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Failure test of laminated rubber bearings with various shapes

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ABSTRACT: Loading tests were conducted on laminated rubber bearings having various geometric shapes. The objective of the test is to grasp the effect of the primary and secondary shape factors of the rubber bearings on the failure limit characteristics. As a result of the tests, it was indicated that the influence of the geometric shapes were significant as the difference in shear deformation capacity of the rubber bearings under high axial pressure.

1 INTRODUCTION

In order to adopt the seismic base isolation structure for important facilities such as the nuclear power plants, it is required to establish a reasonable base isolation design method which ensures that the base isolation devices have an appropriate margin against design seismic force. The important problem for the quantitative evaluation of the safety margin during an earthquake is to grasp the limit characteristics (ultimate strength and deformation) of the base isolation devices and, at the same time, to establish an analytical technique which can estimate the limit response of the structure.

The limit characteristics of laminated rubber bearings are influenced by various factors such as the geometric shapes, external loading patterns to be applied, deterioration of the rubber due to aging. Authors of this paper have investigated experimentally the limit characteristics of laminated rubber bearing with a certain geometric shape (Iizuka 1991). In the present investigation, aiming at defining the effect of geometric shapes of laminated rubber bearing on limit characteristics, loading tests were conducted using primary and secondary shape factors as parameters, with which geometric shapes of rubber bearing were determined.

2 TEST SPECIMENS AND LOADING METHOD

2.1 *Test Specimens*

The geometric shape of laminated rubber bearing with circular section is determined by two shape factors defined as follows :

Primary shape factor (S1)
= cross-sectional area of rubber [$\pi D^2/4$]
/ free surface area of a single layer of a rubber [πDt]
$=D/(4t)$

Secondary shape factor (S2)
= diameter of rubber [D]
/ total thickness of rubber [nt]
$=D/(nt)$

where, t: thickness of a single rubber layer, n: number of layers. Of these factors, S1 is used in the design of the rubber bearing as a factor related to its axial stiffness, and S2 relates to the buckling.

Nine different shapes of test specimens were prepared for the tests by varying S1 as approximately 5, 20, and 40; and varying S2 as approximately 2, 4, and 7 as shown in Fig. 1. A total of 63 samples were tested (7 units for each shape). All the test samples had the same diameter (D=20cm) and the gum material was a natural rubber having a modulus of $5.6kgf/cm^2$(0.55MPa).

2.2 *Loading Pattern*

For the tests, 7 loading patterns comprising different combinations of axial force and shearing force were considered as shown in Fig. 2. Loading patterns ① to ④ are shear loadings under a constant axial stress; σ =0, -50 (-4.9), -100 (-9.8), and $-200kgf/cm^2$(-19.6MPa). Loading patterns ⑤ and ⑥ are tensile loadings under a constant shear strain (γ = 0 and 400%), and loading pattern ⑦ is the inclined loading under σ/γ = $8kgf/cm^2$(0.78MPa).

Repeated loading with gradually increased amplitude was applied quasi-statically (0.01Hz) using a hydraulic actuator until the rubber ruptured.

