Analysis of the Prevention Measures for Earthquake Damage and Flood Disasters of Bridges in Mountainous Areas of Sichuan

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Abstract. Since mountain bridges would be influenced by flood disasters, earthquake damage and other problems, this article puts forward some precautions that might be used during the construction of mountain bridges in Sichuan on the basis of the direct and indirect destruction caused by earthquakes and floods in the construction of Sichuan bridge in the expectation that it can provide some reference for disaster prevention.

Keywords: Mountain bridges; Flood; Earthquake; Direct and indirect destruction.

1. Introduction
The mountainous terrain is rugged and torrents and debris flows are prone to occur. As an important hub connecting mountainous areas, bridges are deeply affected by geological disasters in mountainous areas. To prevent the destruction of torrents can be prevented from both new and existing bridges [1]. After the 5.12 Wenchuan Earthquake, the secondary disasters caused by bridges in mountainous areas due to earthquakes have attracted more and more attention. In the process of bridge design, attention should be paid to the earthquake resistance of bridge to reduce the bridge damage due to the earthquake damage [2]. The mountainous landforms are complex, and geological disasters often occur which are difficult to avoid. Therefore, it is extremely important to reduce the damage of geological disasters to bridge structures. This paper analyzes the damage patterns and impacts of bridges in mountainous regions of Sichuan, and some specific effective defense measures are summarized and proposed.

2. Analysis of the Influence of Earthquake on Bridges in Mountainous Areas

2.1. Earthquake in Sichuan
Sichuan mountain areas is located in the transition zone from basin to Qinghai Tibet Plateau, where geotectonic movement is strong and crust activity is frequent. Affected by three major active fault zones, it has high seismic intensity, frequent strong earthquakes and profound secondary disasters. In recent years, the three earthquakes with high magnitude and serious damage occurred in Sichuan are Wenchuan earthquake, Lushan earthquake and Jiuzhaigou earthquake. The loss of three earthquakes is shown in Table 1.
Table 1. Statistics of recent major earthquakes in Sichuan.

| Name | Wenchuan earthquake | Lushan earthquake | Jiuzhaigou earthquake |
|------|---------------------|-------------------|----------------------|
| Time | 14:28p.m, May 12, 2008, | 8:02a.m, April 20, 2013 | 21:19p.m, August 8, 2017 |
| Geographical position | Wenchuan County, Aba Prefecture | Lushan County, Ya'an City | Jiuzhaigou County, Aba Prefecture |
| Focal depth | 14 kilometres | 13 kilometres | 20 kilometres |
| Magnitude | Richter scale 8 | Richter scale 7 | Richter scale 7 |
| Epicentral intensity | 11 degree | 9.0 degree | 9.0 degree |
| death toll | 69227 | 196 | 25 |
| Number of injured persons | 374643 | 11470 | 525 |
| Missing population | 17923 | 21 | 6 |
| Economic loss | 118.92 dollar | Over 250000 damaged houses | 73671 Rooms damaged |

2.2. Statistics of Earthquake Damage to Bridges

After the Wenchuan earthquake, surveyed 2154 bridges of the national and provincial trunk lines, with simple supported beams, continuous beams, continuous rigid frames and arch bridges; A total of 148 bridges were surveyed after the Lushan earthquake; 95 bridges were surveyed after the Jiuzhaigou earthquake, and the bridge types were simply supported Beams (slabs), continuous beams and arch bridges.

Table 2. Statistics of damage.

| Damage classification | Wenchuan earthquake | Lushan earthquake | Jiuzhaigou earthquake |
|-----------------------|---------------------|-------------------|----------------------|
|                       | number | Proportion | number | Proportion | number | Proportion |
| Level A               | 401 | 18.62% | 133 | 89.90% | 92 | 96.90% |
| Level B               | 279 | 12.95% | 11 | 7.40% | 3 | 3.10% |
| Level C               | 70 | 3.25% | 4 | 2.70% | 0 | - |
| Level D               | 52 | 2.41% | 0 | - | 0 | - |

2.3. The Destruction of the Bridge by the Earthquake

There are various forms of earthquake damage to bridges, which can be divided into earthquake direct damage and indirect damage.

