Study on seismic behaviour for high damping rubber bearings of continuous beam bridges

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Abstract. The seismic response of a viaduct has been analysed in order to investigate the seismic performance and influence of high damping rubber bearings. Nonlinear time-history method has been used to analyse the seismic behaviour of different bearings. The results show that the seismic behaviour of high damping rubber bearing was better than laminated rubber bearing under earthquakes of level E2. Laminated rubber bearing was not suitable to be used in high seismic intensity area as the oversize displacement and sliding resistance.

1. Introduction
The seismic performance of bearings is of great significance for the overall seismic performance of bridge structures. At present, the commonly used isolation bearings include laminated rubber bearing, lead rubber bearings, high damping rubber bearings, and friction pendulum bearings [1]. Compared with the lead rubber bearing, the high damping rubber bearing has the advantages of no pollution, high damping ratio, stable performance [2]. High damping rubber bearing is a kind of rubber bearing which is made of vulcanized rubber with high damping material and steel plate. It has good damping performance and to be widely used in bridge seismic design [3]. Its good mechanical properties and high damping value making it absorb seismic energy and reduce the seismic response of bridges effectively [4].

In order to study the hysteretic behavior of high damping rubber bearings, vertical compression and horizontal shear loading tests have been taken by many researchers [5]. The effects of vertical stress, horizontal ultimate shear strain, loading frequency and loading times on hysteretic properties were investigated. The results show that the hysteretic curve of high damping rubber bearings is rather plump, describing good energy consuming character and after repeated cyclic loading the performance of consuming energy does not appear decreasing trend. In addition loading frequency has some effect on the equivalent bearing stiffness and equivalent damping ratio [6].

Aiming at prove the seismic performance of bearings, the high-damping rubber bearing with different bearing combination have been studied.

2. Finite element analysis model

2.1. Engineering situation
The viaduct as a continuous beam bridge with 4 spans of 40m has been analyzed in the research. The superstructure of bridge is prestressed concrete box beam, and substructure is double column piers. The earthquake fortification intensity of bridge is VIII with the earthquake acceleration 0.2g, and the site classification is II.
The finite element analysis model of bridge was built by large finite element analysis software. The girder and piers were simulated as spatial beam element and pile caps were simulated to be fixed in the foundation.

The time history analysis have been used by three earthquake waves with exceeding probability of 2.5% in 100 years, one of the earthquake waves was shown in Figure 1.

![Figure 1. Earthquake wave with exceeding probability of 2.5%](image)

2.2. Bearing parameters and combinations

The laminated rubber bearing and high damping rubber bearing were both simulated as elastic coupling, and the equivalent bilinear restoring force model of high damping rubber bearing was shown in Figure 2.

![Figure 2. Bilinear restoring force model of high damping rubber bearing](image)

The $K_1$ in Fig.2 is stiffness before yield, $K_2$ is stiffness after yield, $\delta_y$ is yield displacement, $\delta_d$ is the design damping displacement, $F_y$ is yield force and $F_d$ is design damping force [7].

The laminated rubber bearing and high damping rubber bearing with different combination were been applied on bridge. The parameters and combination case of bearings were been shown in Table 1.

| Table 1. The parameters and combination case of bearings / (mm) |
|---------------------------------------------------------------|
| Pier position       | bearing model      | Permissible displacement (mm) | Limiting displacement (mm) |
|---------------------|--------------------|--------------------------------|-----------------------------|
| Case1               |                    |                                |                             |
| discontinuous pier  | GJZ300×400×74      | 33.6                           | /                           |
| continuous pier     | GJZ400×500×99      | 46.2                           | /                           |
| Case2               |                    |                                |                             |
| discontinuous pier  | HDRd370×127-G0.8   | 126                            | 189                         |
| continuous pier     | HDRd470×145-G0.8   | 162                            | 243                         |
| Case3               |                    |                                |                             |
| discontinuous pier  | GJZF4 300×400×76   | 70                             | /                           |
3. The research results and analysis

The dynamic time history analysis method was applied to analyze the seismic response of bridge. The seismic responses of bridge with different bearing combination case under earthquake fortification level E1 and E2 were been compared. As the seismic response of bridge caused by earthquake level E1 were less than E2, so the seismic responses of earthquake fortification level E2 were list to be discuss. The seismic analysis results of bridge with different combination of bearings have shown in Table 2 and Table 3.