3 TEST RESULTS

3.1 *Characteristics of Restoring Forces*

The measured loads and deformation were normalized

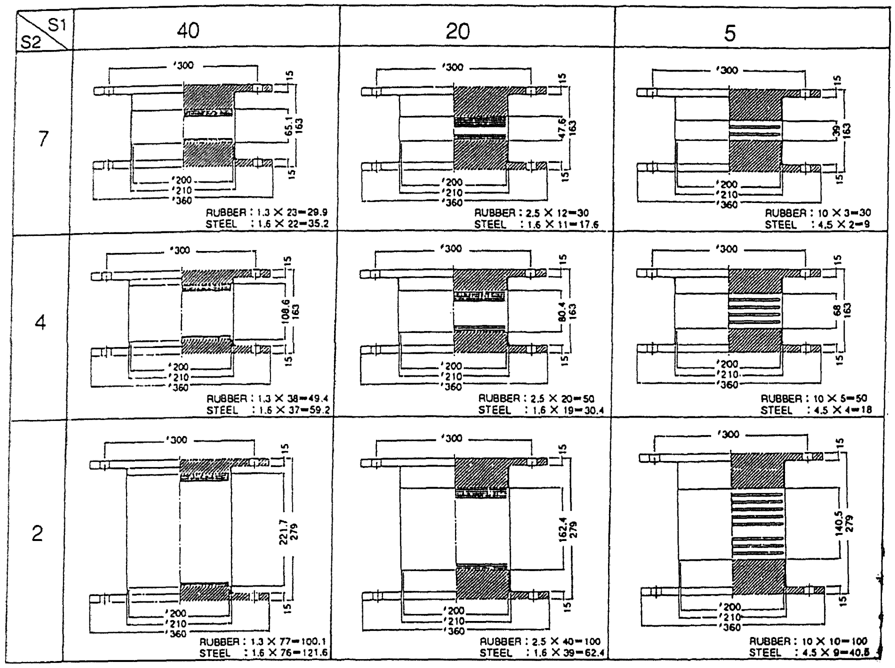


Fig. 1 Test specimens

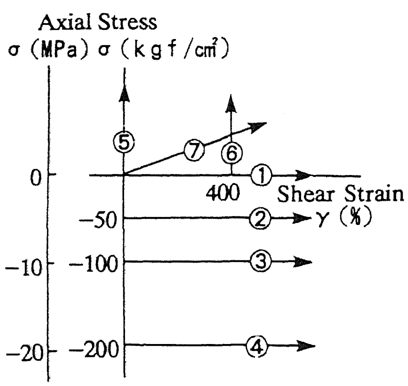


Fig.2 Loading patterns

into the following stress and strain:

Shear stress τ
= Shear force/cross-sectional area of rubber
Shear strain γ
= Horizontal displacement/total thickness of rubber
Axial stress σ
= Axial force/cross-sectional area of rubber
Axial strain ε
= Vertical displacement/total thickness of rubber

Fig. 3 shows as examples the τ - γ curves of the loading pattern ② and the σ - ε curves of loading pattern ⑤ using shape factors as the parameters for comparison.

Fig. 4 shows the envelopes of the stress-strain curves for loading patterns ① to ⑥. From these test results, the following may be pointed out:

1. The characteristics of the τ - γ restoring force against shear loading under constant axial force is markedly influenced by the shape factors. As the primary and secondary shape factors (S1 and S2) become smaller, the hardening rigidities in the large deformation are reduced. This trend is more easily influenced particularly by S2.
2. For some samples whose S2 are less than 4, restoring forces begin to reduce without any rupture of rubber, which is called here as 'buckling'. This behavior appears more markedly as S1 becomes smaller or the working axial force becomes larger. Some test samples show that loads increase again after reduction in the load due to buckling . This is caused by the fact that the fixing bolts of the bearing touch the side of rubber as the deformation proceeds.
3. The influence of shape factors on the characteristics of the σ - ε restoring force against tensile loading in the axial direction is comparatively small. The yielding stress level at which axial strain begins to increase rapidly is approximately 20kgf/cm^2(2.0MPa) and is nearly constant regardless of shape. In the case of tensile loading under the constant shear strain of 400% (loading pattern ⑥), however, the yielding stress level differs depending on shape.
4. The characteristics of restoring forces against inclined loading (loading pattern ⑦) is not greatly subjected to the influence by shape factors.

