Analysis and Research on Anti-seismic Scheme of Railway Simple Supported Beam Bridge

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Abstract. In order to improve the seismic performance of railway simply supported beam bridges, the seismic design schemes in different seismic intensity areas are compared and analyzed in this paper. The results show that the relative displacement of beam piers is too large when the simply supported beam bridge ($\geqslant 0.3g$) in high intensity earthquake area only adopts damping and isolation bearings. In order to reduce the displacement after earthquake, it is necessary to increase damping energy dissipation devices. Simply supported beam bridge in low intensity earthquake area ($\leqslant 0.2g$) adopt shock-absorbing isolation bearing. The cost of bearing will not increase, and the safety of bridge under earthquake will be greatly improved. It is recommended to adopt isolation design in low intensity seismic area.

Keyword. Simply Supported Beam; Bridge Earthquake Damage; Seismic Design; Low-Intensity Earthquake

1. Introduction
If we want to prevent earthquakes, we should first estimate the risk of destructive earthquakes and the intensity of earthquakes, so as to take appropriate defensive measures. Countries in the world usually divide their land into several regions with different seismic risk, and different seismic design standards are adopted in different regions[1].

How to accurately divide different seismic regions becomes particularly important. In essence, seismic zoning belongs to the category of long-term earthquake prediction, which is far from being solved in science. At present, on the basis of a large number of complete or incomplete seismicity data, seismogeological data and geophysical data, the possible reliable seismic zonation map is made after fully studying the occurrence law of earthquakes, the distribution of potential focal areas, and the attenuation of ground motion. However, the ground motion parameters (such as acceleration or velocity peak value) are higher in the high intensity seismic area within a certain period and under a certain probability, and the risk is greater after the earthquake.

When an earthquake occurs in a high-intensity earthquake area, the ground will vibrate violently horizontally or vertically, which will damage or even collapse the bridge. It will not only cause casualties, but also interrupt the railway traffic, seriously affect the rescue and post disaster reconstruction work, and have a profound social and economic impact.

2. Earthquake damage of bridge
The seismic damage of bridge itself is generally the buckling failure of steel structure; the displacement seismic damage is relatively common, which is easy to occur at the expansion joint, which is manifested as the vertical and horizontal displacement and torsional displacement of the upper structure; the collision seismic damage includes the collision of the superstructure of adjacent spans, the collision between the superstructure and the abutment, and the collision between adjacent bridges[2-4].

Bridge bearing is a link with weak seismic performance. In the previous destructive earthquakes,
the bearing damage is more common. The damage of bearing protects the pier and foundation, which is beneficial to the earthquake resistance. But the design of supporting block and coupling beam device is needed to ensure that the beam will not fall after the bearing is damaged.

The common forms of seismic damage of substructure are as follows: (1) ductile failure, the bending failure of pier column is mainly manifested as cracking, concrete spalling and crushing, steel bar exposure and bending, etc., resulting in large plastic deformation. (2) Shear failure, shear failure of pier column is brittle failure, which will cause collapse of pier column and superstructure, and seismic damage is serious. (3) The damage of pier cap is rare, but it is serious. (4) As long as the abutment sliding caused by the loss of bearing capacity of the foundation, the collision between the abutment body and the superstructure and the inclination of the abutment are the main reasons for the seismic damage of the abutment.

The earthquake damage of bridge foundation is one of the most important earthquake damages. Foundation failure (such as soil sliding and sand liquefaction) is the main reason of bridge foundation seismic damage, as well as pile foundation shear and bending damage caused by inertia force from superstructure.

3. Seismic analysis method

The development of seismic analysis methods has gone through three stages of static force, response spectrum and dynamic force. Among them, there are two stages of elasticity and inelasticity in the dynamic stage. Random vibration and deterministic vibration are also two methods that appear in this stage; Deterministic seismic analysis methods are generally used.

The elastic static method assumes that the structure is rigid and the seismic force is equal to the product of the ground acceleration and the total mass of the structure. The seismic acceleration is regarded as the displacement factor of the structure seismic damage, ignoring the dynamic response characteristics of the structure, which has theoretical limitations.