(1) Direct destruction

Through the statistical analysis of the earthquake damage situation of the bridges damaged in recent major earthquakes in Sichuan, the main earthquake damages of the beam system bridge are beam displacement, pier damage, base damage. The displacement of the main beam will cause damage to the support system, bridge deck system, expansion joints and so on. When the displacement of the main beam is too large, the main beam will have unstable support or even drop beams, the bridge will lose all its bearing capacity; Bridge pier damage is a serious structural earthquake damage. Common bridge pier damages include cracking, tilting, plastic hinge, crushing, shearing and overturning. Bridges with severe bridge pier damage may cause the whole bridge to collapse. The main forms of earthquake damage include ground cracking and surface slippage displacement. This form of damage can easily lead to the destruction of the entire bridge, and a small amount of sand liquefaction is also found.

(2) Indirect destruction
After the earthquake in Canyon mountain areas, secondary geological disasters such as falling rocks, landslides and debris flows induced by the earthquake will also cause great damage to the bridge. Although Wenchuan earthquake has lasted for 10 years, its impact has not stopped. Three large-scale regional geological disasters of mountain flood and debris flow occurred in August 2010, July 2011 and July 2013 respectively. In June 2017, a large-scale high-level landslide occurred in Diexi, Maoxian County, with small-scale geological disasters such as collapse, rockfall and river sedimentation everywhere (Figure 1). In July 2018, mudslides in Maoxian County, Wenchuan County, Hongyuan County, Aba County and other places damaged roads and bridges, disrupted traffic, and brought new damage to bridges that survived the earthquake and rebuilt bridges.

(a) River Diversion caused by debris flow
(b) Shidaguan high landslide in Maoxian County in 2017

Figure 1. Secondary disasters caused by earthquakes.

3. Influence of Torrent on Bridges in Mountainous Areas

The special topography and environmental climate in the mountain areas affect the intensity of heavy rain and the distribution of precipitation. Due to the characteristics of short duration, concentrated rainfall, and high intensity of rainfall, it will pose a great threat to mountain road bridges. Mountain rivers have a large river bed ratio, which results in high water flow velocity, strong water handling capacity, high sand content, and even boulders on the river bed surface, so it is easy to cause bridge pier abrasion and collision damage. In addition, due to the undercutting of the riverbed, the burial depth of the bridge pier foundation is insufficient, it is easy to collapse the pier of the expanded foundation, or the bearing capacity of the pile foundation of the pile foundation is insufficient, and there may be insufficient clearance under the bridge, so the bridge is easily submerged and washed out. The bad types of mountain bridges broken by torrents include direct water damage, indirect water damage, erosion and abrasion.

(1) Directly destroyed by water: In recent years, several direct water-damaged bridges in Sichuan are shown in the figure 2. Most of them have been directly destroyed by continuous rainstorms [3]. Flow erosion will have an adverse effect on the stability of the bank slope. The slope of the bank should be avoided as much as possible. For example, the Pengshan Minjiang Bridge in Meishan City under the combined action of frequent flooding and erosion of the river bed undercutting and changes, the foundation of the bridge pier was severely eroded, and the base was partially emptied.

(2) Indirectly destroyed by water: Damage to bridges caused by geological disasters such as landslides, collapses, and mudslides caused by heavy rain. The debris flows into the river, congesting the channel, causing the water level to rise or change direction, and burying bridges, eroded abutments and bridge piers. Although it is not damage to the debris flow itself, it is directly related to secondary disasters. For example, in July 2018, Sichuan Province was hit by heavy rains, resulting in more than 20 landslides and debris flow disasters in the Sichuan-Tibet Highway on the National Highway 318, the Juba Mountain, Tiantuo, Tianlu 72, and Nujiang Valley.

