Seismic Effect Research of Seismic Measures for Beam Bridge under Different Earthquakes

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Abstract. Collision, collapse and expansion device damage are very likely to occur in bridge structures under large earthquakes. Earthquake waves with exceeding probability of 63.2%, 10%, and 2% in 100 years, as well as the Northridge earthquake and Kobe earthquake have been used to analyze the seismic response under earthquakes. The result shows that collision and collapse damage of bridge can be effectively controlled by the seismic measures. When the peak acceleration of earthquake is large and the control ability of the limit device to the excessive displacement of the structure is insufficient, the unseating prevention device can effectively make up the deficiency of the limit device to limit the excessive displacement of bridge.

1. Introduction
In recent years, the unseating of bridge superstructures after collisions and explosions have been widely concerned by the society. As the superstructure is simply supported on the top of the substructure, the beam bridges were more likely collapse under the impact load.

There were many bridges falling down from piers and abutment in the San Fernando earthquake. In 1989, the approach bridge of Auckland Bridge falling off from substructure because the supporting surface was too narrow. Unseating of bridges has become a common earthquake damage in many large earthquakes. It is found that the failure of displacement limiting measures and the insufficient width of superstructure are the main reason of collapse damage, as well the collision damage can hardly be avoided in the earthquake [1].

In order to prevent collision and unseating damage of bridge under earthquakes, many scholars are devoted to studying the control measures of such earthquake damage. The seismic design code of bridge is revised, and it is suggested that when the intensity is greater than 8 degrees, the seismic measures to limit the excessive displacements of bridge should be adopted [2].

2. Damage-Reduction Seismic System of Bridge
As damage-reduction seismic design to be used widely in bridge seismic design, many seismic measures have been applied at the end of bridge beam, such as the limiting device and unseating prevention devices. The measures are used to limit the excessive displacement of the structure under earthquake, and are special design to achieve different seismic requirements and functions [3].

The limit device is mainly used to limit major displacement of bridge under earthquake, in order to prevent the failure of bearing. It is found that the relative displacement between adjacent beams as well as between superstructure and substructure at beam end can be effectively reduced by installing tensile
limiting device. But the demand for the ductility of piers at edge span is increased [4]. Unseating prevention devices is effectively to prevent collision and unseating damage of bridges, as bearings are damaged or the limit device is insufficient to control the excessive displacement of bridge under severe earthquakes [5].

Although researchers have studied separately on the seismic performance and the limit effect of limit device and unseating prevention devices, the studies on control effect of damage-reduction seismic system consisted by limit device and unseating prevention devices were few, especially for the collision and unseating damage in rare or unexpected earthquakes [6]. The bridge with different combinations of damage-reduction seismic measures will be analyzed to obtain the limits and seismic effects of various seismic measures.

3. Finite Element Analysis Model
A continuous beam bridge with 5 spans of 30m has been analyzed, the box girder of bridge is 17m wide and 1.6m high with concrete C50. The laminated rubber bearing were been used to support the superstructure. The piers are 30 meters high and the diameter are 2.0 meters, and the concrete C30 is adopted. The finite-element model of bridge was shown in figure 1.

The girder, capping beam and piers were all simulated as beam elements in the finite element model of the bridge. The bearings were simulated by elastic connection without considering the influence of pile foundation on bridge structure.

In order to analyze the seismic response of bridge and the application effect of seismic measures, the seismic loads adopted in bridge are increased step by step. There are three earthquake waves with exceeding probability of 63.2%, 10%, and 2% in 100 years (small, moderate, and large earthquakes), as well as the Northridge earthquake in the United States and Kobe earthquake in Japan. The peak acceleration of these seismic waves shows an increasing trend, as shown in table 1.

| Name               | Small earthquake | Moderate earthquake | Large earthquake | Northridge earthquake | Kobe earthquake |
|--------------------|------------------|---------------------|------------------|-----------------------|-----------------|
| peak acceleration  | 96.20            | 250.15              | 363.90           | 592.08                | 617.14          |

The time history of the Kobe earthquake wave was shown in figure 2.
4. Seismic Response of Bridge under Different Earthquakes
The seismic response of the bridge can be obtained by using the nonlinear time-history analysis under the excitation of different earthquakes. The seismic analysis results have shown in table 2.

