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Energy Absorbing Capacity of Shock Absorbers Combining Rubber and Steel Pipes

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Abstract. The authors studied the basic characteristics of steel pipes by experiments and analyses, aiming to determine whether steel pipes can be used as shock absorbers. The results of the study proved that steel pipes have enough energy-absorbing capacity to be used as shock absorbers. The authors then made nonlinear response analyses to examine the effect of attaching rectangular rubber and steel pipes as shock absorbers to base-isolated bridges. The analyses showed that when steel-pipe shock absorbers are used alone, the collision force acting between adjacent girders of bridges increases rapidly after the steel pipes fail. The authors conducted static loading tests to the new type of shock absorbers, which use steel pipes wrapped with rubber pipes. From the result, the load-displacement characteristics can be estimated from the basic characteristics of rubber and steel pipes, and the restoration of rubber can decrease the collision force after the steel pipe fails. The authors investigated which dimension of the shock absorber can possess relatively high energy absorbing capacity and collsion force reducing effect.

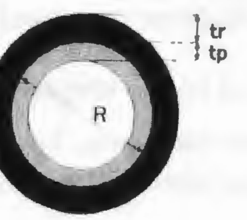
Introduction

Shock absorbers are key devices that enable us to restrict damage to limited parts of a bridge when large earthquake occurs and to quickly restore the damaged parts. Nagashima and others [1] proposed a shock absorber using shape steel in place of rubber and studied its practicality and effectiveness through experiments and analyses. On the other hand, an analytical study [2] by the authors indicated that if steel pipes completely fail, the collision force might be greater than that produced after rubber shock absorbers completely fail.

Because of the above, the authors proposed a new type of shock absorber, by use of steel pipes wrapped with rubber pipes, and conducted static loading tests to construct a load-displacement model from the basic characteristics of rubber and steel pipes [3]. In this study, we conducted static loading tests for shock absorbers with various dimensions. And we discuss suitable dimensions for the shock absorber to possess relative high energy absorbing effect and collision force reducing effect.

Static Compression Test

Specimens and Testing Apparatus. Sizes and shapes of specimens made of steel pipes wrapped with rubber are shown in Fig.1. STKM13A steel and chloroprene rubber with hardness of 60 (measured by a durometer) was used as materials for the specimens. Fig. 2 shows an outline of the loading test equipment used for the test. A universal testing machine having a capacity of 300 kN was used for the static compression test. A laser displacement seismograph having a reference distance of 30 mm and a measuring range of +/-5 mm was used for displacement measurement. The vertical displacement was converted into horizontal displacement by a passive reflector attached to the loading plate.



Rs	tr	tp
70	10, 20, 30, 40	4, 5, 6, 7
80	15, 25, 35, 45	4, 5, 6, 7
95	15, 25, 35, 45	8, 10
110	15, 25, 35, 45	8, 10
Unit : mm		