(3) Scouring and abrasion: The abrasion of the abutment and ground tie beam is exposed, and the depth of the foundation is reduced. The smaller the projected areas perpendicular to the flow direction, the greater the flood flow and the stronger the scouring. Improve the jetting effect of bridge piers, can reduce the scouring of the river [4]. For example, on August 9, 2013, the 4 pile foundations originally buried in the overburden of the Fuyang Siqiaojiang oil bank junction in Mianyang were exposed due to severe erosion, and the erosion depth was about 6 meters. Eventually, the junction pier was caused by multiple flood erosion Exposed pile foundation.
4. Bridge Disaster Response Strategy in Mountain Areas

4.1. Earthquake Disaster Prevention

According to the spread characteristics of earthquake disasters and the degree of damage to mountain bridges, the defensive measures are mainly considered from the following aspects:

(1) Bridge location selection and general design idea

The principle of "big avoidance and small governance" should be followed when choosing a bridge location, and economic efficiency should not be used as a single indicator. In the alpine valley section, it is very important to choose the right bridge position. For potential large dangerous bodies, try to avoid them as far as possible. For difficult road sections, try to cross the tunnel as much as possible to reduce the probability of the bridge being directly exposed to earthquake disasters. In the overall design, the elevation of the bridge deck should be reduced as much as possible to reduce earthquake damage. The bridge structure with good overall regularity should be used as much as possible in the high-intensity earthquake areas. The structural layout should strive for uniform, symmetrical and regular geometric dimensions, quality and rigidity to avoid sudden changes [5].

(2) Bridge selection

Bridges should choose medium- and small-span bridges without using skew beam bridges. The bridge structure should have simple seismic transmission paths and reasonable seismic transmission paths [6]. More and more small and medium-span steel bridges, steel-mixed composite bridges, anti-web steel bridges can be used.

(3) Reasonable Selection of Pier form

Among many high-pier and long-span bridges, reinforced concrete box piers are often used for the pier body type. Cracks are prone to occur during the construction of this type of piers. Therefore, our institute has developed a new structural form of "concrete filled steel tube piers", which uses the ductility of concrete filled steel tubes to improve seismic resistance, successfully applied in Labajin and Heishigou Bridges.

(4) Seismic Fortification Measures

In the high intensity earthquake areas, we should strengthen the design of seismic fortification structure, especially the measures to prevent the falling of beams, increase the size of capping beams, set up blocking blocks, and prevent the falling of chains. Large displacement of the longitudinal bridge to the beam is easy to cause beam falling, while the displacement of the transverse bridge to the beam may cause block damage and beam falling under extreme conditions. According to the different displacement direction of the beam, the following measures are mainly taken: ① increase the effective width of the top surface of the cap beam in longitudinal and transverse direction to achieve the effect of increasing the support length; ② use the special longitudinal anti falling chain device as the final defense line of the longitudinal Bridge to prevent the falling of the beam.③ pay attention to the block design and optimize its structure.

(5) Application of seismic isolation technology
The technology of reducing and isolating earthquake mainly adopts the devices of reducing and isolating earthquake, such as isolation and damping support, energy dissipation device, isolation rubber pad, damper, which make the deformation and energy dissipation caused by earthquake mainly focus on the devices of reducing and isolating earthquake, so as to avoid the excessive earthquake damage of the main structure.

![Damper](image1.png) ![Cable damping support](image2.png)

**Figure 3.** Seismic isolation technology.

4.2. Countermeasures and Measures for Flood Disaster Prevention

Mountain torrents have the characteristics of suddenness, concentration of water, high flow rate, and strong erosion and destructive power. The sediments and even stones in the water flow are very common to the bridge junctions. The defensive measures are mainly considered from the following aspects:

1. Reasonable selection of bridge location and determination of bridge span layout
   The selection of bridge position first needs to carefully lay out large-angle oblique crossing bridges and Shunhe bridges. The oblique crossing bridges with staggered holes are very unfavorable for the flood discharge. The arrangement of the bridges along the rivers in mountain rivers can alleviate mountain hazards, but increases the risk of flooding.

2. The second is to determine a reasonable bridge height. For mountain bridges, raising the elevation of the bridge deck provides a larger space for the passage of debris flow, and can also play a good role in eliminating and reducing the main beam pushing disaster in the debris flow disaster.

