Study on Parametric of Moving Amount of Unseating Prevention Devices for Highway Bridges

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Abstract: Taking a three-span continuous bridge as the research object, the nonlinear time history analysis method is adopted. The influence of the moving amount of the unseating prevention devices on the seismic performance of the bridge under different fortification intensity was studied, and the reasonable value of the moving amount of the unseating prevention devices was discussed. Research shows that, in the starting range of the unseating prevention devices, the smaller the moving volume of the unseating prevention devices, the higher the fortification intensity, the decrease amplitude in the relative displacement of the pier beam, the internal force of the unseating prevention devices and the ratio of bending moment at bottom of side piers to middle piers are all greater. The higher the fortification intensity of the bridge site, the value of the reasonable movement of the unseating prevention devices will have greater. When the acceleration peaks are 220cm/s², 400cm/s² and 620cm/s², the reasonable value of the moving amount can respectively be 9cm, 11cm, and 15cm.

1. Introduction

Under the action of earthquakes, large relative displacements are generated between the upper and lower structures of the bridge, which results in the collision between the beam end of the girder and the main beam. The collision not only damages the beam end, but may even cause falling beam. For example, in the great Hanshin Earthquake of Japan in 1995, the Xigonggang arch bridge collapsed due to the failure of the bearing and restraint components. In the Tangshan earthquake of 1976, falling beam damage was one of the most serious phenomena of bridge damage. In the 2008 Wenchuan earthquake in Sichuan province, many bridges lost their functions due to falling earthquakes and severely affected the work of earthquake relief work.

Unseating prevention device is an effective measure to prevent the bridge beams falling down from the earthquake damage[1-2]. As the second restraining device in the collapse-proof system, the unseating prevention devices is to prevent the falling beam under the action of the unexpected earthquake and plays an important role in the collapse-proof system[3]. Domestic scholars have carried out a systematic study of unseating prevention devices. Wang Fang-fang put forward the calculation method of prestressed steel strand falling beam prevention device by using the principle of dynamic sudden loading[4]. Zhu Wen-zheng considered the ground motion parameters and the importance factor of earthquake load on bridges, and proposed a method for calculating the design seismic force of unseating prevention devices[5]. Zhang Yu-min analyzed the force characteristics and anti-drop beam effects of the unseating prevention devices with different design parametric under the action of a strong earthquake sequence[6].

However, the relevant researchers did not give a clear value for the parameters of the unseating
prevention devices and it was difficult to guide the seismic design of the actual bridge. The value of the moving amount of the unseating prevention devices has a significant influence on the anti-dropping beam effect, and the value of the moving amount varies with the intensity area. Therefore, it is of great significance to study the influence of the moving amount of the unseating prevention devices on the seismic response of the bridge under different fortification intensity and to discuss its reasonable value.

In this paper, taking a three-span continuous bridge as the research object, the nonlinear time history analysis method is adopted. The influence of the moving amount of the unseating prevention devices on the seismic performance of the bridge under different fortification intensity was studied, and the reasonable value of the moving amount of the unseating prevention devices was discussed.

2. Analysis and calculation example of the unseating prevention devices

The calculated example is a 3×30 m continuous beam bridge, as shown in figure 1. The upper structure adopts the continuous beam bridge with single box and single room, and the height of the box girder is 1.5m, the cross section of the main girder is shown in figure 2. The pier is a solid abdominal circular section with a section diameter of 1.6m. The beam body material is C50 concrete and the pier material is C30 concrete. The total width of the bridge deck is 5 m and the asphalt pavement is used. The side pier is made of PTFE slide bearing, and middle piers use plate rubber bearings. The site where the bridge is located belongs to the second class site.

The bridge structure was modeled using finite element software Midas/Civil. The main beam was modeled with elastic beam elements. The bridge piers were modeled with fiber beam elements. The rubber bearings were simulated using a non-linear general connection spring element. The bottom of the pier and the foundation are fixedly connected, and the influence of pile foundation is not considered.