Fig. 1. Sizes and Shape of Test Specimens

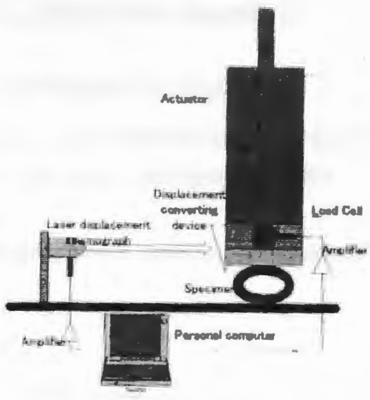


Fig.2. Outline of Loading Test Equipment

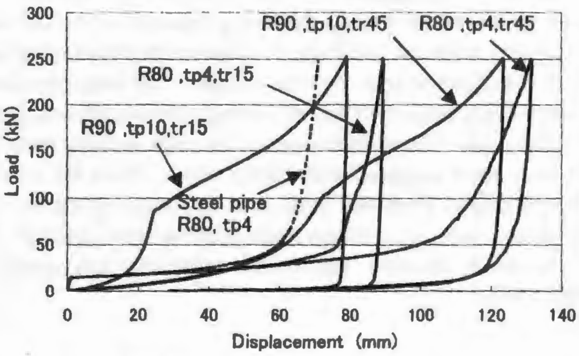
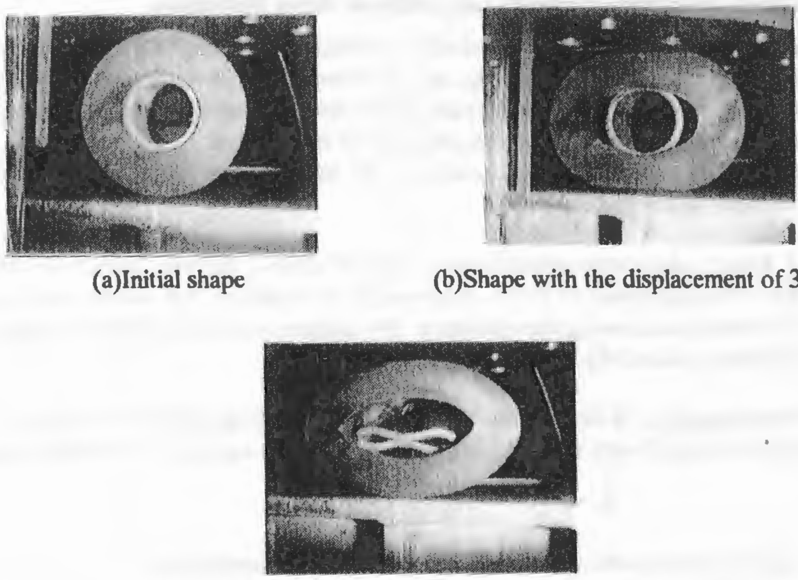


Fig. 3. Load-Displacement Characteristics of Shock Absorbers

Experimental Result. Fig. 3 shows load-displacement characteristics of specimens. There was no unstable phenomenon in which rigidity was lowered. Rigidity increased gradually after the steel pipes yielded. After that, the pipe was deformed into an elliptic shape and the load value increased as deformation progressed. Constrictions were formed near the center of the pipe, and the load rose radically when the upper and lower constricted parts came into contact with each other. Nagashima and others [1] reported a phenomenon in which rigidity decreased gradually after yielding in case that the steel pipe was welded to the loading plates at the top and bottom portions. Such a phenomenon was not observed in this test.

Fig. 4 shows the transitional deformation of a specimen(R80mm, tp6mm, tr40mm). Before yielding, only the rubber was deformed and the rigidity was low (phase I). The displacement measured at yielding was almost in proportion to the thickness of rubber, and the yielding load was higher when the rubber was thicker. After the steel pipe yielded, the rigidity gradually increased. It could be argued that the compressive deformation of rubber was advanced when the plastic deformation of the steel pipe was in progress (phase II). Unloading was done when the load reached 250 kN because of the capacity limit of the testing machine. In the process of unloading and reloading, the steel pipe had



(a)Initial shape (b)Shape with the displacement of 30mm

(c)Shape after testing

Fig. 4. Deformation of a Specimen (R80mm, tp6mm, tr40mm)

