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DYNAMIC EXPERIMENTS OF SHOCK ABSORBERS COMPOSED OF STEEL PIPES AND RUBBER PIPES

M Minagawa, Musashi Institute of Technology, Japan
G Goto, Musashi Institute of Technology, Japan
A Ishikuro, Shimizu Corporation, Japan

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. In this paper, the authors conducted dynamic loading tests to the absorbers and confirmed that dynamic load-displacement characteristics can be evaluated by means of static load-displacement characteristics and loading velocity.

Keywords: shock absorber, rubber pipe, steel pipe, energy absorbing capacity, dynamic loading

1. 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 in order to construct a load-displacement model from the basic characteristics of rubber and steel pipes [3]. In this study, we conducted dynamic loading tests to shock absorbers with various dimensions. And we discuss suitable method to estimate dynamic load-displacement characteristics by means static load-displacement characteristics and loading velocity.

2. Static Load-Displacement Characteristics

2.1 Specimens and Static Load-Displacement Relationships.

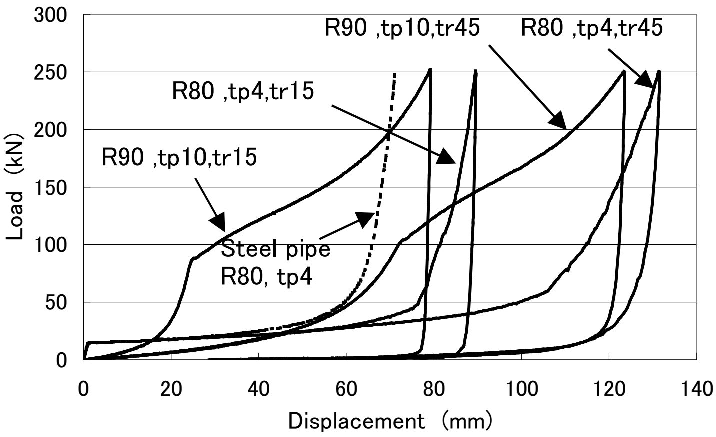
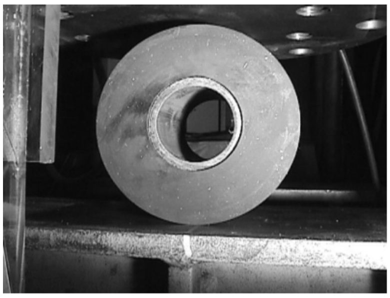
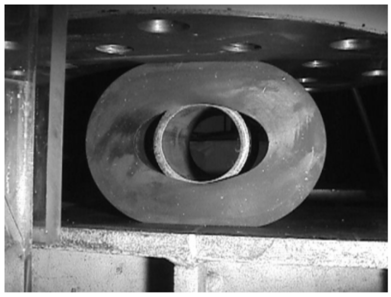


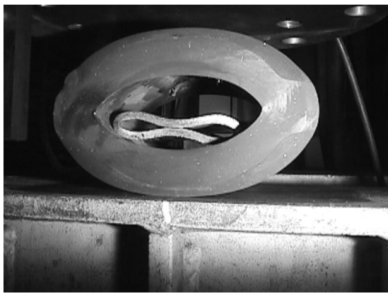
Fig. 1. Static Load-Displacement Characteristics of Shock Absorbers



(a)Initial shape



(b)Shape with the displacement of 30mm



(c)Shape after testing

Fig.2 Deformation of the Specimen (R80mm, tp6mm, tr40mm)

STKM13A steel and chloroprene rubber with hardness of 60 (measured by a durometer) was used as materials for the specimens. Fig. 1 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 rapidly when the upper and lower constricted parts came into contact with each other.

