

Study on the damage of bridges in 2008 Wenchuan Earthquake

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2008 年中国汶川地震で被災した橋梁の被害と復興に関する研究

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Abstract

The Wenchuan earthquake occurred in Sichuan Province on May 12, 2008. About 70,000 people were killed and the some bridges were damaged by the earthquake. On the Maioziping Bridge which is located on the Duwen Highway, the superstructure collapsed, and one span of PC T-type girder fell down. On the Baihua Bridge, four continuous curved span sections (P2-P6) collapsed. The Xiaoyudong Bridge in Xiaoyudong Town on the Peng-Bai Road and the Huilan Bridge on Huilan street in Mianyang were also damaged. After the earthquake, the authors of this paper conducted investigative research into the typical bridge damage that occurred. In this paper, we present our findings based on site investigation.

Keywords: Field damage investigation, damage of bridges, restoration, retrofit

1. Introduction

The Wenchuan earthquake (Mw7.9) occurred in Sichuan Province, China, on May 12, 2008. The earthquake killed about 70,000 people. In Yinxiu Town close to the hypocenter, almost all buildings were destroyed and about 7,700 people, nearly 80% of the residents, were dead or missing. After the earthquake, the authors had three times investigations in the fault regions. We conducted first field-damage investigation of bridges and landslides in the regions of Dujiangyan City, Wenchuan County, and Pengzhou City and Mianzhu City, Beichuan County, on August 29-September 2, 2008. And second and third field-damage investigations were on March 30-April 1, 2009 and September 25-29, 2009. In the investigation, several individual surveys were conducted. Based on the field investigation, damage of some typical bridges and their restoration and retrofit are presented in this report. It should be noted that since the investigation was conducted without prior information on design drawings and analysis, it is highly possible that the authors made incorrect interpretations of the failure mechanism.

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2. Outline of Wenchuan Earthquake

Fig.1 shows relationship between faults and typical damage of bridges. The Wenchuan earthquake was induced by rupture of the Longmen Shan Fault. Large scale thrusting of the Tibetan Plateau towards the east of the rigid block of Sichuan Basin resulted in the NE-SE dip-slip reverse fault [Densmore et al, 2008; Lekkas, 2008]. The fault zone extended from Yingxiu Town, Wenchuan County, to Mianzhu City, Beichuan County, and to Qingchuan County. The epicenter was located at Yingxiu Town. Extensive damage occurred in nearly 300 km long and 50 km wide regions along the fault [Li and Zhao, 2008]. There were precipitous mountainous regions with steep streams. Consequently, shallow and deep slope failures occurred extensively. The damaged regions had very harsh natural conditions.

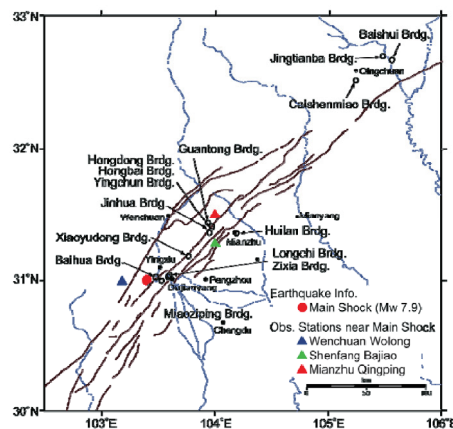


Fig.1 Relationship between faults and bridges

3. Damage of bridges (observed in the first investigation)

We investigated damage of bridges in Dujiangyan City, Wenchuan County, and Pengzhou City and Mianzhu City. Only typical damage is presented in this chapter.

