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SEISMIC PERFORMANCE OF ARCH BRIDGES OBSERVED IN TANGSHAN EARTHQUAKE AND WENCHUAN EARTHQUAKE

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ABSTRACT

Tangshan Earthquake and Wenchuan Earthquake were great earthquakes with the magnitude larger than 7.0 after 1949 in China, which happened in 1976 and 2008 respectively. The epicenter of the former one located in the urban area, however, the latter one lay in remote mountainous area where earthquake-induced disasters were serious. Because of the difference in focal mechanism, intensity, duration time, geology, etc, Wenchun earthquake induced more earthquake loss than Tangshan Earthquake. Bridges are vulnerable to disaster earthquakes, arch bridges behaved with collapse, moderate damage or slight damage, and many bridges have no any damage observed in Wenchuan earthquake and Tangshan Earthquake. Damage and aseismic performance of double curved arch bridge, tied arch bridge, masonry arch bridge were introduced in the paper. The damages induced by the two earthquakes indicated that condition of foundation soil, span length, number of the span, structural type of arch bridge would affect the aseismic performance obviously.

Introduction

Wenchuan Earthquake with a magnitude of 8.0, which is a shallow earthquake, occurred in Wenchuan County, Sichuan Province, China on May 12, 2008. All the highways to Wenchuan and those throughout Sichuan Province were damaged, resulting in delayed arrival of rescue troops. According to official statistics, this earthquake induced damages to 24 expressways, 161 national and provintial trunk highways with 6,140 bridges and 156 tunnels. The earthquake brought us disaster, but also gave us a chance to review the theory of seismic design for highway bridges. Through research team investigated Sichuan Province time after time, performance of different arch bridge was observed in Wenchuan Earthquake. So in the paper, focal mechanism of Wenchuan Earthquake and Tangshan Earthquake were introduced firstly, and then the damage of the arch bridges in the two earthquakes were described according to the structural type firstly, finally the factors effecting the performance of arch bridges were drew.

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Focal Mechanism of Wenchuan Earthquake and Tangshan Earthquake

The 7.8 magnitude Tangshan Earthquake happened on July 28, 1976. The epicenter was Tangshan City, Hebei Province of China, and the depth of the focal was 11 km. The length of fault was less than 100 km, and earthquake fault slip lasted 12.9 sec. Tangshan earthquake effects adjacent regions severely such as Beijing, Tianjin, and other twelve provinces, municipalities and autonomous regions were affected differently,see Figure 1.