2.2 Static Deformation.

Fig. 2 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. I this paper, we call the value of the load and displacement at the end of phase-I as “yield load” and “yield displacement”,

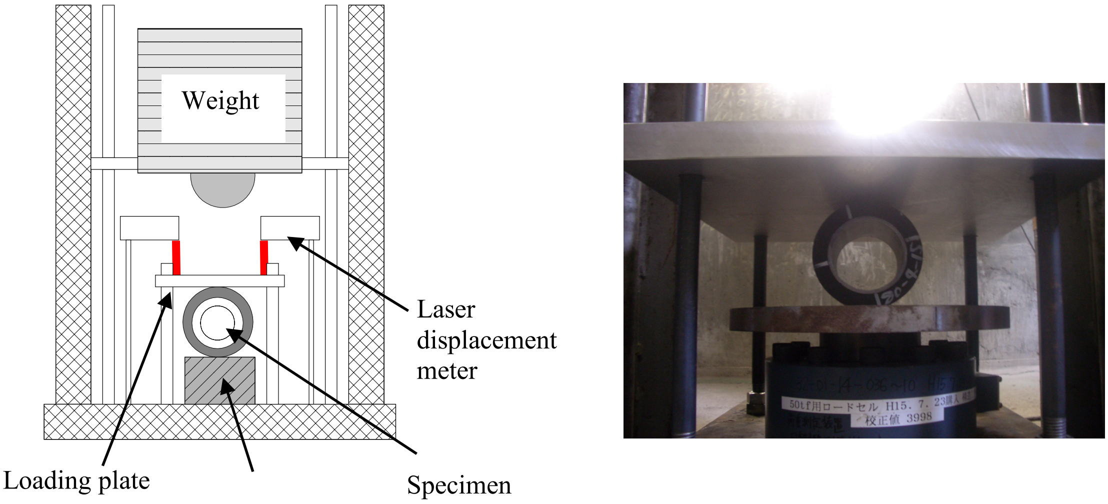


Fig.3 Weight Dropping Impact Test

respectively. 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 failed already.

3. Weight Dropping Impact Test

3.1 Testing Apparatus.

Fig.3 shows the testing apparatus. The same types of specimens were used for weight dropping impact tests. A weight (4.4 kN) was dropped on the specimens over a height range of 0.78m to 2.3m. The height from which the weight was going to be dropped was determined so that the specimen might reach the loading capacity. The loading capacity of each specimen was estimated by means of static load-displacement relationships. Reaction force was measured by the load-cell set up under the specimen, while the displacement of the loading plate was measured by the laser displacement meter, respectively.

3.2 Absorbed Energy.

Fig.4 shows an example of experimental results obtained by the weight dropping impact tests. The horizontal line indicates the time, and the left axis the right axis shows the reaction force and the displacement, respectively. From these relationships obtained by the experiments, we estimated energy absorbed by each specimen and calculated the energy absorbing rates by means of the following equation.

$$\Delta E = \frac{E_1 - E_2}{E_1} \times 100 \qquad (1)$$

where E_1 and E_2 is the kinetic energy of the weight before and after a collision. ΔE ranged from 95% to 100% and this result confirmed that the shock absorber possesses high energy-absorbing capacity.

3.3 Dynamic effect on load-displacement relationships.

Comparing the experimental results obtained by the static loading tests and weight dropping impact tests, dynamic effect on the load-displacement relationships is indicated. As mentioned in the previous section, the load-displacement curve is
composed of two phases called as Phase-I and Phase-II. Only the rubber is deforms in the phase-I, while the steel pipe is deformed and mainly absorbs energy in the phase-II.

In order to compare dynamic behaviors after the steel pipe yielded with the static behaviors, static and dynamic load-displacement relationships on the phase-II were plotted on the same axes. Fig.5 shows the results for some specimens. From the figure, the authors concluded that in the phase-II where the large deformation of the steel pipe is the main part of the deformation of the shock absorber, the effect of the loading speed is not so significant that dynamic and static load-displacement relationships match well. The specimen 80-4-15 is the only exception for the conclusion. This result confirms that the dynamic effect on the load-displacement relationships on the phase-II is mainly due to the characteristics of the rubber.