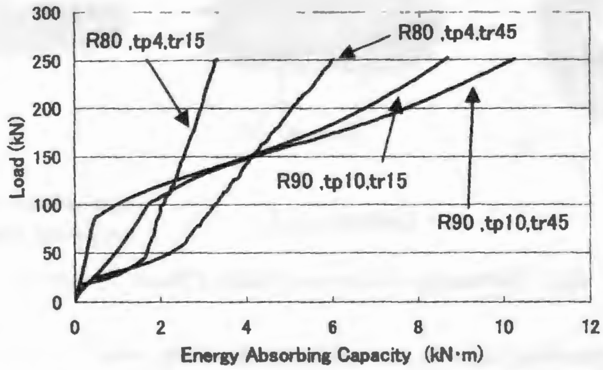


Fig. 5. Load-Energy Absorbing Capacity Characteristics of Shock Absorbers

failed already. It can be assumed that the rubber returned to its original dimensions after the load was removed and that its deformation beyond 250 kN (phase III) can be extrapolated from Fig.3 (Only the type of R95 tp10 tr45 is shown here). Fig.5 shows the load-energy absorbing capacity characteristics of shock absorbers. The rubber absorbed the energy from the beginning of the loading in a low rigidity. As the strength of steel pipes or the thickness of rubber increased, energy absorbing capacity also increased at the point steel pipe failed. But in case that the steel pipes did not fail, low strength shock absorbers decreased the collision force.

Effect of Energy Absorbing Capacity and Collision Force Reduction

Reasonable dimension of shock absorbers shall be considered according to the test results of specimens with R80 tp4 steel pipe. R80 tp4 steel pipe has the lowest yield strength, and completely fails if the maximum load of 250kN acts. Although thick rubber pipes are expected to raise the energy absorbing capacity, relatively large space is needed for the pipe to be attached.

Two amounts of energy absorbing capacity at the same amount of collision force of 250kN are defined to compare absorbing capacity.

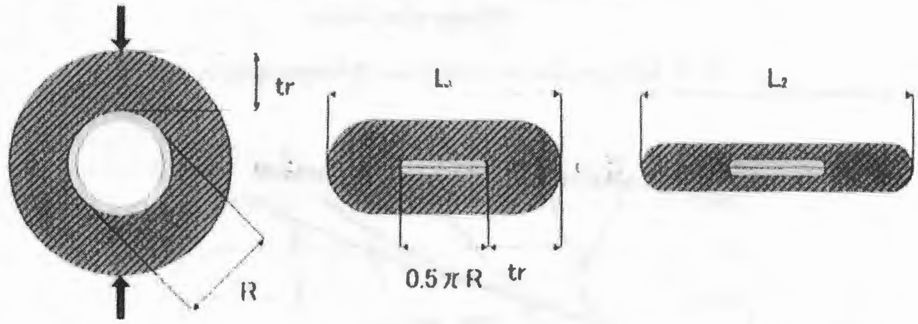
No.1 Energy absorbing capacity per the largest width of deformed shock absorber

Since attaching space of shock absorbers are to be limited, this amount can be one of the parameters showing the efficiency. We estimated horizontal strain by using the following method [4].

Displacement L_1 is estimated from the initial shape. Calculating the horizontal strain by use of Eq.(1) with the measured vertical strain, we estimated the largest width L_2.

$$\lambda_2 = \frac{1}{\sqrt{\lambda_1}}. \tag{1}$$

where λ_1 is the vertical strain and the λ_2 is the horizontal strain.



Initial shape Definition of L_1 L_2 is calculated by assuming horizontal expansion

Fig.6. Estimating Horizontal Strain of Shock Absorbers

No.2 Energy absorbing capacity per volume of shock absorber

The material cost used for making the rubber is expected to be low. Therefore we take the energy absorbing capacity per volume as the second parameter.

Fig. 7 and Fig. 8 show the relationships between the above mentioned two parameters and the thickness of rubber pipes for the first loading process and reloading process. It is obvious that the thicker the rubber pipes become, the worse efficiency the specimens possess except for the case of the first parameter on the reloading process.

Deformation of rubber pipes before steel pipes fail can absorb relatively some energy and decrease the collision force in case that earthquakes with small or medium intensity occur. Fig. 9 shows the relationship between the first parameter and the thickness of the rubber pipes before steel pipes yield. In this case, steel pipes are not damaged and then the repair of shock absorbers is not required.

