Study on reasonable restraint system of double-deck frame bridge subjected to seismic action

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Abstract. In this paper, in order to improve the seismic performance of frame type double deck overpass bridge under seismic action, the most reasonable restraint system of frame double-deck overpass is studied. Based on the typical frame-type double-deck continuous overpass-hushen bridge, the finite element analysis model of the solid bridge is established. Then, from six different directions, eight different constraint combinations are established. Finally, through the analysis of the bridge direction control point of the internal force, displacement and other parameters, research and contrast the frame double-deck overpass under different constraints of the seismic response. The results show that the combination of rubber bearing, steel wire rope and concrete block can effectively limit the relative displacement between piers and beams, and reduce the internal force response of Piers and residual deformation of supports.

Keywords. Multi storey overpass bridge; Bridge seismic; Restraint system; Concrete block.

1. Introduction
With the continuous expansion of the number and scale of cities in China and the rapid growth of traffic flow, the traffic congestion of urban bridges is becoming increasingly serious. Therefore, how to improve the use efficiency of land resources and improve the traffic conditions of urban bridges has become a major problem in urban development. In order to solve the above problems, scholars have proposed the frame type multi-storey overpass bridge structure. The structural system has gradually become a popular structural system in the construction of urban bridges in recent years because it can realize the three-dimensional traffic of the city and meet the greater traffic flow on the limited land. In the existing bridge structures, the United States, Japan, South Korea and China have built a number of frame type double-layer or multi-layer bridges, such as Nanjing Yangtze River Bridge in China, Mingshi Strait Bridge in Japan, Panpu bridge in South Korea, George Washington Bridge in America, etc. With the continuous development and progress of frame type multi-storey overpass bridge, it has become an inevitable trend to apply it to high intensity earthquake area. Therefore, in the design and construction of frame type multi-storey overpass bridge, it is very necessary to study its seismic performance, and present studies have also conducted in-depth research on it. Wang [1] compared and analyzed the vibration reduction measures of double deck viaduct, and found that the isolation effect of the bridge is more obvious. When the plate rubber bearing is used in the double deck viaduct, the bending moment along the bridge direction tends to increase. Kong Deyi et al. [2] studied the seismic effect of isolation bearing in double deck bridge structure. Through comparative analysis, it is concluded that the use of isolation bearing can effectively reduce the seismic response of the structure,
and reasonable arrangement of isolation bearing can also reduce the seismic response of bridge structure under earthquake action. Li Li et al. [3-4] In order to better study the influence of lead rubber bearing on the seismic performance of double deck bridge structure, calculated and analyzed the double deck bridge with lead rubber bearing. The results show that LRB system is in line with the isolation mechanism, has a good seismic isolation effect on the structure, and can be well used in various working conditions. Wang [5] studied the seismic performance of double deck bridge portal pier through finite element analysis, and pointed out the seismic characteristics of double deck bridge pier. In order to prevent the situation of excessive pile top tension, he proposed a new type of anti-seismic block. By selecting appropriate design parameters such as collision stiffness, it can not only reduce the internal force of the substructure, but also ensure that the relative displacement of pier beam is not too large to cause beam falling danger. Pan [6] studied the influence of the arrangement of double deck bridge bearings on the seismic performance of the bridge. The research results show that the upper and lower fixed bearings are arranged separately on two piers, which can effectively reduce the seismic force on the fixed pier. At the same time, if all the movable basin bearings are used in parallel with the elastic-plastic energy dissipation devices, the internal force of the pier will be greatly reduced, and all the piers will be subjected to uniform stress and shock absorption. The effect is obvious.

To sum up, in order to improve the seismic performance of frame type double deck overpass bridge under seismic action, this paper systematically analyzes the seismic performance of the system under different constraint combination systems, and obtains the variation rules of the displacement and bending moment of each key section and node of the bridge under different constraint system combinations, which is the future use of frame type double deck overpass bridge in high earthquake area. This paper provides a reference for the arrangement of restraint system.

