Research on the characteristic of seismic damage and seismic design of reinforced concrete simply-supported girder bridge

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Abstract: In previous earthquakes, the bridge in the earthquake zone has been seriously damaged; especially the reinforced concrete simply-supported girder bridge that with poor integrity. In order to study the earthquake damage character and behavior of the reinforced concrete simply-supported girder bridge, according to the survey data of earthquake damage of the reinforced concrete simply-supported girder bridge, that occurred in several major earthquakes in China in recent years, earthquake damage characters of this kind of bridge are classification analyzed. According to the earthquake damage characters, seismic design countermeasures are put forward, which can provide reference for aseismic design of reinforced concrete simply-supported girder bridge.

1. Introduction

The seismic belt in China is widely distributed with high frequency and intensity. When an earthquake disaster occurs, the lives and property of the people in the seismic area suffered huge losses; the bridge as traffic throats has also been severely damaged. In Tangshan earthquake, Wenchuan earthquake and Lushan earthquake, there are dozens or even hundreds of bridges were damaged in different degrees [1, 4]. As a result of that, the evacuation of people in disaster areas, the entry of various rescue teams, and the transportation of relief supplies are often hindered, which leads to a greater disaster. Therefore, bridge earthquake resistance has always been a subject of great concern.

Bridge earthquake damage investigation is an important way to study bridge seismic resistance. Through the investigation and analysis of bridge seismic damage, it can provide a basis for the development of bridge seismic design. Reinforced concrete (RC) simply-supported girder bridge has the advantages of simple force, convenient calculation and design, low construction cost and so on, which is widely used in the world. Based on the data of seismic damage investigation in several major earthquakes in China, the earthquake damage character and behavior of the reinforced concrete simply-supported girder bridge are classification analyzed, through the earthquake damage inspiration, the seismic design countermeasures are put forward.

2. Seismic damage characteristics and performance of RC simple supported beam bridge

Table 1 shows the damage statistics of RC simply-supported girder bridge in the disaster area of Sichuan Wenchuan earthquake [5]. According to table 1, we know that the proportion of completely...
damaged bridge in the disaster area is relatively small, which indicates that the overall seismic level of RC simply-supported girder bridge is better.

Table 1. Earthquake damage statistics of RC simply-supported girder bridge in Wenchuan earthquake

| Number of bridge | Intact and slightly damaged | Moderate damaged | Serious damaged | Completely damaged |
|------------------|----------------------------|------------------|----------------|-------------------|
| 1337             | 82.87                      | 9.35             | 7.03           | 0.75              |

Table 2 shows the earthquake damage investigation of RC simply-supported girder bridge in the disaster area of Qinghai Yushu earthquake.

Table 2. Earthquake damage types of RC simple-supported girder bridge

| Number of bridge | Primary damages                        |
|------------------|----------------------------------------|
| 9                | Support failure and girder falling     |
| 7                | Pier failure                            |
| 6                | Foundation earthquake damages          |
| 3                | Damages of expansion joints and Continuous slab-deck |
| 3                | Structural damages of girder           |
| 2                | Abutment failure                        |

As showed in Table 2, all relevant parts of the bridge may be damaged during the earthquake. According to earthquake damage types of Table 2, damage types of RC simple-supported girder bridge can be further divided into girder earthquake damage, pier earthquake damage, abutment earthquake damage, foundation earthquake damage, bearing and other earthquake damage. In the following, combined with the earthquake damage investigation of RC simply-supported girder bridge in several earthquakes in China, the characteristics and performance of these types of seismic damage are explained.

2.1 Girder seismic damage

Under the joint action of earthquake dynamic effect and landslide, the girder seismic damages are mainly girder body displacement and girder falling. The displacement of the girder body is mainly represented by a displacement in the longitudinal bridge, displacement in the transverse bridge, and plane rotation. Because the girder body is directly supported on the bridge piers, only the rubber bearings are connected with each other, and there is basically no horizontal constraint [6]. When the horizontal seismic force exceeds the friction force or bearing shear capacity of bearing, relative displacement between girder and pier will occur. The displacement of the girder is also related to the height of the pier. The anti-pushing rigidity of the high pier is small, and the displacement is large under horizontal seismic force. When the girder displacement exceeds the support range, it will cause girder falling. In all seismic damages, girder falling is the most serious earthquake damage, which will directly lead to traffic disruption.