3. Thirdly, the span is properly increased, and the pushing of the bridge piers by torrents and debris flows is essentially because the piers compress the cross section of the torrents and debris flows. At the bridge position where the torrents and debris flows are prone to increase the bridge span appropriately and reduce the number of piers It can increase the discharge space of torrents and debris flows, and can also reduce the pushing of bridge piers by torrents and debris flows to a certain extent.

2) Reasonable selection of bridge foundation form and pile foundation depth
   In order to prevent the foundation from being eroded by mountain flood and debris flow, the foundation expansion should be carefully adopted in the hydrological disaster areas. When pile foundation is adopted, the influence of mountain flood and debris flow shall be considered, and the pile foundation shall be lengthened properly to alleviate the diseases caused by riverbed undercutting, so as to avoid the decline or failure of pile foundation bearing capacity caused by foundation erosion.

3) Anti-wear and anti-collision of pier pile foundation.
   Abrasion is related to the surface hardness of the material. The higher the surface hardness, the lower the abrasion rate. Therefore, for bridges that cross the rapids and the Shunhe Bridge, the steel pipe or surface is wrapped around the pier column foundation between the annual flood level and the maximum scouring line Spraying "iron film" method for erosion and abrasion protection.
Buffer energy consumption and anti-collision structure

Wear resistant and buffering material wrapped with byiron film

Figure 4. Anti-abrasion and Anti-collision structural measures for Pier Pile Foundation.

(4) The diversion channel restricts the flow direction of debris flow
It is the result of debris flow deposition that piers are pushed and bridges are buried. The setting of diversion channel can limit the flow direction and range of debris flow, and can basically eliminate the pushing and burying of the pier.

(5) Grading retaining
For bridges crossing debris flow gullies, part of large boulders and falling stones can be blocked by retaining dam, and the flow velocity of debris flow can be reduced, so as to make the solid deposit, and greatly reduces the number of boulders impacting the bridge and protects the bridge pier from impact and abrasion. The protection of the embankment under the bridge and near the front and back of the bridge can avoid the damage of the riverbed and the embankment caused by the initial water flow [7], thus indirectly protecting the bridge.

5. Summary
According to the above analysis, it can be seen that in the process of the construction of bridges in the mountainous areas of Sichuan, possible disaster risks should be studied and evaluated in the early stage of the project in order to correctly guide the selection of bridge locations and bridge types and avoid or reduce the occurrence of disasters. The use of a new type of effective anti-seismic, anti-collision and anti-abrasion devices for bridge piers can improve the ability of the bridge to prevent earthquakes and floods. Only by choosing a bridge type and construction technology suitable for mountain areas can mountain bridges have good disaster prevention capabilities. In terms of anti-wear and anti-collision, although many schemes have been tried, their effectiveness and economy are not very good, and it is worth further research.

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Reference
[1] Hu Wenxue, Xiao Shengxie. Comprehensive evaluation of the resistance of bridges to torrents[J]. Journal of Chongqing Jiaotong University, 1997(01): 10-16.
[2] Chai Shangfeng. Discussion on the main points of bridge seismic design and application of seismic isolation technology[J]. Sichuan Cement, 2018(12):85.
[3] Liang Zhaoyun. Study on the high impact of water blocking dams across river bridges in mountain areas[J]. Guangdong Water Resources and Hydropower, 2015(12):21-25.
[4] Zhao Zhongwei, Ma Liang, Yuan Shuai. Calculation and analysis of flood control of skew bridges in mountain rivers [J]. People’s Yellow River, 2019, 41(04): 14-19.
[5] Fan Lichu, Li Jianzhong. Earthquake Damage Analysis and Anti-seismic Design Countermeasures of Wenchuan Bridge[J]. Highway, 2009, 000(005):122-128.
[6] Zhuang Weilin, Liu Zhenyu, Jiang Jinsong. Earthquake Damage Analysis and Countermeasures of Wenchuan Earthquake Highway Bridges [J]. Journal of Rock Mechanics and Engineering, 2009(07):85-95.
[7] Wang Jinghui. Analysis and Discussion on general scour hazards and prevention of river bed under bridge in hilly areas [J]. Heilongjiang traffic science and technology, 2015, 38 (09): 17-18.