2. Finite element analysis model of frame type double deck continuous overpass bridge

2.1 Relying on engineering background

The supporting project is a frame type double-layer continuous overpass bridge with 68.5 m high pier and 180 m total length. The span type is 60 m + 60 m + 60 m. The main beam is composed of five T-Beams with a total width of 12.5 m. The pier adopts a solid rectangular section with variable cross-section from the bottom of the pier to the top of the pier. The rectangular section of 5 m × 3 m is adopted at the bottom of the pier and 3 m × 2 m is used at the top of the pier. The bridge pier marks are No. 1, No. 2, No. 3 and No. 4 from small mileage to large mileage. The tie beams are No. 1, No. 2, No. 3, No. 4 and No. 5 respectively from bottom to top. The site type of the bridge is class II, and the characteristic period is 0.35 s. The seismic fortification intensity is VIII and the peak ground acceleration is 0.20 g. The general layout of the bridge is shown in Fig 1.

![Figure 1. Overall layout of double deck overpass](image-url)
2.2 **Seismic wave selection**
Due to the influence of earthquake mechanism, propagation medium and site conditions, earthquake motion has great uncertainty, so it is very difficult to simulate seismic wave time history of different sites [7-8]. Moreover, the displacement and internal force of the structure system are different under different ground motion inputs. Therefore, in the calculation and analysis, it is very necessary to select reasonable ground motion [9-10]. In ATC-63 (2008) report [11], the United States has proposed 22 far-field seismic waves and 28 field seismic waves. According to the selection principle, three natural ground motion records are selected from PEER database, as shown in the Fig. 2.

![Figure 2. 3 Ground motion time histories](image)

2.3 **Finite element modeling of CSI Bridge**
Based on CSI bridge finite element program, the three-dimensional dynamic finite element model of the bridge is established, and the structural dynamic analysis is carried out. Among them, the bridge deck load is simulated by the line load applied on the main beam, the beam body and pier column are simulated by the space beam element, and the component elements are reasonably divided, and the bearing deformation behavior is accurately defined. It is necessary to specify plastic hinge in CSI bridge to realize the ductility energy dissipation capacity of pier under earthquake action and better simulate the response of bridge structure under earthquake action. In this paper, the length of plastic hinge is calculated according to the formula in code for seismic design of highway bridges [12], and the type of hinge is fiber hinge. The constraint form of the finite element model pier bottom adopts the six spring equivalent stiffness to simulate the constraint effect of pile foundation on the pier bottom. The CSI bridge 3D finite element model relying on the project is shown in Fig. 3.

![Figure 3. CSI bridge finite element model of double deck overpass bridge](image)

3. **Research on reasonable restraint system of overpass with double deck frame piers**
On the basis of the finite element analysis model established above, different supports and restraint forms are arranged. Three typical seismic waves are input in both directions, and nonlinear time history analysis is performed on the double-layer frame pier overpass bridge to obtain the seismic response of the bridge structure. Through the analysis and comparison of the relative displacement of the main beam and the relative deformation of the support and the internal force of the members, a more suitable support arrangement and restraint form can be obtained.
3.1 Bearing layout

In view of the commonly used bearing and retaining block layout of medium and small span girder bridges in high intensity areas in China [13], this paper considers six different bearings and sets eight different combination forms of working conditions, so as to select the reasonable restraint system of this kind of bridge structure under earthquake action. See Tab 1 for bearing layout and working condition design.

