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RESEARCH ON HYSTERETIC BEHAVIORS OF A SAPARATED SHOCK ABSORBER APPLIED IN RAILWAY BRIDGE

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Abstract. *Shock absorbers are installed between piers and superstructures in railway bridges. They can act as bridge members which bear the longitudinal force and displacement of the bridges in the serviceability state. When large earthquake occurs, the shock absorbers dissipate energies to reduce the seismic responses of bridges and protect the other bridge members. Based on the single cantilever shock absorber, a new structural type of shock absorber is proposed in this paper. To investigate the hysteretic behaviors of the improved shock absorber, quasi-static cyclic tests using displacement-controlled cyclic loading, including two separated shock absorbers, were carried out. Besides, the hysteresis behavior parameters of the separated shock absorbers, such as hysteretic curves, skeleton curves and damping ratio etc., were analyzed. The test results indicate that the hysteresis curve of this kind of separated shock absorbers is plump and stable. The maximum displacement and force could reach 160mm and 220kN, respectively. And bilinear model could be adopted to describe mechanical model for the separated shock absorber. The initial stiffness is high so that the shock absorbs can meet the demand of stiffness in train operation process. Besides, the equivalent viscous damping ratios can reach 0.46. In addition, this type of shock absorber exhibits sufficient deformation capacity and energy dissipation capacity. Therefore, this new separated shock absorber could be an ideal energy dissipator used in the high speed railway bridges.*

1 INTRODUCTION

The construction of high-speed railway is developing rapidly in China and the use of bridges takes a great proportion in the high-speed railway. In recent destructive earthquakes, many bridges sustained serious damage, leading to a great number of casualties and enormous economic loss [1-2]. So, improving the seismic behavior of high-speed railway bridges is one of the key problems that must be solved [3]. In the past 20 years, the passive energy dissipation technology has attracted high attention and it has been widely used in the practical structural engineering [4]. The passive energy dissipation technology used in the bridges mainly includes the seismic isolation technology, energy dissipation technology and tuning damping technology [5] .

Dampers which is belong to the energy dissipation technology are able to provide additional damping effects to reduce the seismic responses of the structures. According to the energy dissipation materials, commonly available dampers mainly include viscous dampers, viscous elastic dampers, steel dampers, etc [6]. Many steel dampers dissipate the energy by elastic-plastic deformation. Compared with other dampers, steel dampers offer significant advantages in terms of durability and economic efficiency [7]. However, most of steel dampers, such as X-shaped ADAS, HADAS device [8-9], buckling restrained brace [10] and so on, were developed for building structures, which may not be able to satisfy the large deformation demands in bridge engineering [11].

Based on the idea of "separate bearing function", a new type of steel dampers named shock absorber was proposed by Professor Li Chenggen and Gao Ri in China [12]. So a new bearing system (Fig.1) is formed by combining the shock absorber and sliding bearing. The design concept is to change the fixed bearing into the sliding bearing so that the vertical and horizontal function can be separated in railway simply supported beam bridge [13]. Meng Xi and Gao Ri investigated the effects of the single cantilever shock absorber on a bridge, the test and numerical simulation results indicated that the single cantilever shock absorber could provided large energy consumption capacity, and protected the bridge structure effectively [14-15]. However, there are some disadvantages of the single cantilever shock absorber, for example, the high cost and inconvenient installation.

Therefore, a novel type of shock absorber called separated shock absorber is proposed in this paper to solve the problems above. The structure of the shock absorber is first presented. So the first part in this paper introduces the designed details of the shock absorber. In order to investigate the mechanical performance of the separated shock absorber, two specimens were tested by using quasi-static cyclic loading schemes in the second part. The third part presents and analyses the test results.

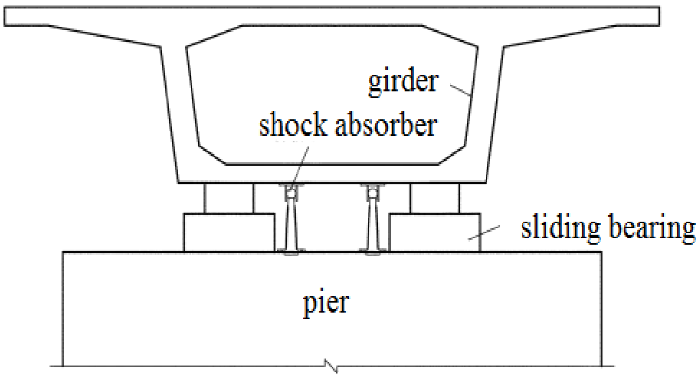

Figure 1: Shock absorber-sliding bearing system [15].