For earthquake damage of girder falling, the longitudinal girder falling accounts for the vast majority. The reasons for the girder of falling are that the overall integrity of the simply supported girder bridge is relatively poor, and the girders of many bridges in the earthquake zone are supported in a relatively small length. The form and arrangement of the bearings are not reasonable. There is no longitudinal displacement constraint; the lateral limit stop is weak [7]. In the Wenchuan earthquake, the 5 span girders of the New Fujiang Bridge in Nanba are completely falling, and some girders on both sides of the north and south sides are falling, as showed in Figure 1. The Gaoyuan Bridge also has the girder falling, as showed in Figure 2. In the Tangshan earthquake, many simple-supported girder bridges were damaged by girder falling [8].
2.2 Pier seismic damage

The piers are the principal component to support the superstructure of the bridge. The seismic damage to bridge piers mainly includes fracture and deformation, the specific performances include: the bridge piers displacement, tilt, bending and shear failure of pier bottom and pier body, the collapse of the top of the pier to form a plastic hinge, shear failure of the cross beam, cover beam cracking, block failure etc. Pier damage occurs mostly at the root and top, lateral stirrups of the piers that are collapsed or sheared are generally less, the sudden change in the stiffness of the pier body is prone to earthquake damage. Masonry piers are more damaged than reinforced concrete piers.

In the Wenchuan earthquake, the piers of the simply-supported girder bridge in the disaster area are in the form of reinforced concrete double-column circular pier, double-column rectangular pier, single-column rectangular pier, and single-column circular pier. Seismic damage survey data show that the double-column pier is preferable to the single-column pier, and the rectangular pier performs better than the circular pier. Piers earthquake damage of the Baihua Bridge in the Wenchuan earthquake is shown in Figure 3.

2.3 Abutment seismic damage

Abutment is the supporting part on both sides of the bridge. Generally, abutment is built on the plain fill or the bank of the river or on the hillside. It’s the support structure built with mortar flag stone or reinforced concrete, which is the direct part of the bridge to resist the earthquake. Abutment seismic damage mainly includes cracking at the wall of the gravity abutment, rib cracking at the ribbed slab abutment, cracking at the back wall and ear wall, abutment tilt, displacement, cracking at the conical slope etc. [5]. Masonry gravity abutment has poor seismic capability, which is easy to damage and hard to repair in an earthquake.

Causes of the abutment damage are mainly the interaction between girder and abutment, foundation slip and subsidence. The subgrade of abutment is generally high, and three facing empty. The stiffness of the abutment and the soil below is different. The foundation soil is prone to deformation and damage under the earthquake load. The strength and deformation of the abutment cannot meet the requirements of the earthquake force, and make the abutment damage. Abutment seismic damage of the Shoujiang Bridge during the Wenchuan earthquake is shown in Figure 4; the abutment seismic damage of the Shahegou Bridge during the Wenchuan earthquake is shown in Figure 5 [8].
2.4 Seismic damages of subgrade and foundation
In the earthquake, serious damage of the subgrade and foundation is the main reason for the collapse of a bridge; this is also the important factor why the bridge is difficult to repair after the earthquake. In the Sichuan Wenchuan earthquake, of the 26 bridges that were destroyed by girder falling, 11 have suffered seismic damages of subgrade and foundation [9]. The destruction of the foundation is closely related to the failure of the subgrade, and the destruction of almost all subgrade will cause the destruction of the foundation. Foundation seismic damage is mainly manifested in displacement, tilt, subsidence, and fracture and buckling instability. Foundation seismic damage of bridge in the Sichuan Wenchuan earthquake is given in Figure 6 [9].

2.5 Seismic damages of bearing and the other
Seismic damage of the bearing is common in an earthquake. The adjacent beams collide with each other and the girder appears longitudinal and lateral displacement generally all happened after the destruction of the bearing. The bearing is subjected to great shear force and deformation during a strong earthquake. The reasons for the widespread failure of the bearing are that the mechanics characteristic of the bearing under the action of the earthquake is special, the seismic requirements of the bearing are not fully considered in the design, and the structural measures are insufficient, some bearing forms and materials are defective. Earthquake damage of the bearing mainly manifests as the bearing displacement, the pulling out of the anchor bolt, the snipping, the dropping of the movable bearing, and the construction damage of the bearing itself. Bearing damage of a bridge on the S105 line in Sichuan Wenchuan earthquake is shown in Figure 7 [10].

