Research Progress in Seismic Structural Design of Bridges Crossing Strike-slip Faults

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Abstract. Bridge structure is an important lifeline project. Bridge structures across strike-slip faults have great risk of damage during earthquakes. It is of great significance to ensure that they can operate safely and reliably during earthquakes. Firstly, this paper introduces the basic characteristics of strike-slip faults; secondly, the main earthquake damage of bridge across fault is summarized, as well as the theoretical research status and existing problems of this kind of bridge; finally, the key problems of the bridge across strike-slip fault need to be studied are prospected.

1. Introduction
Faults are structures with obvious displacement along the fracture plane of rock strata or rock masses. Faults are widely developed in the crust and are one of the most important structures in the crust. Geomorphologically, large faults often form rifts and cliffs.

Academics classify faults into three categories according to their displacement characteristics: ① Normal fault with relative decline of upper wall. ② Reverse faults with relative upward of upper wall. ③ The two walls of a fault move relatively horizontally, also known as strike-slip faults. When the observer stands on one side of the fault and observes the displacement of the other side to the right, it is called right-lateral, and conversely, it is called left-lateral.

Figure 1. Right-lateral strike-slip fault
Figure 2. Left-lateral strike-slip fault
source: https://baike.baidu.com/item/%E8%B5%B0%E6%BB%91%E6%96%AD%E5%B1%82/73136
Since Miocene, the Honghe fault zone, located in Yunnan Province, China, has exhibited a mass right-lateral slip movement. Since Pliocene, the right-lateral dislocation amounts to 30-32 km.

![Honghe fault zone](image)

**Figure 3.** Honghe fault zone

### 2. Summary of Seismic Damage of Bridges Crossing Faults

Bridge structures spanning active faults are at greater risk of damage during earthquakes. The norms and regulations of most countries and regions basically prohibit the construction of new bridges on active faults or the setting of certain avoidance distances between active faults, etc. However, due to the limitations of various objective conditions, bridge structures can not completely avoid crossing active faults.

On September 21, 1999, an earthquake of magnitude 7.3 occurred in Nantou County, Taiwan, China. The earthquake caused surface rupture along the Che-langpu fault, which is about 100km long. The maximum vertical dislocation momentum is 8m. Seven bridges near the fault line or crossed by the surface rupture zone were seriously damaged by the earthquake, as shown in Figure 4. [1]

![Earthquake Damage of Bridges](image)

**Figure 4.** Earthquake Damage of Near-fault and Cross-fault Bridges (Source of data: literature[1])

On May 12, 2008, an earthquake of magnitude 8.0 occurred in Wenchuan County, Sichuan Province. The Wenchuan earthquake occurred in the Longmenshan central fault zone (Beichuan - Yingxiu fault). Characterized by right-handed strike-slip accompanied by thrusting, the fracture length is about 275 km and the width is 15 km.

Buildings, bridges, roads and other structures across seismic faults (major and minor faults) in the meizoseismal area suffered from fault disruption, overturning, serious damage or complete collapse of seismic faults. As shown in Fig. 5, the abutment approach on both sides of the fault has been seriously deformed and lost its discharge capacity.
Figure 5. Xiaotudong Bridge (Source of data: literature[2])

Throughout the analysis of the seismic damage information collected by the author, it is found that the damage direction of bridge across fault is along the bridge direction, so controlling the along-bridge displacement is the key point of bridge structure protection. The failure of bridge structure is mainly caused by lowering of girder, so anti-falling measures are particularly important. In the design of bridges across faults, the principle should be to avoid lowering of girder as far as possible. In the design of bridges across faults, the principle should be to avoid falling beams as far as possible, and the protection system should be composed of abundant overlap length, longitudinal limit device and lateral block. The support should be coordinated with the limit device and anti-drop beam device.

In route selection, bridges across strike-slip faults should be avoided as far as possible, but when avoidance is unavoidable, various factors such as the types of possible faults, the width of fault zones and site geological conditions should be considered comprehensively, and appropriate structural forms should be selected. For example, considering the difficulty of bridge repair after earthquake, bridges across active faults can choose simple and easy bridge form to facilitate emergency repair and reconstruction after earthquake.

3. Research status

There are many bridges across faults in Yunnan, China. For those bridges that must cross faults, how to avoid or reduce damage in earthquakes is a big problem faced by bridge workers all over the world. However, the related research work of bridge across fault is still in the initial stage, and only a few scholars at home and abroad have analyzed and studied this kind of bridge. The seismic design and prevention measures of this kind of bridge need to be analyzed and summarized in more detail, and regular conclusions are drawn, so as to serve the design and production.

3.1 Numbering Research on energy dissipation bearings

The research on energy dissipation isolation bearings of bridges across faults is relatively few, and the research on near faults is more. HE Lin-hun’s [4] Master's thesis: Seismic response analysis for railway bridge Crossing the active fault, discussing the applicability of lead rubber bearing in cross-fault bridges is discussed. It is pointed out that the isolation bearing can play a greater role than the ordinary rubber bearing under the action of fault impulse earthquake. However, the parameters of the isolation bearing need to be optimized in order to achieve the best effect.