To estimate the dynamic effect, the ratio (α)of the dynamic yield load to the static yield load as well as the ratio (β) of the dynamic yield displacement to the static yield displacement are calculated and each values are plotted againgst the input energy (E). Fig.6 shows some examples of the results. From these figures, the authors concluded that the significant linear correlations between these values were obtained. The following equations were estimated by the least square method.

$$\begin{aligned} \alpha &= -0.04E + 1.83 \\ \beta &= 0.025E + 0.269 \end{aligned} \tag{2}$$

3.4 Estimation of Dynamic Load-Displacement Relationships.

By using static load-displacement relationships obtained by the physical model constructed by the authors[3] and the ratios evaluated with the energy input for each specimen in each impact test , we predicted the dynamic load-displacement relationships and compared the rewlationships with experimental results. Fig.7 shows some examples of the results. From these figures, it is clear that the dynamic load-displacement relationships can be predicted accurately by the method proposed here.

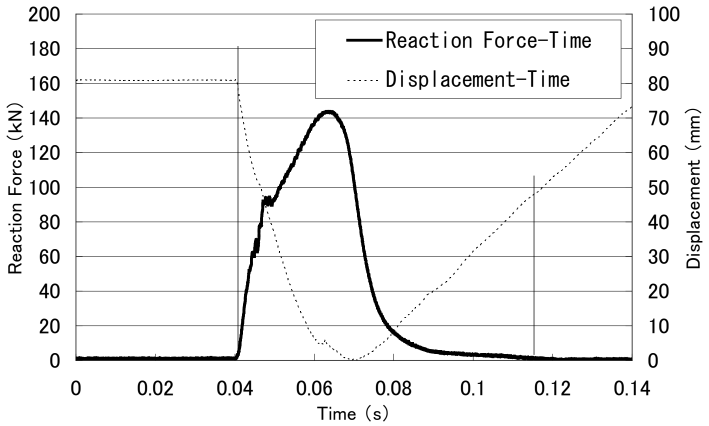


Fig.4 Reaction Force-Time Relationship and Displacement-Time Relationship(R80mm, tp6mm, tr45mm)