3. Selection and Simulation of the unseating prevention devices

According to the characteristics of the bridge model in this paper, the cable-joint beam cable connecting device is selected. Unseating prevention devices is arranged at the end of the beam at the left and right side of the bridge. The simplified model of the finite element model is shown in figure 3.

The unseating prevention devices uses a nonlinear hook element simulation as shown in figure 3. The force-displacement relationship of the nonlinear hook element is:

\[
f = \begin{cases} 
  k(d-s) & d-s > 0 \\
  0 & d-s < 0
\end{cases}
\]

In the formula: \( f \) —— the force of the unseating prevention devices; \( d \) —— relative displacement of pier and beam; \( s \) —— the moving amount of unseating prevention devices.

In this paper, the thickness of the rubber bearing rubber layer used in the bridge structure in this paper is 6.0cm, the maximum allowable shear deformation of the rubber bearing is \( \gamma \times H = 1.5 \times 6.0 = 9 \) cm.
The dead load reaction force of the bridge pier support is 1370 kN, and the unseating prevention devices of the bridge is designed by 1.5 times dead load reaction method. The design bearing capacity of the unseating prevention devices is:

\[ H_F = 1.5R_d = 1.5 \times 1370 = 2055 \text{ kN} \]

The prestressed steel strand (1×7)-9.50-1860-GB/T5224-2014 is selected, and the conditional yield load is 89.8 kN. The number of beam units is:

\[ n = \frac{2055}{89.8 \times 7} = 4 \]

4. Ground motion input

How to reasonably choose the actual ground motion record has important significance for the seismic response analysis of the bridge. Seismic wave selection should consider the three factors of the ground motion characteristics, namely, the spectral characteristics, the ground motion intensity and the duration of the earthquake. According to the site conditions of this bridge, the three seismic waves of El Centro, Taft and Northridge were selected (as shown in Table 1). According to the provisions of JTG B02-2013 Highway Engineering Seismic Code, the acceleration peak value of three seismic waves is adjusted to 220 cm/s\(^2\) (7-degree fortification), 400 cm/s\(^2\) (8-degree fortification), and 620 cm/s\(^2\) (9-degree fortification). The input direction of seismic waves is along the bridge.

| Serial number | Earthquake name | Record site | duration/s | PGA/g |
|---------------|-----------------|-------------|------------|-------|
| 1             | El Centro       | El Centro Site | 53.72 | 0.3569 |
| 2             | Taft            | Taft Lincoln School | 61.84 | 0.3154 |
| 3             | Northridge      | Northridge, Santa Monica, City Hall Grounds | 59.98 | 0.3703 |

5. Influence of the moving amount of the unseating prevention devices on the seismic response of structures

5.1 Parameter selection range of the unseating prevention devices

In order to study the influence of the moving amount of the unseating prevention devices on the seismic response of the structure, the influence law of the moving amount on the seismic response of the structure is analyzed by changing the movement of the unseating prevention devices.

The moving amount of the unseating prevention devices is selected within the range of 9 cm to 30 cm, and the increment is 2 cm. Cable length is 2.0 m. Input the seismic waves in Table 1, and the nonlinear
time history analysis method is adopted. The seismic response results of the moving amount of the unseating prevention devices to the bridge structure under different fortification intensities are calculated, and its laws are analyzed and summarized.

5.2 Influence of the moving amount on the relative displacement of the pier beam

Figure 5 shows the influence law of the moving amount of the unseating prevention devices on the relative displacement of the pier beam under three kinds of fortification intensities. It can be seen from the figure that the relative displacement of the pier beam is obviously reduced when the moving amount of the unseating prevention devices is within a certain range. The reduction rate of the relative displacement of the pier beam is inversely proportional to the moving amount of the unseating prevention devices. The greater the moving amount, the later the action of the unseating prevention devices and the smaller the decrease amplitude in the relative displacement of the pier beam. The moving amount of the unseating prevention devices is the same, and the higher the fortification intensity, the internal force of the unseating prevention devices will have greater. The greater it plays, the greater the decrease amplitude in the relative displacement of the pier beam and the better the anti-drop beam effect. Taking the El Centro seismic wave as an example, when the moving amount of the coupling beam device is 9 cm and the peak acceleration is 620 cm/s², the effect of reducing the relative displacement of the pier beam is best. Compared with the without unseating prevention devices, it is reduced by 50.47%.

