Effects of Near-field Ground Motion Characteristics on Seismic Response of Ground Motion Characteristics

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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. The results show that the seismic response of the bridge under impulsive ground motion is obviously greater than that under non-impulsive ground motion, which is very disadvantageous to the seismic resistance of the pier. Under near-field impulsive ground motion, the seismic response of main girder, support and pier is obviously greater than that of non-impulsive ground motion. The displacement of the main girder is magnified by 4.5 times, the bearing response is magnified by 4 times, and the shear force and bending moment of the most disadvantageous section of the pier are magnified by 2.3 times and 4.04 times.

1. Introduction

Liao [1] adopts 12-storey and 5-storey reinforced concrete frame structures, and Li Shuang et al [2] adopt 5-storey and 15-storey reinforced concrete frame structures to compare the responses of these structures under near-fault and far-field ground motions respectively. The results show that the responses of these structures under near-fault ground motions are larger than that under far-field motions and the near-fault ground motions have higher strength and displacement requirements for structures. Kalkan et al [3] analyzed the effects of different velocity pulses on the seismic response of three steel frame structures with four, six and thirteen stories respectively. The results show that the forward directional effect pulses mainly increase the higher-order mode response. Yang Dixiong et al [4] have studied the response characteristics of the structure under near-fault impulsive seismic excitation. The results show that for isolated buildings and long-span cable-stayed bridges, the effect of near-fault seismic rupture directionality on the structure is significant. Jiang Yi et al [5] studied the influence of near-fault ground motion on seismic response of high-rise steel structures. The results showed that the basic mode responses of structures were mainly excited by impulsive ground motions with slip-impact effect and forward-directional effect, while the high-order mode responses were induced by non-velocity impulsive ground motions, and the structural damage effect of impulsive ground motions was much stronger than that of non-velocity impulsive ground motions.

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. PTFE plate rubber bearings are used for side piers, high friction plate rubber bearings for middle piers, prefabricated piers and PHC pipe piles for lower structures.

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.

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. In order to be comparable, the horizontal peak acceleration of the selected near-field ground motions is adjusted to 0.3g, and the ground motions are input along the longitudinal and transverse directions respectively, without considering the vertical effect.

| 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      |
| TCU071-EW             | 0.528 | 52.30  | 0.10      |
| TCU072-EW             | 0.477 | 71.90  | 0.15      |
| TCU078-EW             | 0.447 | 40.23  | 0.09      |
| TCU079-EW             | 0.592 | 70.53  | 0.12      |
4. Influence of impulse characteristics of ground motion on seismic response of bridges

The influence of impulse earthquake on the seismic response of steel-concrete composite girders is analyzed through the seismic response of main girder displacement, bearing deformation and shear force, and pier seismic force.

4.1. Displacement of main girder end

Table 2 and Figure 3 show the displacement of the end of the main girder under near-field ground motion. It can be seen that the response results of non-impulse effect ground motion are relatively stable. The maximum longitudinal and transverse displacement of the girder end is 124.58 mm, while the response results of impulse effect ground motion are more discrete. The maximum longitudinal and transverse displacement of the girder end is 569.79 mm. The longitudinal and transverse displacements of the main girder under near-field impulsive ground motion are significantly larger than those of the main girder under non-impulsive ground motion, in which the longitudinal displacement of the main girder is amplified by 2.5-4.5 times and the transverse displacement is amplified by 2-4 times. It can be seen that the impulse characteristics of near-field ground motion are very disadvantageous to the seismic response of the main girder.

| Ground motion | Longitudinal displacement (mm) | Transverse displacement (mm) |
|---------------|-----------------------------|-----------------------------|
| TCU051-EW     | 375.28                      | 269.21                      |
| TCU054-EW     | 377.81                      | 270.12                      |
| TCU082-EW     | 234.55                      | 172.35                      |
| TCU102-EW     | 569.79                      | 441.83                      |
| TCU071-EW     | 124.58                      | 102.51                      |
| TCU072-EW     | 91.89                       | 109.28                      |
| TCU078-EW     | 103.50                      | 80.38                       |
| TCU079-EW     | 94.95                       | 112.20                      |

4.2. Bearing response

Because the composite girder is below 7 degrees of fortification intensity, the whole bridge adopts the support arrangement scheme without fixed bearings, and bilinear LINK element is used to simulate the end-bearing PTFE slider bearing. The pre-yield stiffness is 2977 kN/m and the yield force is 70.62 kN, without considering the post-yield stiffness. The high friction plate rubber bearing with middle bearings is simulated by linear LINK element, and the bearing stiffness is 4602kN/m. Table 3, Table 4 and Figure 4 show the calculation results of horizontal shear and deformation of supports.

According to the tables and graphs, under the action of impulsive and non-impulsive earthquakes, the lateral and longitudinal yielding forces of the side bearings reach the horizontal yielding force of the supports, which indicates that the side bearings have yielded. However, compared with the displacement of the support seats, the displacement caused by the impulsive ground motion is
obviously larger than that caused by the non-impulsive ground motion.

