Research status and prospect of seismic transverse beam fall prevention measures for small and medium span beam bridges

Guo Li¹, Lei Yan¹,²*, Xin Yong Wang¹, Kang An¹, Heng Xiao¹, Long Fei Cheng¹, Yuan Chen Guo¹, Fang Ping Liu¹
(1. School of Civil Engineering, Chongqing Three Gorges University, Chongqing 404100; 2. School of Civil Engineering, Chongqing Jiaotong University, Chongqing 400060)

*Corresponding author email: 20170005@sanxiau.edu.cn

Abstract: The current research status of seismic lateral bearings and blocks of small and medium span beam bridges are briefly reviewed. The current research status of the block and bearing is analyzed and discussed, and the future research trend is discussed. The research results show that the research on the bearing is focused on the discussion of the mechanism and influence of the friction coefficient, friction force and slip performance of the plate rubber bearing; in terms of the stop, various new stop structure forms emerge in an endless stream; with the in-depth research of the two, Researchers began to pay attention to the mutual interaction of the support and the block when the actual earthquake occurred, and began to test the conceptual design, but how to fully consider the overall seismic performance of the bridge under the interaction of the two in the small and medium-span girder bridge The impact of this requires more in-depth research.

1. Introduction
In 1923, the first record of bridge falling to beam to damage occurred in the Great Tokyo earthquake in Japan. In 1971, a large number of bridges falling to damage occurred in the San Fernando earthquake in the United States. Researchers at home and abroad began to pay attention to solving bridge fall prevention. The beam problem. The 2008 Wenchuan earthquake had a huge impact on the theory of bridge seismic design in my country, and domestic researchers generally changed their seismic design thinking. In the Wenchuan earthquake, a large number of small-to-medium-span bridges suffered from unexpected lateral earthquake damage, mainly including beam drop, beam displacement, Bearing and block damage, etc. The damage to the substructure was relatively light. The investigation found that this is due to the fact that my country’s small and medium-span girder bridge system is different from that of Europe and the United States. The plate rubber bearing is placed directly under the main beam, which causes the bearing to slip under the action of the earthquake and increases the collision of the stopper. Probability, which plays a role of seismic isolation from the joint action of the Bearing and the stop.

In 2012, Wang Kehai et al. [4] proposed the concept of using the bearing as a fuse to give priority to damage based on the lateral seismic damage characteristics of small and medium-span beam bridges in my country. In 2013, the Lushan earthquake occurred, and rubber bearings performed well [5], which provided a reference to the development of bridge seismic isolation technology and boosted research confidence. In the same year, Shi Yan et al. [6] pointed out that domestic bridge workers did not have enough understanding of the stop, pointed out the lack of domestic regulations and emphasized the...
seriousness of the stop. So far, many scholars have emerged from home and abroad who use plate rubber bearings or stoppers as the core of their research. However, in actual engineering, due to the small proportion of the two in bridge engineering, and no attention, designers at home and abroad mostly rely on experience to design, resulting in the lack of unified seismic analysis models \cite{3,6-7}. The research pattern of a hundred schools of thought. Fan Lichu et al.\cite{8} studied the dynamic performance of the plate rubber bearing sliding under the action of an earthquake and found that the piers of the entire bridge bear less force and the plate rubber bearing has excellent seismic performance. Konstantidis et al. \cite{9} and Steelman et al. \cite{10} carried out experimental studies on square rubber bearings and determined that the ultimate shear strain of the rubber bearings was 150%-225%, and the friction coefficient of the bearings was between 0.25 and 0.50. Tian Guowei \cite{11} conducted seismic simulation shaking table tests for continuous girder bridges with plate rubber bearings. The results showed that when the bearings slipped, the girder body may be displaced too much, which would lead to more serious beam failure. occurring Wang Kehai et al.\cite{2,12} pointed out that the stop is the last line of defense for the transverse bridge to prevent falling beams, and proposed a double-layer stop structure. Wu Gang et al. \cite{13} compared and analyzed three different mechanical models of stoppers commonly used in the transverse direction of small and medium-span girder bridges, and pointed out that the set of stoppers spacing directly affects the collision force between it and the main girder. Wang Kehai et al.\cite{14} proposed the seismic design concept of "one can be three changes", Yan Lei et al. \cite{15} proposed a replaceable lateral limit device, and Li Jian et al. \cite{16} proposed a new type elastic-plastic stop. It can be seen that researchers have carried out a large number of separate studies on bearings or blocks. However, when an actual earthquake occurs, the bearings and blocks interact together. How to fully consider the interaction between the two in small and medium span beam bridges. For the impact on the overall seismic performance of the bridge, the conceptual design will be tested and verified, and further research is needed.