2 STRUCTURE OF THE SEPARATED SHOCK ABSORBER

The separated shock absorbers made of mild steel are commonly installed with the sliding bearing between the upper structures and lower piers. And The separated shock absorbers are distributed uniformly around the sliding bearing. The longitudinal stiffness and force of bridge determine the number of the separated shock absorbers.

As shown in Fig.2, the mild steel separated shock absorber mainly consists of two shock absorber bodies, sleeve and two connection plates. The shock absorber body and connection plate are made of the same steel and they process model together. The two connection plates, which are respectively designated as the upper connection plate and lower connection plate, are bolted to the upper girder and lower pier by using high strength bolts. The sleeve has a function that combines the upper shock absorber body and lower shock absorber body by using limit steel pin. Another function of the sleeve is to transfer horizontal force between the two shock absorber bodies. The transverse section shape of shock absorber body is round and the body can be divided into two parts, i.e. load transfer part and deformed part. When a large earthquake happens, the relative displacement will be produced in horizontal direction between the upper connection plate and lower connection plate. Then the shock absorber bodies occur yielded plastic deformation to dissipate energies, thus reducing the responses of the bridge.

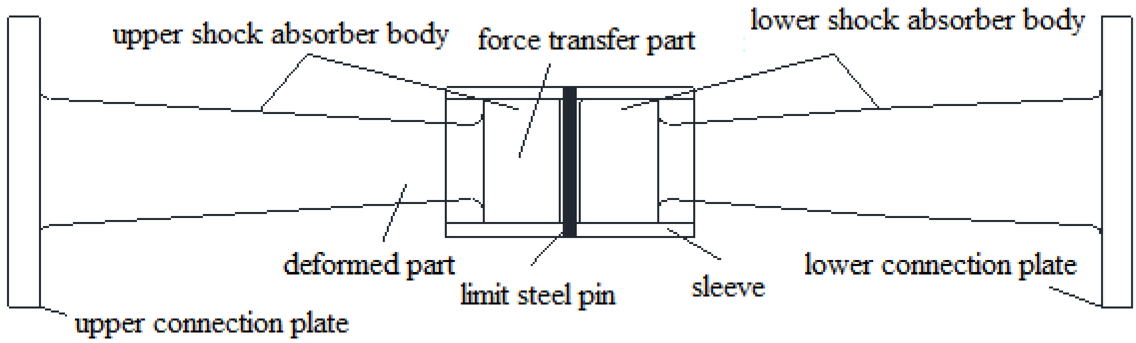

Figure 2: Schematic diagram of separated shock absorber.

At the stage of design, the shock absorber body can be seen as cantilever beam. According to the material mechanics, for more sections of the deformed part along the same shock absorber body to become plastic, the relationship between diameter d and distance x (Fig.3) is presented as follows:

$$\mathrm{d} = \begin{cases} \mathrm{d}_1 & (0 \le x \le L_1) \\ \partial(\Delta + \dfrac{L-\Delta}{L}x)^{1/3} & (L_1 \le x \le L) \end{cases} \tag{1}$$

Where x is the distance from the top of the shock absorber body to cross section and d_1 is the diameter of the force transfer part, which is fixed constant only in connection with the height of the separated shock absorber. ∂ represents the section coefficient and it is fixed value. L_1 and L are the height of force transfer part and shock absorber body, respectively. Δ is the vertical deformation of the shock absorber body when the shock absorber occurs the designed maximal horizontal displacement.