The response spectrum method is to make the dynamic problem static by the concept of response spectrum. It is simple in concept and convenient in calculation. It can obtain the maximum response value of the structure with less calculation. For the seismic response of complex and long-span bridges, various complex influencing factors cannot be well considered.

The time history analysis method can transform the seismic design of bridge from single strength guarantee to double seismic design of strength and deformation (ductility) [5]. The time history analysis method takes the input of appropriate ground motion as the starting point, and considers the interaction of structure, soil and deep foundation, seismic wave phase difference and multi-component multi-point input of different seismic waves. At present, most of the time history analysis methods we use are elastic dynamic time history analysis, but the elastic-plastic dynamic time history analysis method is rarely used.

4. Seismic design

4.1 Seismic fortification concept

Choose the appropriate bridge type according to local conditions, multi-channel fortification, graded energy consumption, one can be three easy (damage part and degree of damage are controllable, damaged part or component is easy to inspect, repair and replace). Seismic design methods. At present, the main seismic codes at home and abroad, such as the AASHTO code in the United States, the EUROCODE code in Europe, and the seismic design code in my country for highway and railway engineering, all adopt the strength-based seismic design method.

The reasonable structure and strong earthquake resistance can greatly reduce or even avoid earthquake damage. In order to make the structure have seismic capability, it is necessary to study the seismic action theory of structure seismic calculation and the failure criterion of seismic design.

At present, there are three kinds of seismic design methods: (1) ductile substructure and elastic superstructure, traditional pier column plastic hinge and passive soil resistance of filling behind abutment limit inertial force, including plastic hinge of foundation under ground. This system is a ductile seismic design. Under earthquake, plastic deformation occurs on the pier column, prolonging the structural period and dissipating seismic energy. (2) Elastic substructure and ductile superstructure are mainly reflected in steel bridges. (3) Elastic upper structure and elastic lower structure. The upper and lower structures have insurance mechanisms, including shock-absorbing and isolating supports.
and energy dissipation devices, which are used to control the transmission of inertial forces between the upper and lower structures and dissipate them during earthquakes. Dissipate energy and limit displacement.

4.2. Seismic design ideas
According to the analysis of seismic intensity and earthquake grade, the damage degree of buildings is more serious when earthquakes occur in high intensity earthquake area within 100 years. The characteristics of high-intensity earthquakes are not only reflected in the characteristics of high-intensity peak acceleration, but also a series of problems such as fault zone, active fault, near-field earthquake, long-term characteristic period and so on.

Aiming at the problem of more serious damage after the earthquake in the high-intensity earthquake area, the seismic design method of "multi-channel fortification and graded energy consumption" is adopted[6].

The first line of defense: shock-absorbing and isolating bearings. Damage to the shock-absorbing and isolating bearings should occur before the plasticity of the pier column appears. The shock-absorbing and isolating bearings are effective and the seismic displacement is small.

The second line of Defense: the energy dissipation limit device and the isolation bearing work together to resist the earthquake action.

The third line of defense: the anti-dropping beam device intervenes in the work to prevent the falling beam, the energy-consuming limit device can be destroyed, and the post-earthquake displacement of the shock-absorbing and isolating support must be guaranteed.

Small earthquakes (frequently encountered earthquakes): under frequent earthquakes, the shock-absorbing and isolating bearing limit device will not be damaged, and the seismic-absorbing and isolating bearing will function as a hard and anti-bearing bearing. Only normal displacement slides, and the bridge pier maintains an elastic state; frequent earthquakes When the damping and isolating bearing limit device is damaged (the time of damage can be advanced appropriately according to the situation), the damping and isolating bearing starts to function. At this time, the energy consuming limit device is not in working condition, and the bridge pier remains elastic.

Moderate earthquake (design earthquake): The shock-absorbing and isolating support swings, the energy-dissipating limit device plays a role, and the bridge pier remains elastic.

Large earthquakes (rare earthquakes): The shock-absorbing and isolating support swings, the energy-consuming limit device can be damaged, and the anti-dropping device plays a role, allowing the pier to undergo the plastic stage (limited ductility, control ductility ratio: Railway Seismic Code 4.8, controllable Within 3).