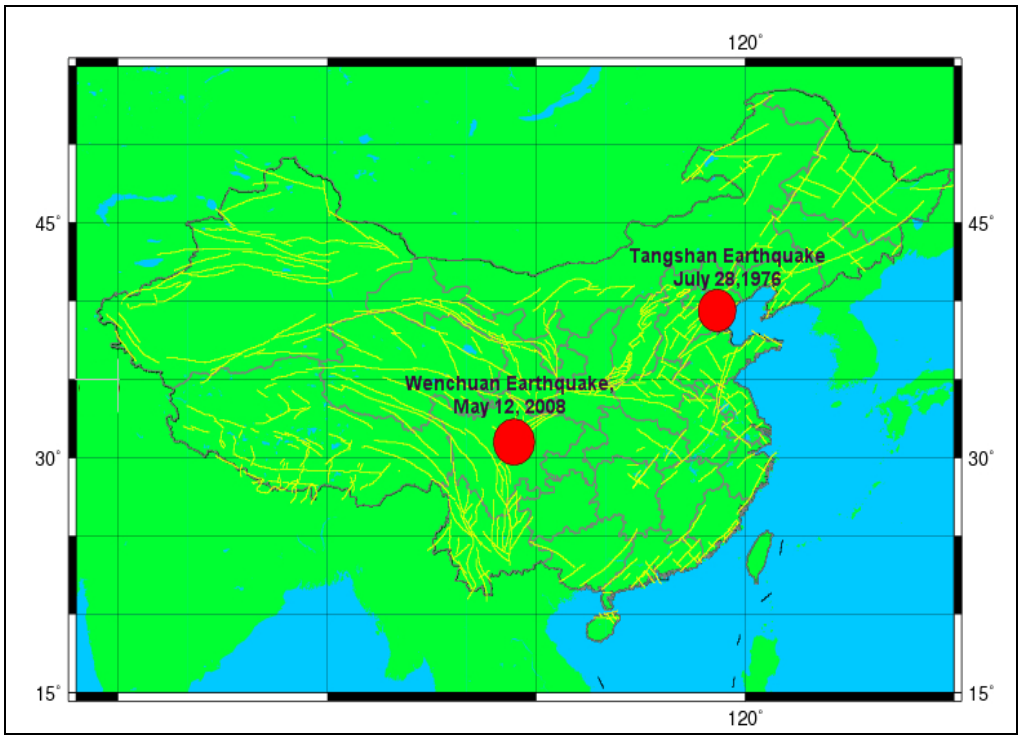

Figure 1. Location of 1976 Tangshan and 2008 Wenchuan earthquakes

Wenchuan Earthquake was a thrust with strike-slip type. The surface ruptures were located in Yingxiu-Beichuan fault zone and Pengxian-Guanxian fault zone. The focal depth was 14 km and fault shifting lasted 22.2 sec that was longer than Tangshan Earthquake. Shaanxi Province, Gansu Province, Chongqing City, etc, were affected severely and Beijing, Tianjin, Shanxi Province, etc, twenty-six provinces, municipalities and autonomous regions felt the shock.

Wenchuan Earthquake and Tangshan Earthquake were compared by length of faults to show that the energy released in Wenchuan Earthquake is about three times that in Tangshan earthquake. After both earthquakes, aftershock occurred frequently, nearly 300 aftershocks happened after Wenchuan Earthquake. So those were why the disaster induced by Wenchuan Earthquake was larger than Tangshan Earthquake.

Arch Bridge Performance Observed in Tangshan Earthquake

There were 9 arterial highways and 28 county roads through Tangshan, and 11 roads and highways were destroyed by the earthquake. 32 arch bridges were investigated after earthquake,

damage degree was listed in Table1 (Liu 1986). The table showed that 6 bridges collapsed in the earthquake, and five of those were built on the unfavorable foundation soil. On the contra, structures built on the perfect foundation soil were in good condition.

Table 1. Damage of arch bridge in Tangshan Earthquake

Damage	Collapse	Destroyed seriously	Destroyed moderately	Damaged slightly	No damage	Total
Number	6	2	8	6	10	32

Double Curved Arch Bridges

Double curved arch bridge is different with ordinary arch bridge at the main arch ring which is made of one or more cross curved plates in the trancverse direction. That is, the ring shape is curved in both derections.

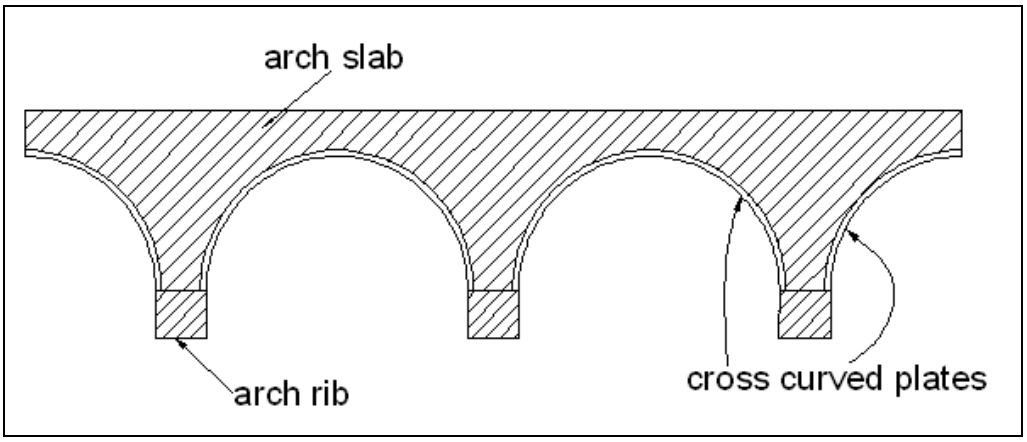

Figure 2. Cross section of double curved bridge

Xiao Bo Zhuang Bridge located in the extreme shock district where the earthquake intensity was Ⅸ degree. Figure 3 showed the panorama (Liu 1986). The bridge was a ten-span double curved arch bridge with the span length of 22 m. After strong shock, only one span was left. Distyle pier with the height of 9 m was used, in which five piers were broken and others were sloped to the south. Two abutments inclined about 4 degree and one sloped to the south, but the other to the north.

Yang Hua Zhuang Bridge was a double curved arch bridge with 8 spans and the span length was 22 m. The type of the pier was same as Xiao Bo Zhuang Bridge and the height was 5.82 m. Figure 4 described the damage (Liu 1986). The 4^{th} span length was shortened 85 cm and arch crown was lifted 147cm. Crack width at the crown and spring of arch was 10cm, moreover, compressed concrete was crushed with steels exposing. Pier 4, 5 cracked at the top and the steels exposed.