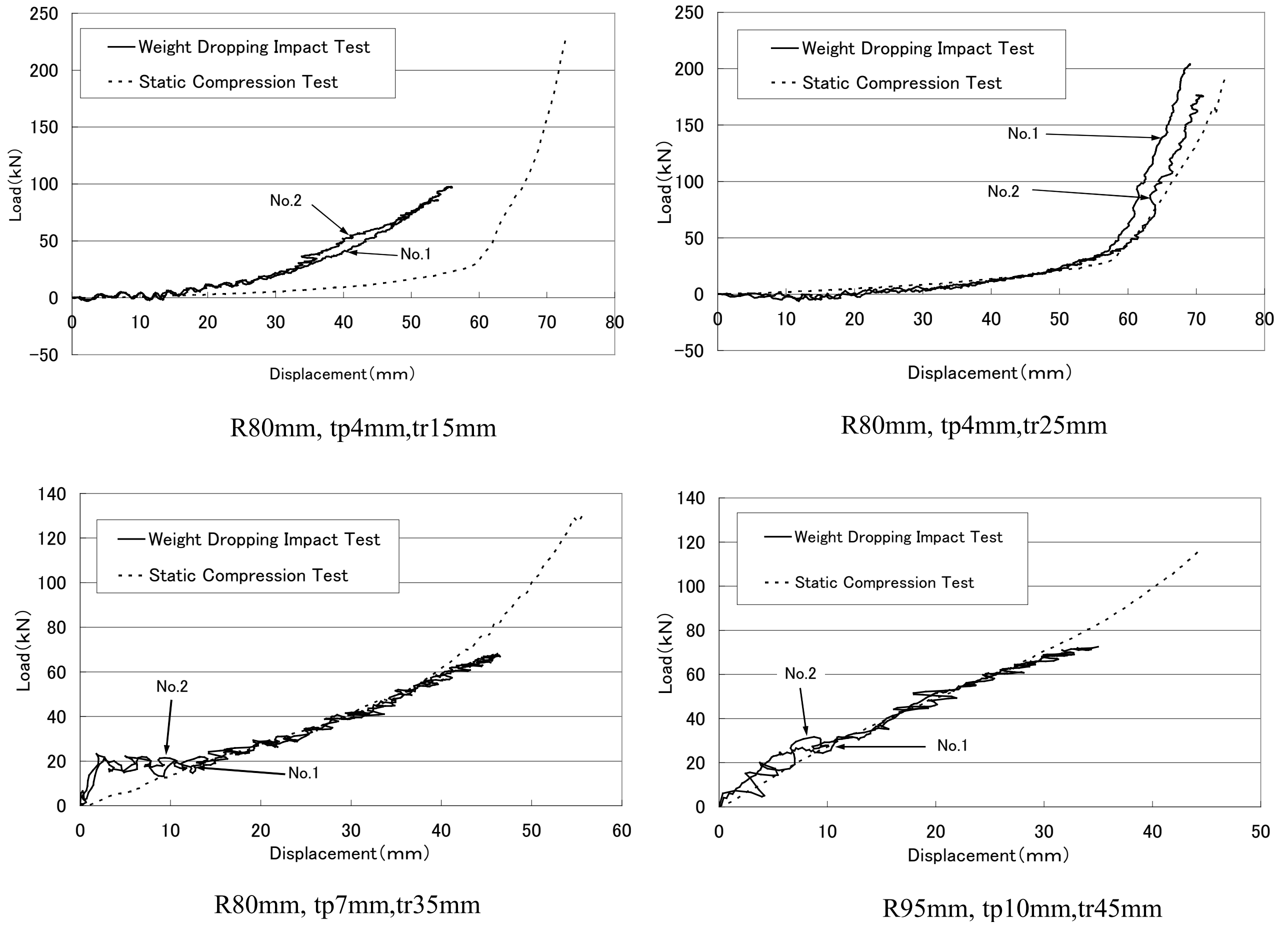


Fig.5 Dynamic Effect on Load-Displacement Relationships of Phase-II

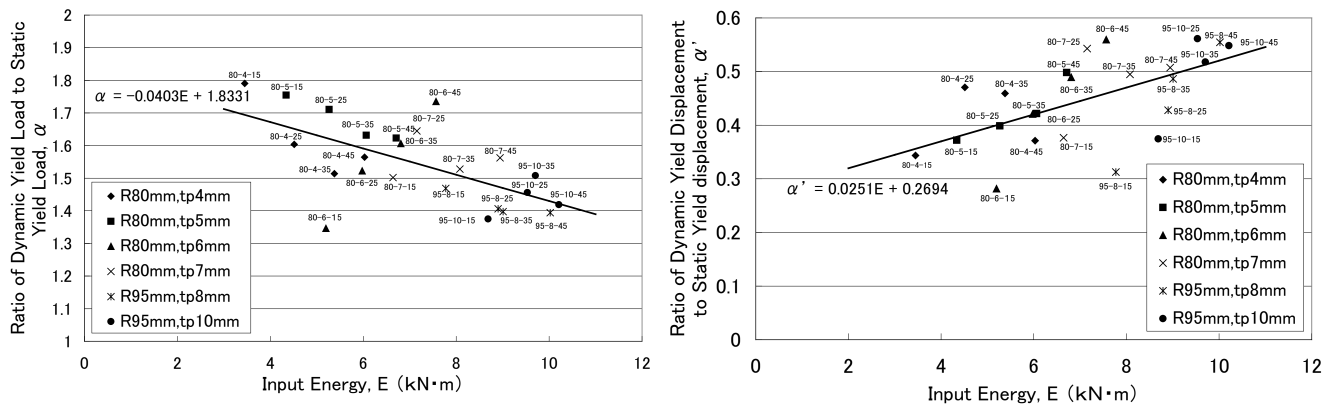
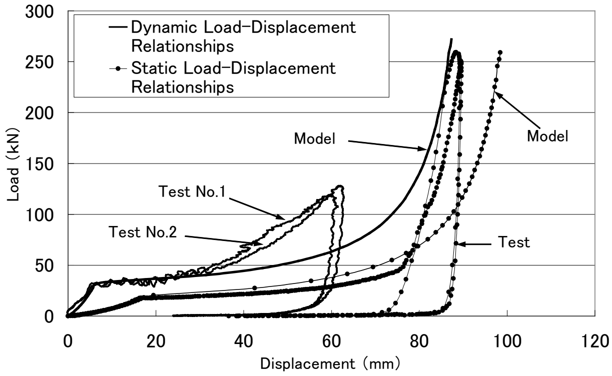
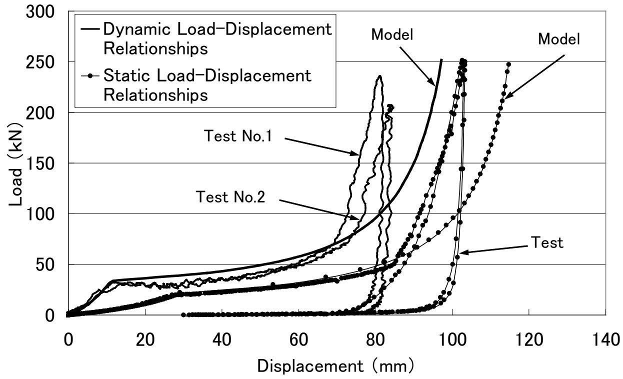


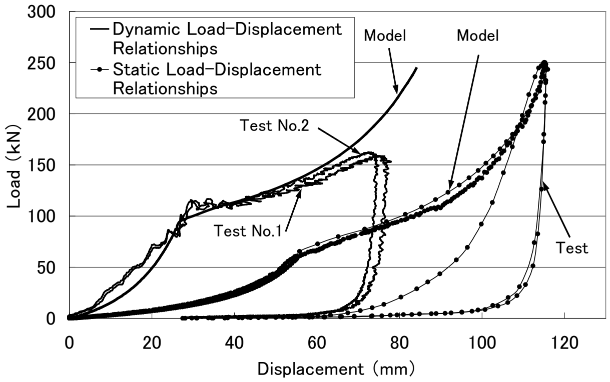
Fig.6 Rate of Yield Load and Yield Displacement



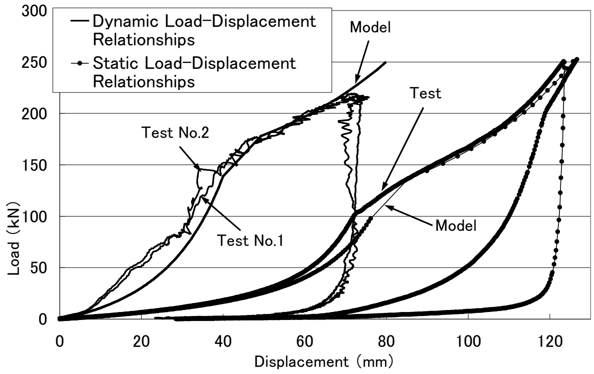
R80mm, tp4mm, tr15mm



R80mm, tp4mm, tr25mm



R80mm, tp7mm, tr35mm



R95mm, tp10mm, tr45mm

Fig.7 Prediction of Dynamic Load-Displacement Relationships

4. Conclusion

Conclusion obtained according to the experimental results are summarized as follows:
1) The shock absorber the authors proposed possesses high energy-absorbing capacity.
2) The dynamic load-displacement relationships of the shock absorbers can be predicted accurately by the physical model proposed by the authors and the input energy.

References

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