Extremely rare earthquakes: it can exceed the design displacement of the shock-absorbing and isolating support, the energy consumption limit device is damaged, the anti-dropping beam device can be damaged, and the beam will not fall (guarantee the overlap length of the beam pier).

5. Research on the Seismic Plan of Simply Supported Beam Bridge
5.1 Seismic design principles
The principle of seismic design of railway engineering, the route is selected to pass through the section with low intensity and favorable seismic resistance; the building should be simple in shape, clear in force, light in weight, uniform in rigidity and mass, and low in center of gravity; adopting is conducive to improving the structure Integral connection method; when conditions permit, use seismic isolation and energy-consuming devices to reduce the seismic response of structures [7]; adopt advanced technology, economical and reasonable seismic measures that are easy to repair and strengthen; adopt ductile structures or structures that are advantageous for earthquake resistance. Materials; For non-rock foundations, especially sandy soil liquefaction areas, strengthening measures should be taken to the foundation.

Analyze the seismic fortification targets of traditional simply supported beam bridges. Under frequent earthquakes, it will not be damaged or slightly damaged after the earthquake, and the structure can maintain normal use functions. The structure is in the flexible working stage; under the design earthquake, the upper and lower structure connection structure should be checked. After the earthquake, it may be damaged. After the earthquake, it will be repaired in a short time. The structure can be restored to normal use and the structure as a whole is in the inelastic working stage; under rare
earthquakes, large damage may occur after the earthquake, but the overall collapse does not occur. After repairs, the speed can be limited and the structure is in the elasto-plastic working stage. However, the above requirements are not applicable to bridges designed with seismic mitigation and isolation. For reinforced concrete piers with ductile design, the bearings should be checked according to rare earthquakes; that is, when ductile design is adopted, the bearings cannot be damaged under rare earthquakes.

The seismic analysis plan of the simply supported beam bridge is studied. First, the basic acceleration of horizontal earthquake under different seismic intensities is analyzed, as shown in Table 1.

| Fortification intensity | 6degrees | 7degrees | 8degrees | 9degrees |
|------------------------|----------|----------|----------|----------|
| Design EarthquakeAg    | 0.05g    | 0.1g     | 0.15g    | 0.2g     | 0.3g     | 0.4g     |
| Frequent Earthquakes   | 0.02g    | 0.04g    | 0.05g    | 0.07g    | 0.1g     | 0.14g    |
| Rare earthquake        | 0.11g    | 0.21g    | 0.32g    | 0.38g    | 0.57g    | 0.64g    |

The code stipulates that the bridges in the 6 degree area should be fortified at 7 degrees, and the above-mentioned fortification intensity can be classified as 7, 8, and 9 degrees for defense. The content of the seismic design check calculation is to check the strength, eccentricity and stability of the bridge pier and foundation according to frequent earthquakes; check the strength of the upper and lower structure connection structure according to the designed earthquake; check the ductility or maximum displacement of the reinforced concrete pier according to the rare earthquake analysis. When the bridge must pass through an earthquake fault, a simple beam bridge with a small span and low pier height should be adopted.

5.2. Analysis of anti-seismic schemes of different earthquake intensities

According to the above-mentioned anti-seismic design principles, analysis and comparison of anti-seismic schemes are carried out for sites with different earthquake intensities. Considering the small space and low cost of railway simply-supported beams, the high cost of viscous dampers and speed lockers, and the complicated installation, they are not suitable for use in simply-supported beams. In this paper, the following five schemes as follow in table 2 are selected to conduct a comparative analysis of seismic schemes with different intensities.

| number  | Bearing Type          | Damping Device | Anti Falling Beam |
|---------|-----------------------|----------------|------------------|
| Programme 1 | Common Bearing        | /              | √                |
| Programme 2 | Slide Bearing         | /              | √                |
| Programme 3 | Friction Pendulum System | /              | √                |
| Programme 4 | Slide Bearing         | Damper         | √                |
| Programme 5 | Friction Pendulum System | Damper         | √                |