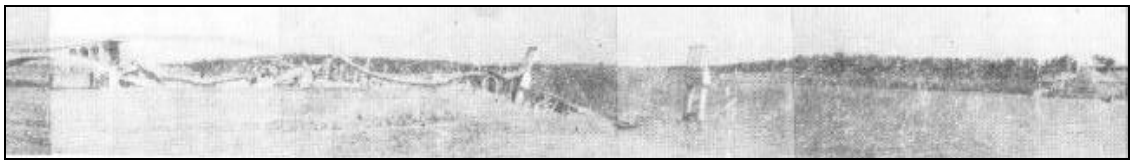

Figure 3. Xiao Bo Zhuang Bridge collapsed entirely

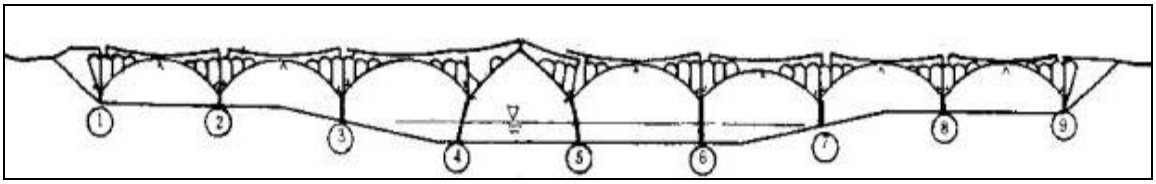

Figure 4. Damage sketch map for Yang Hua Zhuang Bridge

Nan Mai Zhu Bridge and Da Yu Zhuang Bridge located in the extreme shock region too. Damage of latter bridges were slighter than Xiao Bo Zhuang Bridge and Yang Hua Zhuang Bridge although those were all double curved arch bridge built on the favorable foundation soil. Cracks at arch apex, skewback and at the quarter span, which were primary damage of Nan Mai Zhu Bridge and Da Yu Zhuang Bridge.

Figure 5 and Figure 6 (Wang 2007) were single-span double curved arch bridges, which were built on the unfavorable foundation soil and the span length was 37 m and 40 m, respectively. They collapsed as the earthquake occurred. However, the earthquake damage of those bridges that located on the well soil was slight or no damage occurred, such as Zhao Ge Zhuang Bridge, Si Zhuang Zi Bridge and several small bridges.

Figure 5. Ye Li Hong Qi Bridge collapsed

Figure 6. Liu Guan Tun Bridge collapsed

Tied Arch Bridge

Nan Cai Cun Bridge was a tied arch bridge with five spans and the length of span was 16 m. Two spans were unseated as the earthquake happened, see Figure 7 (Liu 1986). Piers and abutments sloped maximum 13 degree in the longitudinal direction and 6 degree in the transverse direction. Sand liquefaction was observed near the bridge, piers and abutment settled about 5 cm.

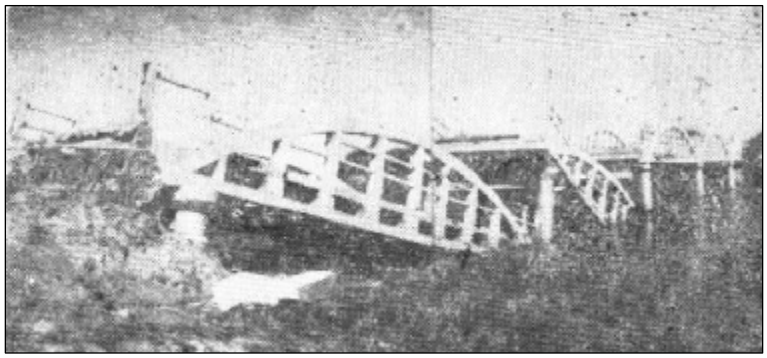

Figure 7. Nan Cai Cun Bridge collapsed

Damage of Single-span Arch Bridge

Same as the multi-span arch bridge, aseismic performance of bridges that sited on the well foundation soil excelled bridges built on the unfavorable geology. Comparing with the multi-span bridge, more single-span stone arch bridges and the double curved arch bridges located in Ⅷ degrees district survived after Tangshan earthquake, even masonry arch bridges with poor ductility also have shown good capability.

Arch Bridge Seismic Performance in Wenchuan Earthquake

The authors have attended in several field investigation teams after shock. In the itinerary, the arch bridge accounted 241 in total. It included box arch bridge, truss arch bridge, reinforced concrete arch bridge and masonry arch bridge (See Figure 8).