5.3 Influence of the moving amount on the internal forces of the unseating prevention devices

Figure 6 shows the influence law of the moving amount of the unseating prevention devices on the internal force of the unseating prevention devices under three kinds of fortification intensities. It can be seen from the figure that the moving amount of the unseating prevention devices is within a certain range, and as the moving amount increases, the internal force of the unseating prevention devices gradually decreases. With the same moving amount, the higher the fortification intensity, the greater the internal force of the unseating prevention devices. When the unseating prevention devices no longer functions, its internal force is 0. Taking the action of the El Centro seismic wave and the acceleration peak at 400 cm/s² as an example, when the moving amount is 9 cm, the internal force of the unseating prevention devices is 927 kN, and when the moving amount is 13 cm, the internal force of the unseating prevention devices is 691 kN, a difference of 236 kN. Therefore, the moving amount has a significant effect on the internal force of the unseating prevention devices. In the case of ensuring that the relative displacements of the upper and lower structures of the bridge are reasonable, it is advisable to use an unseating prevention device with a large moving amount. When designing the unseating prevention devices parameters.
5.4 Influence of the moving amount on the bending moment of the bottom of the pier

Figure 6 shows the influence law of the moving amount of the unseating prevention devices on the ratio of bending moment at bottom of side piers to middle piers under three kinds of fortification intensities. It can be seen from the figure that the moving amount of the unseating prevention devices is within a certain range, and as the moving amount increases, the ratio of bending moment at bottom of side piers to middle piers gradually decreases. When the unseating prevention devices no longer functions, the ratio of bending moment at bottom of side piers to middle piers remains stable.

The fortification intensity has a significant effect on the ratio of bending moment at bottom of side piers to middle piers. In the starting range of the unseating prevention devices, the moving amount is the same, the higher the fortification intensity, the greater the ratio of bending moment at bottom of side piers to middle piers. The higher the fortification intensity, the greater the corresponding moving amount when the ratio of bending moment at bottom of side piers to middle piers is 1. It can be seen that the value of the moving amount of the unseating prevention devices has a significant influence on the distribution of seismic force among the piers. Therefore, when designing the parameters of the unseating prevention devices, a reasonable moving amount should be selected according to the area where the bridge site is located.

According to the results and laws of the response of the unseating prevention devices to the bridge structure under the above different fortification intensity, when the acceleration peaks are 220cm/s², 400cm/s² and 620cm/s², the reasonable value of the moving amount can respectively be 9cm, 11cm, and 15cm. At this time, the anti-dropping beam of the unseating prevention devices has a better effect, the internal force of side pier and middle pier is close, and the integrity of bridge structure is better.

6. Conclusions

1) The relative displacement of pier beam can be reduced effectively and the risk of falling beam damage
can be reduced by adding unseating prevention devices. In the starting range of the unseating prevention devices, the smaller the moving amount of the unseating prevention devices, the decrease amplitude of the relative displacement of the pier beam will have greater. With the same moving amount, the higher the fortification intensity, the decrease amplitude of the relative displacement of the pier beam will have greater.

2) The moving amount has a significant effect on the internal force of the unseating prevention devices. In the case of ensuring that the relative displacements of the upper and lower structures of the bridge are reasonable, it is advisable to use a unseating prevention devices with a large moving amount when designing the unseating prevention devices parameters.

3) The value of the moving amount of the unseating prevention devices has a significant influence on the distribution of seismic force among the piers. Therefore, when designing the parameters of the unseating prevention devices, a reasonable moving amount should be selected according to the area where the bridge site is located, so that the seismic force can be evenly distributed among the piers and the integrity of the bridge structure can be improved.

4) The higher the fortification intensity of the bridge site, the value of the reasonable movement of the unseating prevention devices will have greater. When the acceleration peaks are 220cm/s², 400cm/s² and 620cm/s², the reasonable value of the moving amount can respectively be 9cm, 11cm, and 15cm.

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