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Experimental study on impact behaviors of rubber shock absorbers

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HIGHLIGHTS

- Some factors are investigated on force-displacement of rubber shock absorbers (RSAs).
- Maximum impact force decreases to a limit value as the shape factor reciprocal (1/S) increases.
- RSAs still have some residual deformation after the pendulum rebounds.
- Different material and shape show influence on the maximum impact force for N-RSA and HD-RSA.

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ABSTRACT

In the seismic design of continuous girder bridges, rubber shock absorbers set between the girders and between the girders and the abutments could reduce the magnitude of impact behaviors and mitigate the damage incurred by structural collisions effectively. However, in practice, rubber shock absorbers are only considered as a construction measure, and the current research on the impact mechanical properties of rubber shock absorbers is very limited. In this paper, two types of rubber shock absorbers: natural rubber shock absorbers (N-RSA) and high-damping rubber shock absorbers (HD-RSA) were selected for study. Shape factor, volume, and shape (square vs round shapes) were proposed as controlling variables for the design of multiple sets of rubber shock absorbers. We also studied the impact of various factors on the force-displacement of rubber shock absorbers under the application of static loading. Using self-designed pendulum impact equipment, this research investigated the impact of pendulum impact velocity, the shape factor, volume, and shape of the rubber shock absorber on the force-displacement of the shock absorber. The results of this work may provide reference for the establishment of a nonlinear impacting mechanical model of a rubber shock absorber and the seismic design and analysis of bridge structure.

1. Introduction

During earthquakes, the superstructure of bridges is prone to displacement damage. Collisions between girders or between girders and abutments and parapets are common earthquake damage producers for bridge structure. In general, the expansion joints between the girders are prone to collision and squeezing deformation. Adding the gap of the expansion joint will definitely affect integrity of the bridge surface and driving comfort. Decreasing the space between the bridge girders would likely increase the risk of collision [1,2]. Earthquakes can cause portions of the bridge structure to collide. The impact can be huge and result in severe damage (Fig. 1).

Post-earthquake investigation reports of the 1994 Northridge Earthquake and the 1995 Japan Kobe Earthquake showed that many bridges sustained cracks in the concrete at the ends of their girders. The concrete then fell off, and the expansion devices were damaged by squeezing, the local compression failure of abutment were all caused by collision, and the excessive movements of bridge girders along the bridge surface resulted in girder collapse [3]. The damage that earthquakes can inflict on bridge structures is enormous, and it is necessary to take effective measures (such as rubber shock absorbers, as shown in Fig. 2) to prevent this kind of damage.

One report showing that installing shock absorbers at the expansion joints between girders or between girders and abutments can reduce the damage caused by structural collisions

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Fig. 1. Collision between girders.