After Wenchuan Great Earthquake happened, the strong motion of earthquake caused arch bridge to collapse, buckling of arch rib, shear failure, as well as crack on the soffit, which are showed in Figure 9 and Figure 10 (Wang 2008; Chen 2009). But many arch bridges located in the meizoseismal area survived and kept the traffic capacity (see Figure 11, 12 and 13). The lengths of bridges were not greater than 30 m, which means most of the arch bridges were small bridges. And most of the masonry arch bridges and double curved arch bridge were built in 1970s and 1980s.

Lots of lessons and experience were got from Tangshan Earthquake, subsequently, a new highway seismic design code was published in 1989 and the aseismic capacity of bridge was enhanced. Compared with the damage of arch bridges in Tangshan Earthquake, in meizoseismal district, many double curved arch bridges and medium-small masonry arch bridges located on the approved foundation soil behaved well in Wenchuan Earthquake.

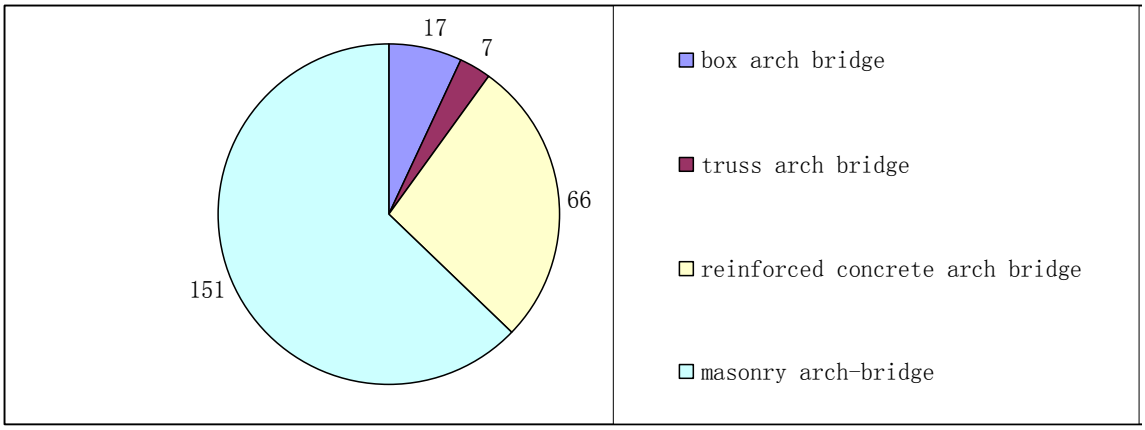

Figure 8. Type of arch bridge investigated

Figure 9. Xiao Yu Dong Bridge collapsed

Figure 10. Jing Tian Ba Bridge, a two-span box arch bridge, collapsed

Figure 11. Qian Jin Bridge, a double curved arch arch bridge with a span length of 75m, was intact

Figure 12. Tong Zi Liang Bridge, a rib bridge with a span length of 30 m, no damage occurred

Figure 13. A small stone arch bridge beside the Bai Hua Bridge survived while Ba Hua Bridge collapsed in earthquake

Conclusions

Great earthquakes brought large disaster and they made the highway bridges suffered severe damage. At the same time, lessons and experience summarized from earthquake damage would direct the seismic design to advance. Tangshan Earthquake and Wenchuan Earthquake were both catastrophic extreme events since 1949, highway bridges with different structural type showed diverse performance, which would be valuable for development of seismic design codes. From two earthquake conclusions about arch bridge were draw as follows:

(1) Approved foundation soil was important for exerting structural aseismic capacity. Similar arch bridge built on the different geologic condition showed different damage in the two great earthquakes, even masonry arch bridges with poor ductility also have shown perfect capability as the geology was good. From the observation, most of multi-span arch bridges or simple span bridges with span length of more than 40m collapsed entirely, which indicated that those were more sensitive to soil.

(2) For arch rib, damage mainly focused on the arch apex, springing of arch and quarter span. Crack, longitudinal deformation and uplift were prevalent. Moreover, for spandrel structure, damage showed as web member cracked or broken and spandrel wall cracked.

(3) For piers and abutment, slope to the longitudinal direction of the bridge, broken and collapse were observed frequently. And slope resulted in arch ring slumping from seat.

(4) Masonry arch bridges could also resist the earthquake dynamic load. Most of the masonry arch bridges still stood after the earthquake and opened to the traffic. If the foundation soil were perfect and the span length was not too long, masonry arch bridges would be a superior structural type, especially when considered about the secondary disaster.

(5) Double curved arch bridges should not be neglected in the future. Although several this type bridge collapse in Tangshan Earthquak, few new this type arch bridges were no or minor damage observed in Wenchuan Earthquake.

Acknowledgments

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