In addition to the earthquake damage to the main parts mentioned above, there are some non-structural seismic damages, including the failure of the joints, the destruction of the expansion joints, destruction of the handrail guardrails, and the failure of the block, etc. Although these parts of the damage will not cause the bridge to collapse, it will also greatly aggravate the seismic damage of the bridge, so the bridge seismic design and bridge construction should be given recognition and appropriate treatment. The damage of the expansion joint of the Mianyuanhe Bridge during the Wenchuan earthquake is shown in Figure 8 [9].
3. Suggestions for seismic design

Combined with the above seismic damage characteristics of bridge, the following suggestions are proposed for the seismic design of the RC simply-supported bridge:

(1) When choosing the bridge site, the active fault and its adjacent areas should be avoided as far as possible, the areas that threaten the safety of the bridge structure, such as a landslide, soft soil layer should be also avoided. Slope protection and ground improvement should be carried out on a bridge that must pass through adverse geological conditions.

(2) Design of collapse-proof systems. The design idea is that the girder can be allowed to move to the maximum extent, but the girders falling should be avoided. The longitudinal displacement of the girder is very easy to cause the girder falling. Therefore, the girder restrainer and the appropriate support length of the girder are very important for the seismic resistance of simply-supported bridge, especially the high-pier and multi-span long bridge. In the design, the bearing, girder support length and girder restrainer should be considered as a unified collapse-proof system. Japan and the United States attach great importance to collapse-proof. In the Japanese code, the displacement limit bearing is taken as the first line of defense, the support length of the girder and the girder restrainer are used as the second line of defense, and the collapse-proof device is used as the third line of defense. The United States has also adopted similar measures.

(3) The seismic design of the pier and abutment. Role of stirrup in bridge piers should be fully considered. The stirrup should be configured according to shear calculation. Choosing reasonable stirrup spacing and pays attention to construction details of stirrup joints. Avoid using masonry gravity abutments as far as possible, adopting reinforced concrete abutment and properly control abutment height. The transverse displacement of the girder is easy to cause the failure of the pier block. When the horizontal seismic force is taken into consideration, the block is a stress component; attention should be paid to the reasonable strength of the block but not too rigid. The block reinforcement should have enough anchorage length and go deep into the cover beam, and optimize its structure. Increasing the distance between the block and the girder, and the buffer device should be set at the same time. The pile foundation should be used as much as possible and the embedded depth should be increased. Special protective measures should be adopted.

(4) The seismic design of the bearing. Bearing form and arrangement have a significant influence on the earthquake resistance of the bridge, and the supporting damage in an earthquake is unavoidable. The application scope of aseismic bearing should be extended. Change the existing floating to connect with the pier anchor bolt at the bottom to bear the bearing pull force that may be generated by the earthquake. The anchor bolt and shock proof plate of the bearing must have sufficient seismic strength.

4. Conclusions

In this paper, seismic damage characteristics of the simple-supported girder bridge are studied through seismic damage data on the simple-supported girder bridge in several major earthquakes in China. According to seismic damage characteristics of the girder, the pier, the abutment, the subgrade and foundation, the bearing and the other, the seismic design countermeasures are put forward, which can provide reference for seismic design of simply-supported girder bridge.
References

[1] Jianting Ding, Shuzhen Jiang, Feng Bao, World Earthquake Engineering, Vol. 22(2006), p. 68 (in Chinese)

[2] Jing Chen, Journal of Seismological Research, Vol. 22(2000) p 436 (in Chinese)

[3] Jinxin Gong, Xueting Wang, Qin Zhang, Journal of Dalian University of Technology, Vol. 49(2009), p. 739 (in Chinese)

[4] Dongsheng Wang, Jiying Wang, Zhiguo Sun, et al, Journal of Disaster Prevention and Mitigation Engineering, Vol. 31(2011), p. 595 (in Chinese)

[5] Weilin Zhuang, Zhenyu Liu, Jinsong Jiang, Chinese Journal of Rock Mechanics and Engineering, Vol. 28(2009), p. 1377 (in Chinese)

[6] Kai Chen, Lifeng Yang, Yuliang Cha, Journal of Qinghai University (Natural Science), Vol. 30(2012), p. 85 (in Chinese)

[7] Dongsheng Wang, Xun Guo, Zhiguo Sun, et al, Journal of Earthquake Engineering and Engineering Vibration, Vol. 29(2009), p. 84 (in Chinese)

[8] Hongjing Li, Ming Lu, Zengping Wen, et al, Journal of Nanjing University of Technology (Natural Science Edition), Vol. 31(2009), p. 24(in Chinese)

[9] Zairong Wang, Endong Guo, Zhao Zhao, et al, Journal of Catastrophology, Vol. 25(2010), p. 37 (in Chinese)

[10] Shuping Li, Chao Zeng, Xianquan Yang, et al, Highway, Vol. 7(2009), p. 125 (in Chinese)