In this regard, in view of the large number of small and medium-span girder bridges built in my country, this article first reviews the current research status of bearings and blocks respectively, and then analyzes and summarizes the current research considering the interaction of the two. Finally, the current problems are discussed to provide a reference to the improvement in related research in our country. The summary of this article is shown in Figure 1.

![Fig.1 Block diagram](image-url)

### 2. Bearing

The bearing is a force transmission device that connects the beam body and the pier. Most of the small and medium-span beam bridges in China use plate rubber bearings. A large number of seismic damage investigations and studies have shown that the plate rubber bearings have seismic isolation from the piers and foundations. The effect has also been unanimously recognized by scholars at home and abroad \cite{8}. The "Code for Seismic Design of Highway Bridges" (JTG/T 2231-01-2020) \cite{16} pointed out that the commonly used integral shock-absorbing and isolating devices include lead rubber bearings, high-damping rubber bearings, and friction pendulum-type shock-absorbing and isolating bearings. However, these devices are complicated in structure and high in cost, so it is recommended using them when the plate rubber bearing does not meet the requirements. At present, domestic and foreign studies on the lateral seismic resistance of plate rubber bearings on small and medium-span girder bridges mainly focus on its sliding mechanism and influence. Yan Lei et al. \cite{17} found that the friction coefficient of the plate rubber bearing has a great influence on the sliding performance of the bearing. Li Chong et al. \cite{18} carried out reciprocating load tests of different vertical load and found that the friction forces when the bearing slides are proportional to the vertical pressure. Li Yue et al. \cite{19} found that the plate-type rubber bearing relies on friction and slippage, and its single-cycle maximum energy consumption can reach 126% of the lead rubber bearing. Wang Kehai et al. \cite{20} found that the loading speed of the plate rubber bearing without top and bottom steel plate has little effect on the sliding energy consumption of the bearing, and
the use of the Coulomb friction model will overestimate the nonlinear characteristics of the plate rubber bearing after sliding. And once again advocated the plate rubber bearing as a "fuse" designs. Xu Lueqin et al. [21] found that the larger the friction factor, the smaller the sliding displacement of the bearing and the effect of seismic isolation. Zhang Qinwu et al. [22] pointed out that the combined limit device has been widely used on other bridges. Li Jianzhong [15,23] based on the research of the plate rubber bearing, considering the interaction with the stopper, proposed a new type of seismic isolation system and carried out shaking table tests for good results. Xiang Nailiang and Xu Lueqin et al. [21,24-25] conducted in-depth studies on the sliding mechanism and influence of the plate rubber bearing, and realized that the plate rubber bearing and the stopper are a kind of mutual interaction under the action of strong earthquakes. The relationship of containment and mutual assistance.

In summary, with the in-depth study of plate rubber bearings under earthquake action of small and medium-span girder bridges, researchers have a deeper understanding of the mechanism and influence of plate rubber bearings such as friction coefficient, friction force, and slip performance. On the one hand, I found that its energy consumption performance is strong, not weaker than that of shock-absorbing and isolating bearings such as lead-core rubber bearings. It is recommended as a "fuse" designs. On the other hand, I have become more aware of plate rubber bearings and stoppers. The blocks are mutually interacting and begin to change research thinking.