(1) Miaozi Bridge

Photo 1 shows Miaozi Bridge. It is located where Duwen Highway (connecting Chengdu and Wenchuan) crosses the Zipingpu dam reservoir. The structure is 1,440 m long and consists of a three-span continuous PC-box type girder bridge with PC-T type girder approach bridges of two, four, and five spans. The main structure is a 450 m long (a main span of 220 m) three-span continuous pre-stressed concrete frame bridge. A PC-T type girder was constructed by connecting 50 m long, simply supported. The bridges were supported by elastomeric bearings. All spans were supported by nearly 100 m tall RC type piers. When the earthquake occurred, the bridges were almost completed, but expansion joints were not yet set. One of the two end-spans of a five-span continuous T-girder bridge collapsed as shown in Photo 2. It was reported that the distance between two adjacent piers which supported the fallen span was extended by about 0.69 m at the top based on measurements taken after the earthquake. Any damage in the piers above

the water level was not identified; however, it was reported that piers suffered several small cracks at their base. It was likely that foundation flexibility further amplified the lateral displacement of the bridge. The fact that residual extension was nearly 0.69 m between the two piers implies that peak relative displacement between the two piers was possibly over a meter.

Photo 3 shows the damage of bearings at the fallen span. We see from the Photo 3 that the remaining part of the bearings and reinforced concrete side blocks were extensive damaged. Although reinforced concrete side blocks were installed at both sides of the deck, they could not fully restrict the deck displacement in the transverse direction. If unseating prevention devices were installed at this span, collapse could have possibly been prevented.

There were many other pieces of evidence that show that deck displacement was extremely large during the earthquake. Obviously failure of side blocks at both sides of the bridge allowed residual drift to develop in the transverse direction. Almost all side blocks suffered damage. Photo 4 shows one of the damaged elastomeric bearing. We see from Photo 4 that it was occurred extremely large displacement at the bearing. Vertical offset was also developed here because almost all elastomeric bearings moved out from their position due to the excessive relative bridge response displacement.



Photo 1 Miaoziping Bridge



Photo 2 Span of falling PC-T type girder

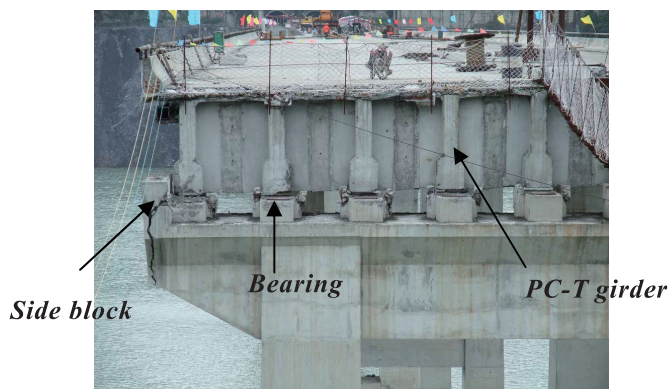


Photo 3 Damage of bearings and side walls



Photo 4 One of the damaged elastomeric bearing

(2) Baihua Bridge

Baihua Bridge is located near main shock. It is about 500 m long PC type girder connecting Yingxiu and Dujianyang. It was completed in 2004. Photo 5 shows damage of Baihua Bridge. We can see from Photo 5 that it is located between a precipitous mountain and a river section. The four-span continuous curved section collapsed. By numbering the piers from P2 to P6, spans between P2 and P6 were supported by about 30 m tall moment-resisting frame piers consisting of two circular reinforced concrete columns and lateral beams. Other sections did not collapse but suffered extensive damage interrupting refuge and rescue, the remaining sections were removed by explosion as shown in Photo 6. Therefore, it was difficult to identify the section which collapsed during the earthquake; however, the collapsed section was preserved in its original condition after the earthquake.

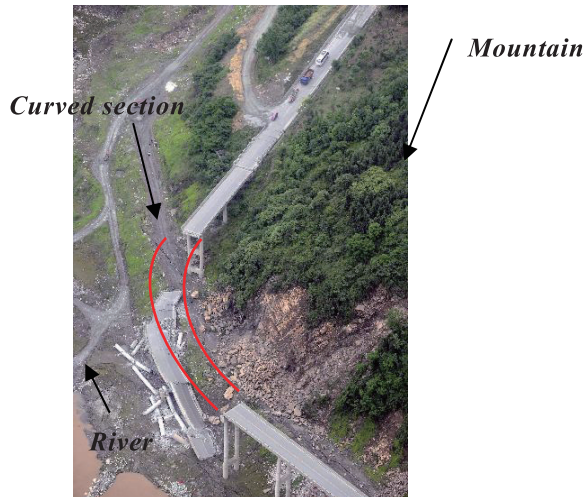


Photo 5 Baihua Bridge (From SINA Corporation)



