | Ordinary support | Isolation bearing |
|---------------|---------------|-------------------|------------------|------------------|
|               | Longitudinal | Longitudinal      | transversal      | transversal      |
|               | displacement | displacement /mm | displacement /mm | displacement /mm |
| TCU051-EW     | 375.28        | 198.98            | 269.21           | 159.41           |
| TCU054-EW     | 377.81        | 264.36            | 270.12           | 193.62           |
| TCU082-EW     | 234.55        | 204.36            | 172.35           | 153.62           |
| TCU102-EW     | 569.79        | 345.67            | 441.83           | 250.45           |

Note: Plate bearings are the type of bearings arranged in the design of plate composite beam bridges, and cable-stayed bearings are the type of seismic isolation bearings.
4.2. Bearing response

Table 3, Table 4 and Figure 4 show the comparison of bearing deformation and shear force. It can be seen that the displacement and shear force of plate composite beam bridges with isolation bearings are less than those of plate composite beam bridges with plate rubber bearings under near-field long-period impulsive ground motion. Among them, the maximum reduction of longitudinal displacement of side bearing is 59.4%, the maximum reduction of transverse displacement is 58.04%, the maximum reduction of longitudinal displacement of middle bearing is 35.91%, and the maximum reduction of transverse displacement is 37.56%. For the bearing shear of the middle pier, the maximum reduction of the longitudinal and transverse bearing shear of the plate composite beam bridges with seismic isolation is 41.45% and 48.27%, respectively. It can be seen that the bearing response of plate composite beam bridges under near-field ground motions is greatly reduced after the use of isolation bearings. Although it still exceeds the capacity of bearing displacement and causes the bearing damage, the cable of isolation bearings limits the horizontal displacement of the bearings, so the bearing displacement is well controlled.
4.3. Seismic force of pier

Figure 5 lists the shear and bending moments of the middle piers of composite beams subjected to various ground motions (the axial forces are not listed). After using cable-stayed bearing, the transverse shear force and bending moment of pier increase slightly under TCU102-EW ground motion, but overall, the longitudinal and transverse shear force and bending moment of mid-pier are significantly smaller than those of composite beam pier with plate bearing, and the longitudinal and transverse shear force and bending moment decrease are about 50%.

5. conclusion

(1) The seismic response of steel plate composite beam bridges is less than that of non-isolation girder bridge, in which the main girder displacement decreases by about 40%, the support response decreases by up to 58.04%, and the longitudinal and transverse shear and bending moment decreases of piers are about 50%. The results show that the shock absorption effect of the isolation bearing is good.

(2) Compared with non-isolation plate composite beam bridges, the arrangement of isolation bearing still exceeds the capacity of bearing displacement, which leads to the damage of bearing, but the cable of isolation bearing restricts the horizontal displacement of bearing, so the displacement of bearing seat is well controlled, which greatly reduces the possibility of the main girder sliding out along the longitudinal and transverse directions and the collision of longitudinal girder.

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