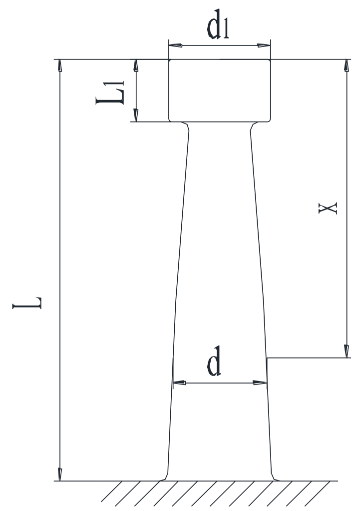

Figure 3: Theoretical calculation model.

The height of deformed part largely determines deformation capacity of the separated shock absorber. Hence the deformation capacity of the shock absorber can be enlarged by increasing the height of the shock absorber body. In addition, such design can significantly improve the low cycle fatigue behavior of the separated shock absorber because it avoids the concentration of plasticity at one cross section.

Compared with the single cantilever shock absorber, the structural form of separated shock absorber is simpler. And the shock absorber body can be more easily installed and replaced if damaged.

3 EXPERIMENTAL PROCESS

3.1 Specimen design

There were two specimens designed for this experiment and they were named A1 and A2. The dimensions of two specimens were the same. The major parameters of specimens are given in the table 1.

The designed maximal horizontal displacement was 160 mm in this experiment. As mentioned before, the value of Δ was 18.8 mm through finite element analysis with the maximal horizontal displacement. The length and inner diameter of the sleeve with a thickness of 40 mm were 250 mm and 120 mm, respectively. Specimen adopt the connection plate with a height of 30 mm and its diameter was 250 mm. The number and diameter of the high strength bolts were 6 and 32 mm, respectively.

The shock absorber body and connection plate for the two specimens are all made of one specially made mild steel in China. Uniaxial tensile test for the mild steel was carried out. The results indicated that the yield strength and ultimate tensile strength were 250 Mpa and 420 Mpa, respectively. In order to limit the vertical displacement of the shock absorber body, the strength of sleeve must be higher than the strength of the specially made mild steel. So we choose 45 steel (in Chinese rule) as the base metal of sleeve.

Parameter	L (mm)	L_1 (mm)	d_1 (mm)	∂
Value	430	75	120	15.472

Table 1: The major parameters of specimens.

3.2 Test setup and loading scheme

The test was conducted in the structural laboratory of Beijing Jiaotong University. Fig.4 gives a photograph of the loading frame, which mainly includes one truss and an electro-hydraulic loading system. The loading system mainly consists of three subsystems: the controlling system, oil hydraulic and measurement system.

A1 and A2 are to investigate the hysteretic behaviors subjected to cyclic loading. And the experiment was all conducted using a displacement controlled cyclic loading. The loading scheme follows a triangular loading pattern with increasing amplitudes. The first cycle amplitude was 2 mm, and increased by 2 mm for the succeeding cycles until it reached 20 mm. After 20 mm, the amplitude was increased by 10 mm until it reached 80mm. Then the amplitude was increased by 20 mm until it reached 160 mm. When the amplitude was smaller than 20 mm, the loading speed was 2 mm/s. While the amplitude was larger than 20mm, the loading speed was 8 mm/s. And the loading test was repeated for 5 cycles at every amplitude.

Figure 4: Test setup.

4 EXPERIMENTAL RESULTS

4.1 Experimental phenomena and analysis

The experimental phenomena of A1 and A2 was turned out to be similar. When the amplitude was smaller than 30 mm, the center line of separated shock absorber was approximately a straight line which was perpendicular to the horizontal ground at the equilibrium position. When the amplitude was from 30 mm to 140 mm, there were no cracking on the mild steel separated shock absorber. However, we found that the deformed parts of the shock absorber bodies were buckled. At the amplitude of 140 mm, the first micro-crack was observed at the junction site of shock absorber body and connection plate. Finally, as the amplitude increased to 160 mm, the crack was not expanding. The photographs of two specimens' crack at the fifth cycle for amplitude of 160 mm were shown in Figs.5(a), 5(b). It is found that the two specimens sustained large deformation without fracture for the designed maximal horizontal displacement.