| Working condition | Pier 1 | Pier 2 | Pier 3 | Pier 4 |
|-------------------|--------|--------|--------|--------|
| 1#                | Upper  | SB(DX) | PB     | PEB(DX)| SB(DX) |
|                   | Lower  | SB(DX) | PEB(DX)| PB     | SB(DX) |
| 2#                | Upper  | PEB    | PEB    | PEB    | PEB    |
|                   | Lower  | PEB    | PEB    | PEB    | PEB    |
| 3#                | Upper  | LRB    | LRB    | LRB    | LRB    |
|                   | Lower  | LRB    | LRB    | LRB    | LRB    |
| 4#                | Upper  | PEB+DK | PEB+DK | PEB+DK | PEB+DK |
|                   | Lower  | PEB+DK | PEB+DK | PEB+DK | PEB+DK |
| 5#                | Upper  | PTFE   | URB    | PTFE   | PTFE   |
|                   | Lower  | PTFE   | PTFE   | URB    | PTFE   |
| 6#                | Upper  | PTFE   | PTFE   | PTFE   | PTFE   |
|                   | Lower  | PTFE   | PTFE   | PTFE   | PTFE   |
| 7#                | Upper  | URB    | URB    | URB    | URB    |
|                   | Lower  | URB    | URB    | URB    | URB    |
| 8#                | Upper  | PTFE+DK| URB+DK | URB+DK | PTFE+DK|
|                   | Lower  | PTFE+DK| URB+DK | URB+DK | PTFE+DK|

Note: DX refers to unidirectional movable bearing, DK refers to stopper, Sb refers to pot type movable bearing, Pb refers to basin type fixed bearing, PEB refers to plate type rubber bearing, LRB refers to lead core rubber bearing, PTFE refers to tetrafluoro slide plate type rubber bearing, urb refers to ordinary anti falling beam plate rubber bearing [14-15].

3.2 Analysis of seismic response along bridge direction

Three typical seismic waves are input along the bridge, and the nonlinear time history analysis is carried out by using CSI bridge and the maximum value of seismic response is selected as the contrast value. The calculation results are as follows: F is the number of main girder layers, which are 1~2 layers from bottom to top; R and L are right and left sides respectively; P is pier, which is 1~4 from small pile number to large pile number; X is tie beam, which is 1~5 from bottom to top. For example, the left side of No .2 pier of the lower main beam is indicated as F1P2L. The main calculation results are as follows:

3.2.1 Relative displacement of pier beam
As can be seen from Fig 4, the relative displacement response of pier and beam under earthquake action in 2# and 4# working conditions is basically the same. The relative displacement of the top pier beam is greater than that of the bottom pier beam under the conditions of 2#, 3# and 4# of the anti-falling beam device along the bridge. At the same time, the relative displacement of pier beam is smaller than that of 2# and 4# conditions because of the good isolation effect of lead rubber bearing in 3# working conditions. The steel wire rope of anti falling beam is set in 5#, 6#, 7# and 8# working conditions, and this type of bearing has good limit function. In 7# working conditions, all bearings adopt ordinary anti falling beam plate rubber bearing. Due to the effect of anti falling beam steel wire rope, the relative displacement of pier beam on each pier is almost the same. The bearing of 6# working condition adopts tetrafluoro slide plate anti falling beam bearing. Since the initial clearance of steel wire rope is set as 0.09 m, the relative displacement of pier beam on each pier is larger than that under other conditions with limit wire rope. The relative displacement of pier beam under 8# working conditions is between 6# and 7# working conditions.

3.2.2 Displacements of each control point of bridge pier
It can be seen from Fig. 5 to Fig. 6 that the displacement response pattern of each control point of the piers along the bridge is basically the same, and the displacement response from the bottom of the pier to the top of the pier increases in turn, the displacement response under working condition 1# is the largest, and the displacement response under working condition 2# and 4# is the smallest. The reason is that the plate rubber bearing is used in working conditions 2# and 4#, and the constraint stiffness of the pier to the girder is the smallest, so that the inertia force transferred to the pier by the girder is the smallest. Therefore, the displacement of pier control point is smaller than that of other working conditions. It can be seen from Fig. 7-8 that under different restraint systems, in addition to the change of the peak value of the seismic response of the structure, it will also affect the frequency spectrum of the structural response. Different restraint systems will change the frequency of the structure by affecting the stiffness of the structure itself, thus affecting the seismic response of the structure under the earthquake action.
3.2.3 Bending moment of each control section of pier