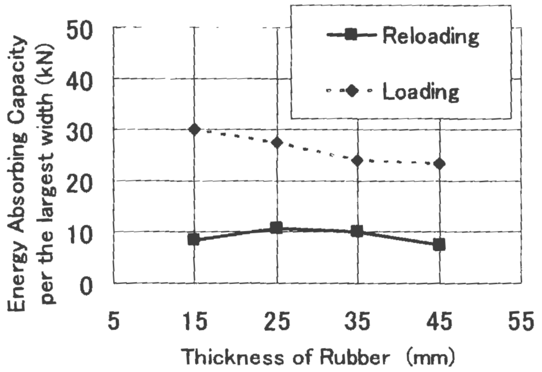


Fig.7 Energy Absorbing Capacity per the Largest Width

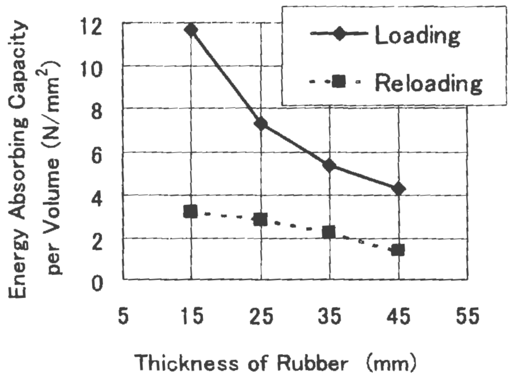


Fig.8 Energy Absorbing Capacities per Volume

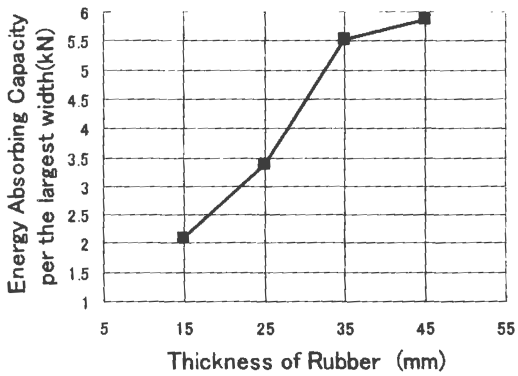


Fig.9 Comparison of Energy Absorbing Capacity Before Steel Pipes Yield

From this figure, it is proven that thick rubbers show better energy absorbing capacity.

Fig. 10 shows the comparison of load-energy absorbing capacity characteristics of two specimens. Only the thickness of rubber pipe is not the same for these specimens. The relationship for the specimen with tr15 is laterally expanded in such a way that the amount of energy at the failure point coincides with that for the other specimen. This result shows that shock absorbers with thinner rubber pipes can absorb the same amount of energy with relatively low collision force.

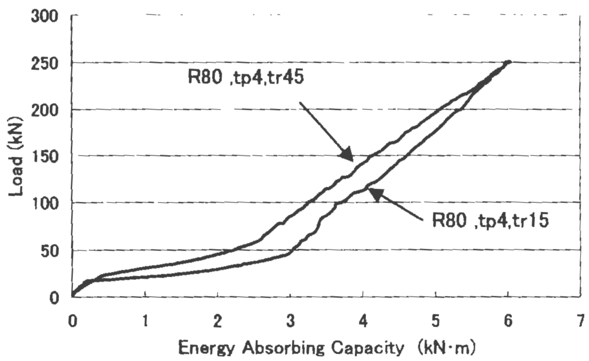


Fig. 10 Comparison of Collision Force

Conclusion

Conclusion obtained according to the experimental results are summarized as follows:

1) The authors examined the efficiency of the new type of shock absorbers, which combines steel and rubber pipes.

2) After the steel pipe yields, thicker rubber pipe shows worse efficiency of energy absorption, mainly because the steel pipe absorbs much energy by plastic deformation.

3)Before the steel pipe yields and after the pipe completely fails, thicker rubber pipe shows better efficiency.

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