It is noteworthy that, since the bridge end support of the example uses a PTFE sliding plate bearing, the longitudinal limit displacement is 130 mm; the longitudinal and lateral limit displacement of the high friction plate rubber bearing used in the intermediate pier is 63 mm. However, under the selected near-field Seismic action, whether impulse or non-impulse effects, the bridge supports exceed the horizontal displacement limit. Therefore, anti-drop girders and limit devices should be adopted to prevent falling girders and girder end collision and other seismic hazards.

Tab.3 Seismic response comparison of side bearing under different ground motion

| Ground motion | Vertical input | Horizontal input |
|---------------|----------------|------------------|
|               | displacement /mm | shear force /kN | displacement /mm | shear force /kN |
| TCU051-EW     | 311.51          | 70.25            | 275.68          | 70.23            |
| TCU054-EW     | 291.03          | 70.24            | 271.87          | 70.23            |
| TCU082-EW     | 170.14          | 70.17            | 170.46          | 70.17            |
| TCU102-EW     | 577.31          | 70.41            | 438.79          | 70.33            |
| TCU071-EW     | 119.22          | 70.14            | 112.15          | 70.13            |
| TCU072-EW     | 104.07          | 70.13            | 110.91          | 70.13            |
| TCU078-EW     | 86.55           | 70.11            | 87.01           | 70.12            |
| TCU079-EW     | 67.64           | 70.11            | 109.22          | 70.13            |

Tab.4 Seismic response comparison of side bearing under different ground motion

| Ground motion | Vertical input | Horizontal input |
|---------------|----------------|------------------|
|               | displacement /mm | shear force /kN | displacement /mm | shear force /kN |
| TCU051-EW     | 184.06          | 847.04           | 201.02          | 925.10           |
| TCU054-EW     | 171.91          | 791.13           | 202.43          | 931.60           |
| TCU082-EW     | 141.85          | 657.38           | 147.24          | 723.12           |
| TCU102-EW     | 319.28          | 1469.33          | 324.01          | 1491.08          |
| TCU071-EW     | 81.94           | 377.10           | 80.59           | 370.86           |
| TCU072-EW     | 61.65           | 283.73           | 92.07           | 423.70           |
| TCU078-EW     | 63.08           | 290.28           | 63.78           | 293.53           |
| TCU079-EW     | 43.29           | 199.24           | 86.30           | 397.13           |

4.3. Seismic force of pier

Pier is the key component of bridge seismic resistance. For the integral prefabricated pier used in the composite girder, its pier bottom structure is extremely complex, which may affect the seismic performance of pier and even the whole bridge. In order to analyze the seismic response of piers under different input conditions, only the shear force and bending moment of middle piers are listed here (because the axial force of piers is mainly affected by vertical earthquake, but the vertical earthquake
action is not considered here, so the axial force is not listed), as shown in Tables 5 and Figure 5.

| Ground motion | Vertical input | | Horizontal input |
|---------------|---------------|---------------|-----------------|
|               | displacement /mm | shear force /kN | displacement /mm | shear force /kN |
| TCU051-EW     | 953.11         | 9967.88       | 967.69          | 3721.3          |
| TCU054-EW     | 862.88         | 10121.7       | 908.18          | 4537.4          |
| TCU082-EW     | 506.79         | 6270.95       | 565.75          | 2739.7          |
| TCU102-EW     | 1450.2         | 14410.53      | 1447.2          | 6334.7          |
| TCU071-EW     | 386.61         | 3804.80       | 482.52          | 1567.5          |
| TCU072-EW     | 296.52         | 2699.33       | 457.72          | 1714.3          |
| TCU078-EW     | 343.91         | 2726.86       | 395.68          | 1579.6          |
| TCU079-EW     | 238.99         | 2706.98       | 453.04          | 1682.7          |

From Table 4 and Figure 5, it can be seen that the seismic force of the pier under impulsive ground motion is significantly higher than that under non-impulsive ground motion, and the shear force and bending moment of the most disadvantageous section of the pier are magnified by 2.3 and 4.04 times.

5. conclusion

(1) The longitudinal and transverse displacements of the main girder under near-field impulsive ground motion are significantly larger than those of the main girder under non-impulsive ground motion, in which the longitudinal displacement of the main girder is amplified by 2.5-4.5 times and the transverse displacement is amplified by 2-4 times.

(2) For the horizontal displacement and shear force of the middle support, the response caused by the impulse effect ground motion is obviously increased. Specifically, the longitudinal response of the bearing is 2-4 times that of the non-impulse effect ground motion, and the transverse response of the bearing is 2-3.5 times that of the non-impulse effect ground motion.

(3) The seismic force of the pier under impulsive ground motion is significantly higher than that under non-impulsive ground motion, and the shear force and bending moment of the most disadvantageous section of the pier are magnified by 2.3 and 4.04 times.

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