| Pier number | shearing force (kN) | bending moment (kN m⁻¹) |
|-------------|---------------------|-------------------------|
|             | Case1   | Case2   | Case3   | Case1   | Case2   | Case3   |
| 1           | 1431    | 1533    | 1588    | 21697   | 16358   | 15420   |
| 2           | 1804    | 1526    | 1711    | 23657   | 165483  | 17619   |
| 3           | 1973    | 1598    | 1589    | 23563   | 16469   | 17529   |
| 4           | 1804    | 1526    | 1710    | 23457   | 16421   | 17461   |
| 5           | 1431    | 1533    | 1588    | 22438   | 16849   | 16502   |

The Table 2 and Table 3 show that the bending moment and shear force of pier bottom in case 1 and 3 have a great different between discontinuous piers and continuous piers. The forces among piers in case 2 were much more approximate, so the earthquake load was equally separated as high damper bearings to be set on all the piers. The bottom bending moment and shear force of piers in case 2 is decreased to 30% of the seismic response of case 1. Both longitudinal and transversal seismic response in case 2 and 3 were less than case 1, and decreased approximately as 30% of case 1. It is thus clear that as high damper bearings to be used on bridge, the seismic responses of bridge were reduced, and the earthquake isolation effect was obviously.

The displacements of bearings and beam with different combination of bearings have shown in Table 4 and Table 5.

| Pier number | Case1 Dx | Case1 Dy | Case2 Dx | Case2 Dy | Case2 Dx | Case2 Dy | Case3 Dx | Case3 Dy |
|-------------|----------|----------|----------|----------|----------|----------|----------|----------|
| 1           | 350      | 108      | 274      | 175      | 320      | 181      |
| 5           | 352      | 108      | 278      | 180      | 328      | 184      |

The Dx in table is longitudinal displacement, Dy is transversal displacement.

As show in Table 4, the displacement of beam is different as the laminated rubber bearings and high damping rubber bearings to be applied with different combination. The beam displacement in case 2 is less than case 1 and 3, and the longitudinal displacement is larger than transversal.
Table 5. Bearing displacement with different bearing combination case (mm)

| Pier number | Case1 Dx | Case1 Dy | Case2 Dx | Case2 Dy | Case3 Dx | Case3 Dy |
|-------------|---------|---------|---------|---------|---------|---------|
| 1           | 72      | 51      | 88      | 118     | 143     | 120     |
| 2           | 54      | 59      | 70      | 123     | 96      | 114     |
| 3           | 55      | 68      | 70      | 125     | 96      | 109     |
| 4           | 54      | 59      | 70      | 123     | 96      | 114     |
| 5           | 72      | 51      | 88      | 118     | 143     | 120     |

As bearing displacements show in Table 5, the change of bearing displacement with bearing combination case is different compared with beam displacement. The longitudinal bearings displacements are larger than transversal in case 1, on the contrary transversal bearing displacements are larger in case 2. And the displacements of slide bearings are obviously larger than other bearings, which is oversize the permissible displacement of bearings on discontinuous piers.

By the analysis above, it is obviously that the seismic response of bridge was relatively reasonable as the high damping rubber bearings were set on all piers, and earthquake load was equally separated. Although the slide bearings have isolation effect, their displacement were excessively large than the permissible displacement. The seismic response of bridge was relatively reasonable as high damper bearings to be used, and the high damping rubber bearings can effectively reduce the seismic response of bridge by hysteresis energy dissipation.

4. Conclusion
The viaduct with 4 spans of 40m has been analyzed with different bearing combination, and the isolation effect of high damping rubber bearing have been discussed. Comparing the seismic response of bridge with different bearing combination, the conclusions can be obtained as follows:

The seismic response of bridge with high damping rubber bearing were less than bridge with laminated rubber bearing combination, most could be reduce to 30% of the response with case 1 and case 3.

No matter high damping rubber bearing or laminated rubber bearing to be applied, the longitudinal the bending moment and shear force of pier bottom were much more than transversal. And the load distribution among piers is more reasonable in case 2.

The displacement of beam is been reduced as high damping rubber bearings been set on all piers, and the high damping rubber bearings can effectively reduce the seismic response of bridge by hysteresis energy dissipation. Laminated rubber bearing was suggested not to be used in highly seismic area.

Acknowledgments
This work was financially supported by Scientific Research Program Funded by Shaanxi Communications Department（Program No.13-21K ）and Scientific Research Program Funded by Shaanxi Provincial Education Department (Program No.12JK0900 and Program No 17JK0618).

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