3. Restrain block

In 1995, a foreign earthquake disaster investigation [26] found that the transverse bridge was prone to block to damage. In 2004, Zhu Wenzheng [27] first proposed the theory and method of anti-falling beam system design in China, emphasizing the need to develop limit devices sex. The "Code for Seismic Design of Highway Bridges" (JTG/T 2231-01-2020) [17] clearly pointed out that the seismic system of bridge structures should have clear and reliable displacement constraints, which can effectively control the seismic displacement of the structure and prevent the falling beams. For small and medium-span girder bridges, the lateral stopper mainly plays the role of limit and force transmission. The American AASHTO Seismic Standard [28] divides the bridge anti-seismic block of two types: inner block and outer block. Wang Kehai et al. [12] based on the characteristics of weaker inner block and stronger outer block, proposed "multi-channel The design concept of “Fortification, Grading Energy Consumption”, and proposed a double-layer stop [29]. Yan Lei et al. [14] proposed a replaceable lateral limit device for energy-consuming sections. The rubber buffers block proposed by Fan Lichu et al. [30] performed well in the 2008 Wenchuan earthquake. Liu Rongcan et al. [31] proposed the concept of sliding stop. Xiang Nailiang et al. [32] proposed a new type of friction stops, which consumes energy through sliding. Xu Xiang et al. [33] set a weak layer on the ordinary concrete block, and made use of the sliding energy dissipation at the weak layer. The American CALTRANS code [34] recommends the use of sliding stoppers in seismic design. Xu Lueqin et al. [35] proposed a new type of sliding block that can perform well within a deformation range of 200mm. Du Xiuli et al. [36] pointed out that the bearing capacity of some blocks of our country is insufficient, and the effect of the anti-falling beams is useless, and proposed a new type of resettable sliding block. Bhuiyan et al. [37] proposed to use SMA material to improve the energy dissipation performance of the stopper. Wu Wenpeng et al. [38] proposed the use of ultra-high performance concrete (UHPC) materials to ensure the strength of the block body. Deng Kailai [39] and others designed a new type of energy-consuming block using steel, and verified through experiments that its load-bearing capacity is sufficient and can effectively consume energy. Xiang Nailiang et al. [24] considered the influence of the sliding of the slab bearing when carrying out the shaking table test, and found that as the slab rubber bearing began to slip, the limiting effect of the concrete block gradually weakened.

In summary, for the stopper, except for the ordinary monolithic concrete stopper, a brief summary found that the main research directions are now divided into three categories, rubber buffer stopper, slippery stopper, and energy-consuming type. Stopper, as shown in Figure 2. And with the in-depth study of the stopper under the action of the earthquake of the small and medium-span girder bridge, the researchers no longer simply strengthen the structure of the stopper, and gradually began to consider the impact of the bearing slip on it, and began to explore the interaction between the two effect.
4. Seismic isolation

The anti-seismic system that uses the sliding of the bearing and the sacrifice to the block has been around for a long time, but it has been lingering in the conceptual design stage, and there are not many related experimental studies. In the Wenchuan earthquake [3], the actual earthquake damage showed that the proportions of the simultaneous damage of the bearing and the block were basically the same. Xu Lueqin et al. [21] pointed out that the bearing and the stop are a pair of contradictions, which are both restraining and mutually beneficial. Li Jianzhong [23] analyzed and summarized the actual earthquake damage, and also talked about the bearing slip and the block failure to jointly play the role of seismic isolation. Foreign scholars [4-5] calls the system that uses common rubber bearings and limit devices to prevent falling beams as quasi-seismic isolation systems. Wu Wenming et al. [38] summarized the development research status of the stopper and pointed out that the mutual interaction between the lateral stopper and other components needs further study. It can be seen that many scholars have realized that it is very important to consider the combination of the bearing and the block as an anti-seismic system and study the interaction. Yan Lei et al. [40] proposed a floating seismic system composed of two parts: sliding bearing friction energy dissipation and block limit. It is divided into three working phases corresponding to small, moderate and large earthquakes. It combines the concept of multi-channel fortifications and grading energy consumption proposed by Wang Kehai et al. [4].

It can be seen that although many scholars have realized that the interaction between the bearing and the stop should be considered based on the information about the actual earthquake damage investigation, the actual research carried out is relatively small.

5. Conclusions

(1) Researchers have a deeper understanding of the friction coefficient, friction force, sliding performance and other mechanisms and effects of the plate rubber bearing. On the one hand, they found that its energy consumption performance is strong, not weaker than that of lead rubber bearings. This type of shock-absorbing and isolating bearing is recommended as a "fuse" designs. On the other hand, people have become more aware of the mutual interaction between the plate rubber bearing and the stopper, and they have begun to change their research thinking.

(2) As the last line of defense for the lateral seismic resistance of small and medium-span girder bridges, the stopper has emerged from various structural forms of home and abroad, which are roughly divided into rubber buffer stoppers, sliding stoppers, and energy-consuming stoppers. The third category, and with the in-depth study of the stopper under the action of the small and medium-span girder bridge under earthquake, the researchers are no longer simply strengthening the stopper structure form, and gradually began to consider the impact on the bearing slip on it, and began to explore the two Interaction.

(3) When an actual earthquake occurs, the bearing and the stopper interact together, how to fully consider the interaction between the two in the small and medium span beam bridge Under the influence of the overall seismic performance of the bridge, the conceptual design will be tested and verified, and further research is needed.

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