Table 2. Seismic responses of bridge under different earthquakes.

| Earthquakes  | Positions | Beam displacement (cm) | Displacement of pier top (cm) | Bearing displacement (cm) | Bending moment of pier bottom (kN·m) |
|--------------|-----------|------------------------|-------------------------------|---------------------------|-------------------------------------|
| small        | Side pier | 3.92                   | 0.21                          | 3.71                      | 1374                                |
| moderate     | Side pier | 14.99                  | 0.59                          | 14.40                     | 3858                                |
| moderate     | middle pier | 14.99                  | 3.25                          | 11.74                     | 19108                               |
| large        | Side pier | 19.12                   | 0.78                          | 18.34                     | 5099                                |
| moderate     | middle pier | 19.12                  | 4.28                          | 14.84                     | 25258                               |
| Northridge   | Side pier | 24.92                   | 1.14                          | 23.78                     | 7564                                |
| large        | middle pier | 24.92                  | 5.54                          | 19.38                     | 32594                               |
| Kobe         | Side pier | 19.06                   | 1.38                          | 17.68                     | 9047                                |
| large        | middle pier | 19.06                  | 4.25                          | 14.81                     | 33742                               |

As the results been shown in table 2, the seismic responses such as beam displacement, displacement of pier top, bearing displacement and bending moment of pier bottom increased gradually as the earthquake intensity increased, and the top displacement and bottom bending moment of middle pier are larger than those of the side piers.

It must pay attention to the displacement of bridge, the displacement of beam-end will exceed the permissible displacement of the expansion device as the peak acceleration of the seismic load exceeds moderate earthquake, and the bearing displacement have exceeded its shear deformation. This means that bearing and expansion device will be destroyed as the earthquake intensity larger than moderate earthquake, the beam of bridge may be falling down from piers or to be collision under larger earthquake. So it is necessary to adopt seismic measures to limit its excessive displacement.

5. Seismic Response of Bridge Setting on Seismic Measures
In order to obtain the influence rule of seismic measures on the seismic response of bridge under the action of earthquake, the original design structure with different combination seismic measures is defined as different cases for comparative study. The distribution of cases is as follows:

Case 1: original design structure;
Case 2: original design structure + expansion device;  
Case 3: original design structure + expansion device + limit device;  
Case 4: original design structure + expansion device + limit device + unseating prevention device.

The results show that seismic measures have obvious influence on seismic response of bridge, especially the beam end displacement and bearing displacement of side piers. The variation of the seismic response of the structure setting on different combinations of seismic measures are shown in figure 3 and figure 4.

![Figure 3](image3.png)

**Figure 3.** The displacement of beam-end under earthquakes with different case of seismic measures.

![Figure 4](image4.png)

**Figure 4.** Bearing displacement of side piers under earthquakes with different case of seismic Measures.

As shown in figure 3 and figure 4, the displacements of the beam-end and bearings under earthquakes have greatly been decreased as seismic measures to be adopted, except for small earthquakes excited. And all seismic measures have play a role to decrease the displacement of bridge, according to the changing trend of the curve, the displacement of beam-end and bearings of the side piers were both decrease with the increase of seismic measures, and the bearing displacement of the side piers decreases greater than middle piers.

As limit device and the unseating prevention device both adopted on the bridge (case 4), the displacement of the beam-end (at the expansion joint) was almost controlled within the permissible
displacement of the expansion device under the action of various earthquakes, and the collision damage could be avoiding except for under the largest Kobe earthquake. The displacement of side piers can be well controlled to prevent the superstructure falling off from the substructure.

In case 4, the limit device and the unseating prevention device were combined use to limit the displacement of bridge under earthquakes, the limit device come into play as the relative displacement of superstructure and substructure lager than 3.2 cm, when the relative displacement increases to 8 cm the unseating prevention device will in action. The stress of the limit device was decreased as the unseating prevention device working with the limit device.

6. Conclusion
In view of the collision and collapse of bridge under large earthquake, combined with the existing research conclusions of seismic measures such as limit device and unseating prevention device, the nonlinear time-history analysis of bridge with different seismic measures have been carried under different earthquakes. The main conclusions are as follows:

Collision, collapse and expansion device damage are very likely to occur in bridge structures under large earthquakes. The collision and beam falling damage of bridge can be effectively controlled by the seismic measures such as limit device and unseating prevention device.

For the bridge structure considering seismic design, the displacement demand of expansion device under earthquake should be considered, expansion device with large displacement should be selected. The limit device can effectively reduce the displacement of beam and bearing, and can also increase the overall stiffness of the bridge. However, the limiting capacity of the limiting device is slightly insufficient under larger earthquake.

When the peak acceleration of earthquake is large and the control ability of the limit device to the excessive displacement of the structure is insufficient, the unseating prevention device can effectively make up the deficiency of the limit device to limit the excessive displacement of bridge. The limit device and unseating prevention device can form an optimized limit system, which can reasonably distribute the impact force of earthquake, so as to ensure the integrity of the structure.

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