In order to reduce the influence of the side piers, a simple-supported beam structure with 6 piers and 5 spans was used for modeling, and the seismic response of the two middle piers was analyzed. In the analysis process, the maximum value is taken for the 3rd and 4th piers according to the envelope results. The schematic diagram of five span simply supported beam is show in figure 1.
Figure 1. Schematic diagram of five Span Simply Supported Beam

From the two aspects of bridge pier force and bearing displacement, the results of seismic analysis of different seismic schemes in areas with different seismic intensity are compared. The stresses of piers with hard-resistant bearings in frequent earthquakes as follow in Table 3.

| Earthquake Intensity | Basic Acceleration | Pier Top Shear (kN) | Pier Bottom shear (kN) | Pier bottom bending moment (kN*m) |
|-----------------------|--------------------|---------------------|-----------------------|-------------------------------|
| 7                     | 0.1g               | 890                 | 1335                  | 995                           | 11522                          | 17283                          |
| 7                     | 0.15g              | 1112                | 1670                  | 1243                          | 14402                          | 21603                          |
| 8                     | 0.2g               | 1558                | 2336                  | 1740                          | 20163                          | 30244                          |
| 8                     | 0.3g               | 2225                | 3338                  | 2486                          | 28804                          | 43207                          |
| 9                     | 0.4g               | 3115                | 4673                  | 3480                          | 40326                          | 60490                          |

Note: in this paper, the model pier height is 12M, the seismic wave characteristic period is 0.45s, and the longitudinal bridge seismic data; the vertical bearing capacity of bearing is 5000kN. The design earthquake resistance bearing pier force is show in Table 4.

| Earthquake Intensity | Basic Acceleration | Pier Top Shear (kN) | Pier Bottom shear (kN) | Pier bottom bending moment (kN*m) |
|-----------------------|--------------------|---------------------|-----------------------|-------------------------------|
| 7                     | 0.1g               | 2225                | 2486                  | 28805                         |
| 7                     | 0.15g              | 3338                | 3729                  | 43207                         |
| 8                     | 0.2g               | 4451                | 4972                  | 57609                         |
| 8                     | 0.3g               | 6676                | 7459                  | 86414                         |
| 9                     | 0.4g               | 8902                | 9945                  | 115218                        |

The forces on piers of hard-resisting bearings in rare earthquakes is show in Table 5.

| Earthquake Intensity | Basic Acceleration | Pier Top Shear (kN) | Pier Bottom shear (kN) | Pier bottom bending moment (kN*m) |
|-----------------------|--------------------|---------------------|-----------------------|-------------------------------|
| 7                     | 0.1g               | 4674                | 5221                  | 60490                         |
| 7                     | 0.15g              | 7121                | 7956                  | 92175                         |
| 8                     | 0.2g               | 8457                | 9448                  | 109458                        |
| 8                     | 0.3g               | 12685               | 14172                 | 164186                        |
| 9                     | 0.4g               | 14243               | 15912                 | 184350                        |

The forces on piers of skateboard bearings in rare earthquakes is show in Table 6.
The forces on piers with hyperboloid bearings in rare earthquakes is shown in Table 7.

Table 7. Forces Of Piers With Hyperboloid Bearings In Rare Earthquakes

| Earthquake Intensity | Basic Acceleration | Pier Top Shear (kN) | Pier Bottom shear (KkN) | Pier bottom bending moment (kN*m) |
|----------------------|--------------------|---------------------|-------------------------|--------------------------------|
| 7                    | 0.1g               | 464                 | 1441                    | 13403                            |
| 7                    | 0.15g              | 502                 | 2966                    | 25190                            |
| 8                    | 0.2g               | 546                 | 3860                    | 32909                            |
| 8                    | 0.3g               | 608                 | 5580                    | 46832                            |
| 9                    | 0.4g               | 630                 | 6216                    | 51986                            |

The rare earthquake mitigation and isolation support displacement is shown in Table 8.