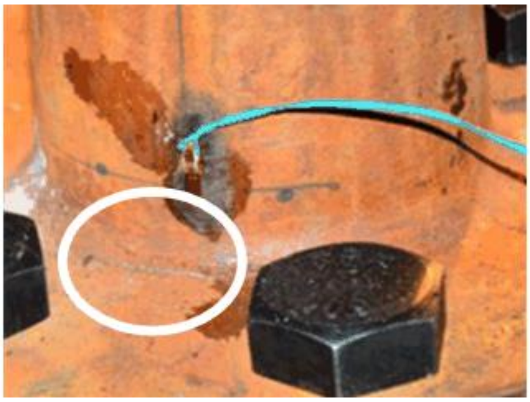

Fig.5(a): The crack state of A1

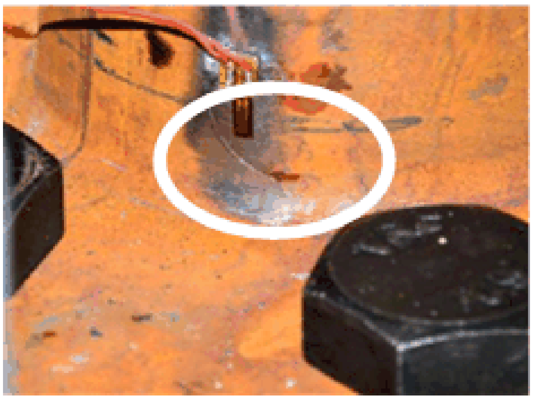

Fig.5(b): The crack state of A2

Figure 5: The crack states of A1 and A2 at the amplitude of 160mm.

After that, the loading test was still conducted at the amplitude of 180 mm. Finally, loading at the amplitude of 180mm for A1 was repeated for six cycles. while A2 got fractured at the fifth cycle 180 mm loading amplitude. The conjunction crack of the shock absorber body and connection plate failed suddenly. This was because that the thickness of connection plate was too thin to resist pulling force of the high strength bolts. And another reason is that the conjunction is stress concentration area. It is recommended to increase the thickness of the connection plate to add the pulling force and enhance the conjunction of the shock absorber body and connection plate.

4.2 Hysteretic behavior

4.2.1 Hysteretic curve and skeleton curve

The loading-displacement hysteretic loops of two specimens at the third cycle for every amplitude were plotted in Figs.6(a), 6(b). From the Fig.6, we can see that the two hysteretic curves are plumper and the shape of the hysteretic loops are spindle. The elastic stiffness of two specimens is high in the condition of small displacement. When the displacement reaches about 20 mm, the separated shock absorbers sustain significant plasticity. Besides, degradations of stiffness and strength are not obvious. The low cycle fatigue behaviors of A1 and A2 are not obviously produced at the amplitude of 160 mm.

As presented in Fig.6(a) and Fig.6(b), the hysteresis loops of A1 and A2 are similar. It indicates that the properties of separated shock absorber are stable.

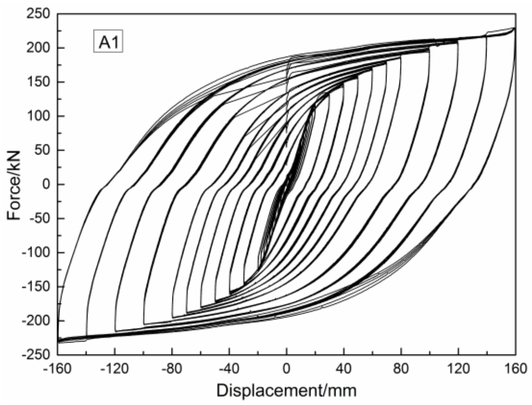

Fig.6(a): A1

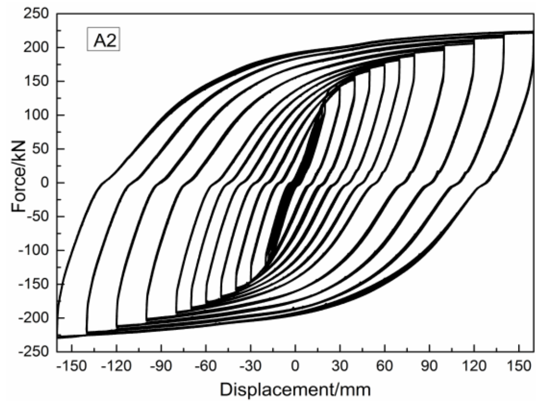

Fig.6(b): A2

Figure 6: Hysteresis curve for the specimens:(a) A1 and (b) A2.