Photo 6 Exploded spans after earthquake

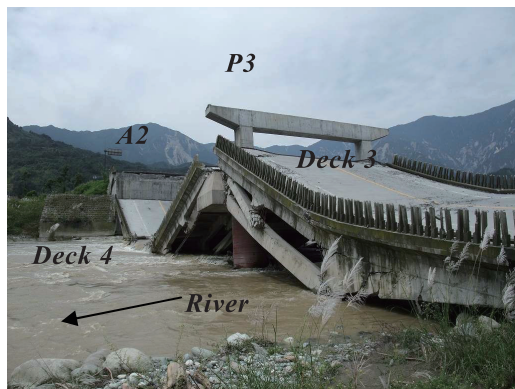
(3) Xiaoyudong Bridge

Xiaoyudong Bridge is located in Xiaoyudong Town on Peng-Bai Road, which connects Pengzhou and Longmenshanzhen. It is a 187 m long, four-span, simply supported, slant-leg, frame bridge that was built in 1998. A pier consists of a single story reinforced concrete moment-resisting frame with two columns and a cap beam on which two decks were simply supported. Two columns of a pier and 12 slant-legs of two adjacent bridges were connected to a pile cap supported by two reinforced concrete piles without a footing. It is likely in such a structure that piles become unstable if lateral force equilibrium from two adjacent decks is lost.

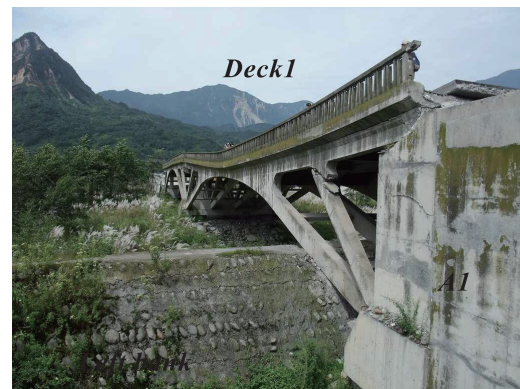
Photo 7 shows the damage of Xiaoyudong Bridge, and Photo 8 shows damage of slant-leg at Deck1. By numbering abutments, piers, and decks from the left bank, decks 1, 3 and 4 collapsed. And Deck3 and 4 was fallen. At right abutment A2, pavement permanently displaced about 0.2 m in the backsoil side due to the collision of deck 4 and A2. Extensive shear cracks were developed in the side walls resulting from

the collision. Most likely, deck 4 dislodged from A2 support due to excessive response displacement in the longitudinal direction, and then fell down, which resulted in the columns breaking. In the Deck2, flexural and shear failure developed at the slant-legs. These were a typical failure with limited plastic deformation capacity due to insufficient reinforcement. Reinforced concrete pile P2 suffered extensive cracks. This resulted from the extensive drift of P3 in the A2 side. This suggests that Deck 4 collapsed earlier than Deck 3. Once Deck 4 collapsed, the equilibrium of lateral forces between Decks 3 and 4 was lost, and P3 tilted extensively toward A2, which, in turn, resulted in Deck 3 being dislodged from its reliance on P3 and P4. As will be described later, this evaluation is consistent with a farmer's account that Deck 3 collapsed after Deck 4. Several surface fault displacements occurred around the bridge.

This fault displacement extended downstream along the left dyke and crossed the approaching road behind A2. The fault displacement caused the large cracks on concrete pavements.