Table 8. Rare Earthquake Mitigation And Isolation Support Displacement (m)

| Earthquake Intensity | Basic Acceleration | Slide Bearing | Friction System | Pendulum | Friction System+ Damper |
|----------------------|--------------------|---------------|-----------------|----------|------------------------|
| 7                    | 0.1g               | 0.32          | 0.05            | --       | --                     |
| 7                    | 0.15g              | 0.96          | 0.10            | --       | --                     |
| 8                    | 0.2g               | 1.38          | 0.13            | --       | --                     |
| 8                    | 0.3g               | 2.71          | 0.27            | 0.20     |                        |
| 9                    | 0.4g               | 3.22          | 0.31            | 0.19     |                        |

Note: 0.3g damping force 260KN; 0.4g damping force 690KN.

At present, the seismic design scheme of the railway simply supported beam bridge is to adopt ductile design (hard resistance design) in the 6, 7, and 8 (0.2g) areas, and the conventional spherical steel bearings are used for the bearings. In the 8 degree (0.3g) and 9 degree areas, the seismic isolation design method is adopted for seismic fortification, and the seismic isolation support and energy dissipation device are used to control the transmission of inertial force between the upper and lower structures, and in the earthquake dissipate energy and limit displacement.

5.3. Comparison of seismic mitigation and isolation schemes in low seismic intensity areas

The above seismic analysis shows that under the seismic conditions of 8 degrees (0.3g) and 9 degrees, the bridge piers are subjected to large forces. The use of ductile design is not good for the bridge structure, and the seismic isolation design should be adopted. This article will focus on the analysis of whether the seismic isolation design is adopted in areas below 0.3g.

Based on the seismic analysis of the last section, the design parameters of the bearing in low intensity seismic area are summarized.

Table 9. Parameters Of seismic Isolation Bearing

| Earthquake Intensity | Basic Acceleration | Shear force (kN) | Displacement Earthquake (m) |
|----------------------|--------------------|------------------|-----------------------------|
| 7                    | 0.1g               | 440 660          | 0.05                        |
| 7                    | 0.15g              | 550 830          | 0.10                        |
| 8                    | 0.2g               | 780 1160         | 0.13                        |

According to the bearing design parameters in Table 9, the shock-absorbing and isolating bearing was designed and compared with the ordinary bearing. The data is shown in the following table 10.

Table 10. Bearing Weight Comparison Table

| Earthquake Intensity | Basic Acceleration | Seismic Isolation Bearing | Hard Bearing |
|----------------------|--------------------|---------------------------|--------------|
|                      |                    |                           |              |


According to the comparison of the weights of ordinary bearings and seismic isolation bearings in Table 9, when the seismic isolation scheme is adopted in the low-intensity earthquake area, the weight of the seismic isolation bearings is equivalent to that of ordinary bearings, that is, the cost of the bearing part is not increased or slightly increased, but the structural safety of the bridge design is greatly improved. Through the analysis of different anti-seismic schemes in this paper, it is concluded that the low-intensity earthquake area is more suitable for the concept of using seismic isolation bearings.

6. Conclusion

From the type of bridge earthquake damage as a starting point, discuss the relationship between earthquake intensity and earthquake level, and analyze the possibility of various earthquake intensities under a certain earthquake level. Through the analysis of seismic analysis methods, the exploration of seismic fortification concepts and the arrangement of seismic design ideas, the study of seismic design schemes of simply supported beam bridges under different seismic intensities is carried out. Through the comparison of different anti-seismic schemes under different earthquake intensities, the following conclusions can be drawn:

1. Simply supported beam bridge in high-intensity earthquake areas (≥0.3g) only use shock-absorbing and isolating bearings, and the relative displacement of the beam piers is too large. It is necessary to add a damping energy dissipation device to reduce the displacement after the earthquake.

2. Simply supported beam bridge in low-intensity earthquake areas (≤0.2g) adopt shock-absorbing and isolating bearings. The cost of the bearings will not increase, and the safety of the bridge under earthquakes will be greatly improved. It is recommended that low-intensity earthquake areas adopt seismic isolation design.

3. With the development of economy and technological progress, the understanding of seismic design has been continuously improved. In the safety-oriented and people-oriented era, not only the safety of bridge structures under earthquakes must be ensured, but also the safety of people. The use of seismic isolation design is the best choice to ensure personal safety.

7. References

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