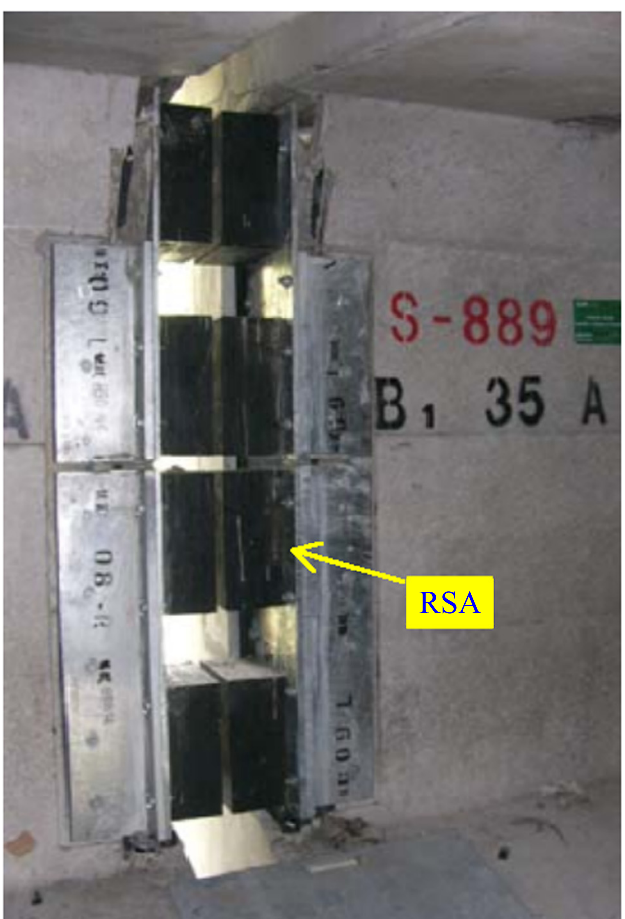

Fig. 2. Installation of rubber shock absorbers between girders.

(Fig. 3) has drawn the attention of scholars all over the world [4,5]. Since rubber can undergo considerable compression deformation, the instantaneous strong impact kinetic energy can be partially transformed into the deformation energy through this buffer material, then released slowly at a lower frequency. Rubber also has a large damping effect on the process of deformation. The mutual friction of rubber molecules can transfer some of the mechanical energy from the impact into heat energy. Sun and Goto [6] investigated the shock-absorbing effect of rubber shock absorbers. When the bridge structure was subjected to different earthquake actions, they compared the impact of rubber shock absorbers on the girder displacement and abutment displacement. The results of this analysis indicated that, during small and middling earthquakes, rubber bumper devices could limit upper displacement effectively, and the abutment displacement reduction effect was also very apparent. Current bumper devices need to have strong energy-absorbing ability, light weight, and small size. Several studies focusing on the pounding test have been carried out [7,8]. In these papers, a mass collides with a concrete wall which is fitted with several kinds of shock absorbers, such as a natural rubber and a sandbag. Results indicate the shock absorbers have an important effect on the reduction of the impact force. Kajita et al. [9] carried out a collision test by developing a new test apparatus between two steel solid bars in order to investigate the relationship between the maximum impact force and collision velocity for the natural rubber during collision. The maximum impact force depends strongly on the collision velocity and the thickness of the natural rubber. Polycarpou et al. [10,11] developed a new nonlinear inelastic force-based impact model to appropriately describe the behavior of rubber under impact loading, and relevant numerical simulations and parametric studies were performed in order to investigate the effectiveness of the rubber shock absorbers as an impact mitigation measure. Zhu et al. [12] proposed a calculation model and design method for a cylindrical bumper device with strong energy dissipation performance based on the response spectrum method. Their investigation indicated that cylindrical bumper devices had a marked bumper effect. Unlike ordinary bumper devices, the maximum relative displacement between the girder and the block and the plastic deformation of the abutment all decreased to different extents. He et al. [13] utilized common industrial rubber material and designed a honeycomb-type bumper device. Through cyclic compression tests, they developed a bumper with suitable mechanical properties. In addition, they suggested the reasonable numbers of this honeycomb type of bumper device to be installed on 30 m-span simple girders for various types of sites and intensity zones, and evaluated the effectiveness of the bumpers.

Chinese code "Guidelines for Seismic Design of Highway Bridges" (JTG/T B02-01-2008) [14] stipulates that for the bridges at a seismic intensity of 7 or above, the bridge abutment wall should be appropriately strengthened, and rubber pads or other elastic gaskets should be installed between the girders and

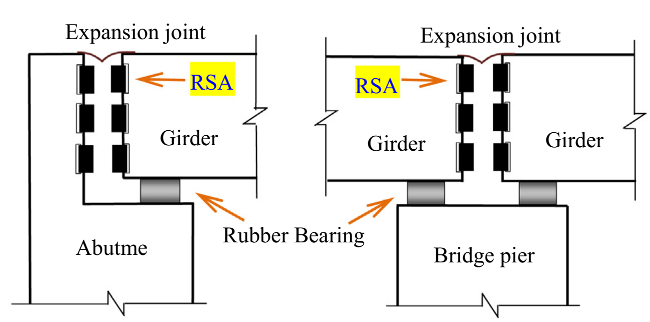

Fig. 3. Diagram of rubber shock absorbers installed.