(a) Deck3-4



(b) Deck1

Photo 7 Damage of Xiaoyudong Bridge



Photo 8 Damage of the slant-legs at Deck1

(4) Huilan Bridge

Huilan Bridge which is an interchange bridge is located in Mianyang. It is a railway crossing, consisting of a main bridge and four curved ramp bridges for light vehicles and passengers as shown in Photo 9. They

were 170-200 m long hollow deck girders with a plane curvature of 25.25m, and they were supported by 0.8 m diameter circular reinforced concrete piers. Girders were alternatively supported by rubber pad bearings and rigid connections. It was supposed that spans were too short to fully support the girders by rigid connections, and full support by rubber pad bearings would induce a large span displacement in the transverse direction because of the small radius of curvature.

A ramp bridge suffered damage, and other ramp bridges suffered similar damage. Photos 10 show flexure and shear failure of piers which were rigidly connected to the girders. The failures resulted in settlement in the girders, and a number of extensive transverse cracks occurred at the bottom of deck panels near the support.



Photo 9 Huilan Bridge



Photo 10 Typical damage of pier

4. Restoration of Bridges (observed in the second and third investigation)

The second investigation was conducted six months after the first investigation, and the third investigation was conducted about six months after that. These field investigations aim at identifying the damage and subsequent restoration of the bridges in question. In this chapter, we report on the restoration of typical bridges based on second and third investigations.

(1) Miaoziping Bridge

In the second investigation, the restoration of the fallen PC-T type girder span was completed. The restored girder was of the same type as that which was damaged. Moreover, the piers which suffered several small cracks were reinforced, with steel frames and concrete. After the earthquake, the fallen span was extended by about 0.7m from the original length. However we did not clear up the issue of displacement in this investigation. In the third investigation, the Duwen Highway was opened as shown in Photo 11.

(2) Baihua Bridge

In the second investigation, the road location and new bridge were moved downstream from their original location as shown in Photo 12. The substructure and foundation were constructed at the new

location. In the third investigation, the construction of the new bridge's substructure was finished as shown in Photo 13. The PC girder was made on the left bank, and the girders were erected using an erection girder from the left bank. The new bridge was a different type and used PC-T type girders, simply supported



Photo 11 Miaozi Ping Bridge after restoration
(Third investigation)



Photo 12 Baihua Bridge
(Second investigation)



Photo 13 Baihua Bridge
(Third investigation)



Photo 14 Xiaoyudong Bridge
(Third investigation)

(3) Xiaoyudong Bridge

In the second investigation, we surveyed the pre-earthquake characteristics of the bridge to determine the cause of damage. The restoration of this bridge was conducted upstream from the original site. In the third investigation, we again measured the same characteristics, as well as surveying for additional information. The new bridge and road were opened as shown in Photo 14. The bridge used simply supported PC-T girders and was supported by elastomeric bearings.

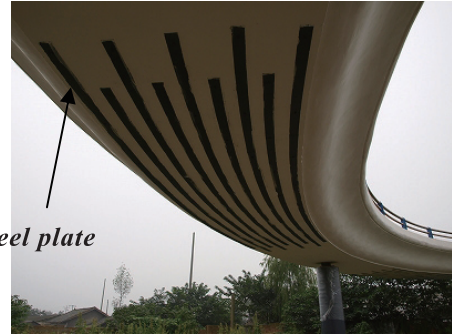
(4) Huilan Bridge

In the second investigation, the proportions and characteristics of the bridge prior to the earthquake were measured. During this investigation, only the initial stages of restoration were observed involving the support of superstructure at the damaged piers.

However, in the third investigation, the restoration of superstructure, substructure and foundation was finished as shown in Photo 15. This was completed within six months. At the damaged pier, restoration based on reinforced concrete was carried out. Steel plates were used on the superstructure.



(a) Huilan Bridge



(b) Superstructure



(c) Pier

Photo 15 Huilan Bridge
(Third investigation)

5. Conclusions

Three field investigations and surveys have been conducted: August-September (2008); March-April (2009); September (2009). In the investigation, we have obtained pre-earthquake data on the bridges which suffered damage and note that restoration on these has advanced quickly. As close analysis of the information obtained is now being carried out, in order to determine and to report on the cause of damage. This report will be made available after the analysis is complete.

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