4.2.2 Skeleton curve

Fig.7 shows the skeleton curves for A1 and A2 from envelope diagram of the hysteresis loops. It could be seen from the figure that the skeleton curves are approximately bilinear. Therefore, the mechanical model for the separated shock absorber could be described by bilinear mode. The bearing capacity of both A1 and A2 could reach 220 kN when loading amplitude reached 160 mm. And it is not decreased of the bearing capacity for A1 and A2 with increasing of displacement. So it exhibits sufficient deformation capacity of the mild steel separated shock absorber.

From the Fig.7, the skeleton curve for A1 was almost coincided with that of A2. The mechanical behaviors of the mild steel shock absorber are stable.

4.3 Energy dissipation capacity

As mentioned above, the primary function of the mild steel shock absorber is to dissipate energy and protect the bridge structure under large earthquake occurs. In this paper, the equivalent viscous damping ratio ξ is taken to evaluate the energy dissipation capacity of the mild steel separated shock absorber. The calculating formula is as follow [16].

$$\xi = \frac{E_{DS}}{2\pi E_S} \tag{2}$$

Where E_{DS} is the damping energy dissipation and it equals to the area of hysteresis loop in one cycle. E_S is the maximal strain energy.

The comparison of equivalent viscous damping ratio between A1 and A2 is shown in the Fig.8. It is found that the equivalent viscous damping ratio increases with the increase of displacement. The growth becomes slowly after the displacement is larger than 80 mm. And the maximum damping ration could be reach 0.46.

In addition, the equivalent viscous damping ratios of A1 and A2 are almost at the same. Hence the energy consumption of mild steel separated shock absorber is excellent, and the aseismic performance is stable.

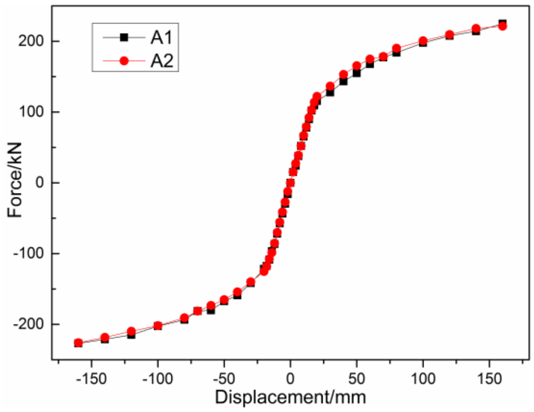

Figure 7: Skeleton cure for A1 and A2.

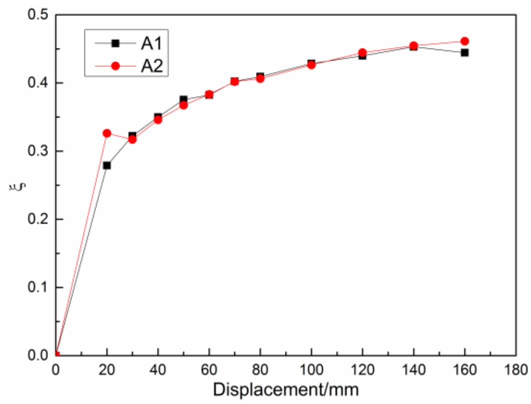

Figure 8: The damping ratio for A1 and A2.

5 CONCLUSIONS

New type of shock absorber for railway bridges has been proposed in this paper. The quasi-static tests of two specimens were conducted to investigate hysteretic performances. The major findings obtained are as follows:

- The separated shock absorber consists of two shock absorber bodies, sleeve and two connection plates. The shock absorber body is the main energy dissipation region through plastic deformation.
- Experimental results show that this shock absorber has good strength and deformation capacity. The hysteresis curve is stable and plump. The mechanical model for the separated shock absorber could be described by bilinear mode.
- The initial stiffness is high so that the shock absorbs can meet the demand of stiffness in train operation process. Besides, the energy consumption of mild steel separated shock absorber is excellent the aseismic performance is stable.
- The structural type of separated shock absorber is reasonable except that the thickness of the connection plate must increase. And it provides a theoretical basis for its future design.

6 ACKNOWLEDEMENT

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