From Fig. 9-11, it can be seen that the bending moment response pattern of the key section of the pier is basically same under all working conditions. The bending moment of the control section from the bottom of the pier to the top of the pier is gradually reduce. The eight working conditions are divided into three categories, i.e. 1# working condition, 2#, 3#, 4# working conditions are classified into one category and recorded as 2# working condition, 5#, 6#, 7# and 8# working conditions are classified as one category and recorded as 5# working condition. The bending moment of each control section under 2# working condition is more than that of other working conditions. The reason is that
the plate rubber bearing or lead core bearing is used in this kind of working condition. Under the earthquake action, this kind of bearing has good isolation effect. Because the steel wire rope component of anti falling girder is set longitudinally under 5# working condition, the bending moment response of pier control section is greater than that of 2# working condition. The bending moment response of pier 1# is larger than that of other working conditions because of the fixed supports. The analysis results show that the maximum increase of bending moment of working condition 1# is 91.89% compared with that of working condition 2#, and that of working condition 5# is 55.78% compared with that of working condition 2#.

3.2.4 Bearing deformation

Figure 12. Deformation of each pier rubber bearing

According to the deformation response of each pier bearing shown in Fig. 12, the eight working conditions are divided into three categories, i.e. 1# working condition is one category, 2#, 3# and 4# working conditions are classified as one category and recorded as 2# working conditions, 5#, 6#, 7# and 8# are classified into one category and recorded as 5# working conditions. For 1# working condition, the bearing deformation on pier 1 and pier 4 is the largest, because the bearing type on the pier is PTFE sliding plate bearing, and its critical friction resistance is very small, so the bearing deformation is the largest. At the same time, the bearing deformation of 2 layer is greater than that of 1 layer. Under 2# working conditions, plate rubber bearings or lead rubber bearings are used, the stiffness distribution of each pier bearing is relatively uniform, so the deformation of bearings on each layer is relatively uniform, and the deformation of bearings on intermediate piers is slightly greater than that on side piers. Due to the use of limit devices such as anti falling girder steel wire rope under 5# working conditions, the deformation of each pier bearing is consistent and less than that of other working conditions. In terms of bearing deformation, 5# working condition is the best restraint system.

Figure 13. Load-displacement curve of 8#F2P1 PTFE sliding unseating-prevention laminated rubber bearing
From Fig. 13-14, it can be seen that the limiting capacity of the rubber bearing with anti falling girder plate is very significant. At the same time, it can be seen that the working principle of the rubber bearing is to limit the deformation of the bearing by sacrificing force.

4. Conclusion

Compared with different bearing and restraint system layout schemes, the response pattern of the bridge structure under earthquake action is analyzed, and the optimal constraint scheme of the bridge structure is selected. After calculation and analysis, the main conclusions of this paper are as follows:

A) Under the earthquake action, for this kind of double deck overpass bridge, seismic response patterns of along bridge direction are as follows: the displacement response of each key point of the pier increases gradually from the bottom of pier to the top of pier, and the bending moment of each control section decreases gradually from the bottom of pier to the top of pier.

B) For this study of this type of double deck overpass, due to the same pier height, if the pier adopts the form of fixed bearings, due to the higher constraint stiffness of the pier and the dynamic coupling phenomenon between the upper and lower girders, making the middle pier of the internal force response increase, which may cause damage to the pier. Therefore, the anti falling girder plate rubber bearing is introduced in this paper, which can reduce the internal force response of the pier and limit the relative displacement of the pier girder after the reasonable wire rope parameters are given. Meanwhile, this kind of bearing can effectively reduce the residual deformation of the bearing, thus effectively avoiding the occurrence of beam falling earthquake damage.

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