3.2 Research on Flexible Block

Limited stop is the main component of bridge structure to limit the displacement of main girder in transverse protection bearing, and also an important structural measure for transverse seismic resistance in seismic area. Although the statistics of earthquake damage cases show that the damage of transverse bridge retaining blocks is more serious in the earthquake. But it has played an active role in preventing lowering of girder. Therefore, in the design of a new type of transverse seismic block, the function of the block should be brought into play and the effect of seismic response on the lower structure of the bridge should be reduced.
There are few studies on flexible blocks for bridges across faults. Several new types of blocks have been proposed in previous studies, but the specific structure and reliability of these blocks still need to be studied.

3.3 Normative provisions
At present, there are few provisions for bridges across strike-slip faults in the code, and few anti-seismic measures can be taken. There is no theoretical basis for the seismic analysis of such bridges, and there is no specific requirement for bridges across faults in the code.

In this case, the <Guidelines for Seismic of Highway Bridge> only makes qualitative provisions on the selection of bridge location, foundation treatment and seismic measures in Chapter 4: 1) Address survey should be complete, and seismic favorable areas should be fully utilized; 2) It is inappropriate to build long-span statically indeterminate bridges in seismic disadvantageous areas; 3) Highway bridges at all levels should avoid seismic dangerous areas. For expressways and first-class highways, seismic dangerous areas must be adopted, and address safety evaluation should be done.

Rule 4.1.9 states that when there are earthquake-induced faults in the site of a bridge project, the engineering impact of the faults should be evaluated.

For bridges spanning strike-slip faults, no specific structural measures are given, which only states that when the bridge location can not avoid the development of seismic faults, it is advisable to place all piers on the same wall of the fault (preferably the lower wall).

4. Conclusion and Prospect
There are two main types of seismic responses to structures: Firstly, the vibration of the structure is caused by the movement of the site; The other is the relative displacement between different parts of the site when the site is broken, uneven settlement of the foundation and liquefaction, which causes the forced deformation of the structure and leads to its structural damage. The second kind of influence mostly occurs in the fault. Because of the relative displacement of the site, it is difficult to prevent the forced deformation of the bridge, and the seismic design is more difficult. At present, the related research activities are still in the initial stage.

1) The problems and damages in the secondary earthquake show the shortcomings and limitations of the current seismic research. How to avoid or mitigate bridge damage caused by surface rupture of seismogenic fault is the main subject of seismic research.
2) For the seismic response analysis and anti-seismic structural measures of highway bridges across strike-slip faults, the current codes do not give a specific description, and there is a lot of research space on the theoretical system.
3) Flexible isolation technology is more suitable for bridges spanning strike-slip faults. Future research should focus on appropriate flexible isolation technology. For example, a new type of energy dissipation flexible bridge seismic retaining block is proposed for bridges across faults.
4) The construction measures and design calculation theory of intelligent isolation bearing are mainly studied. The purpose is to develop intelligent isolation bearings, rationally utilize the superelastic properties, shape memory effect, high damping and elastic modulus of some new materials with temperature changes, so as to make intelligent isolation bearings have better controllability, expand the scope of application and accelerate the promotion.

References
[1] HUI Ying-xin WANG Ke-hai LI Chong. Study of Seismic Damage and Seismic Conceptual Design of Bridges across Fault Surface Rupture Zones[J].Journal of Highway and Transportation Research and Development,2014,31(10):51-57.
[2] CHEN Le-sheng, ZHUANG Wei-lin. Damage of Highway in Wenchuan Earthquake; Bridges[M].Beijing: China Communications Press, 2012.
[3] CHEN Libo. Seismic Vulnerability Analysis for Highway Bridges in Wenchuan Region [D]. ChengDu: Southwest Jiaotong University Doctor Degree Dissertation, 2007.
[4] HE Linkun. Seismic response analysis for railway bridge Crossing the active fault. [D]. Lanzhou : Lanzhou Jiaotong University, 2016.

[5] Jangid RS. Equivalent linear stochastic seismic response of isolated bridges. JSound Vib 2008;309(3–5):805–22.

[6] JTG/TB02-01-2008. Guidelines for Seismic Design of Highway Bridges. Beijing: China Communications Press [M]. 2008.

[7] Goel R, Qu B, Tures J, et al. Validation of fault rupture-response spectrum analysis method for curved bridges crossing strike-slip fault rupture zones. Journal of Bridge Engineering, 2014, 19(5):06014002-1-06014002-4.

[8] Vaez S R H , Sharbatdar M K, Am iri G G, et al. Dominant pulse si mulation of near-fault ground motions. Earthquake and Engineering Vibration, 2013, 12:267.