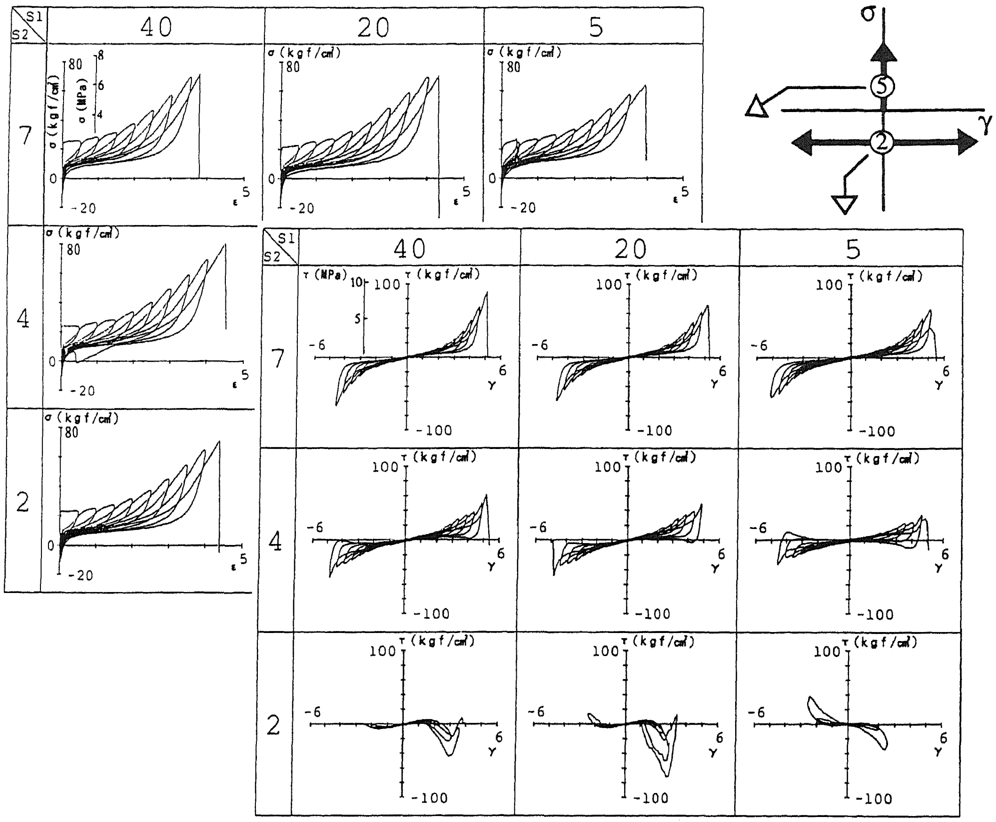
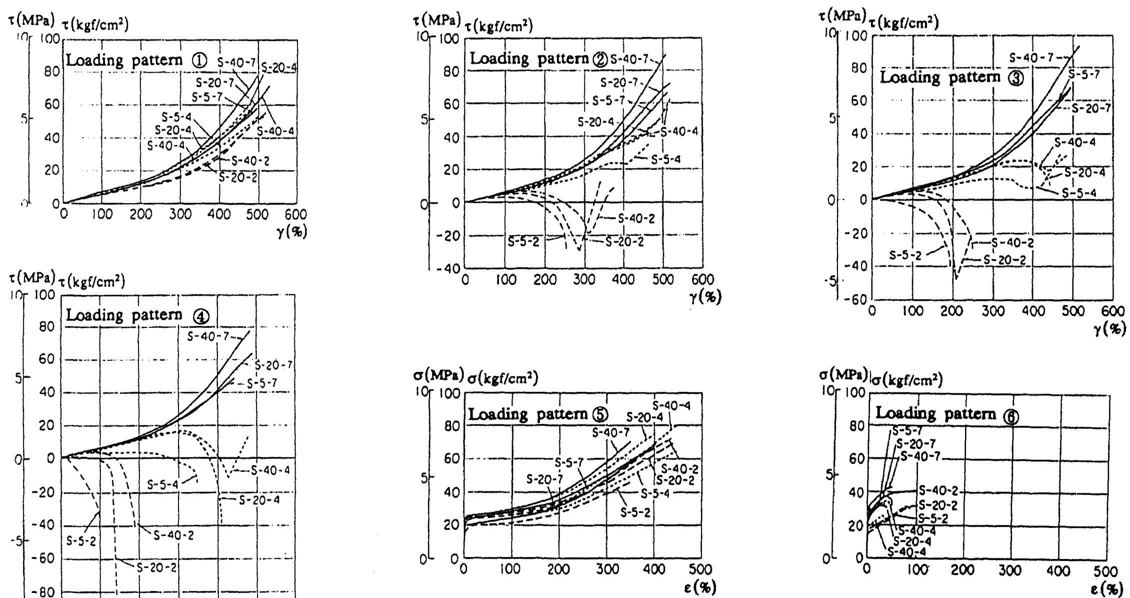


Fig.3 Stress-strain curves for loading patterns ② and ⑤



Name of specimen; S-S1-S2

Fig.4 Enveolpes of stress-strain curves (Loading pattern ⑦ is omitted)

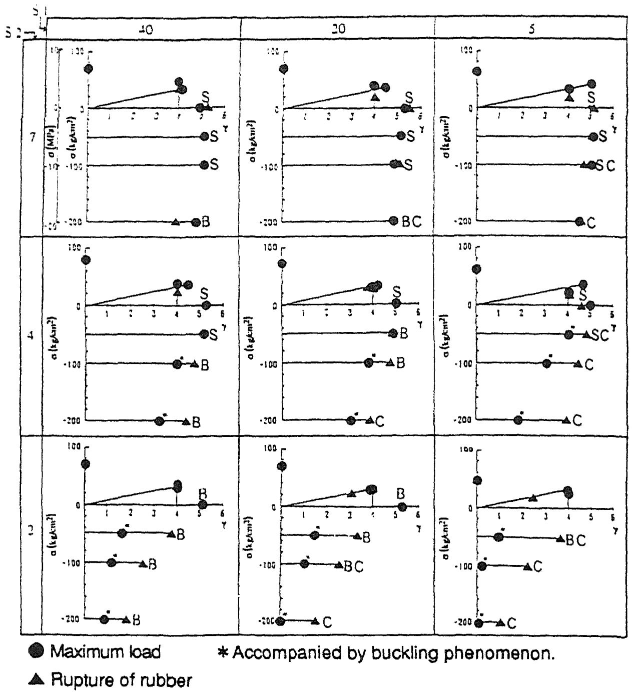


Fig.5 Failure limits on σ - γ plane

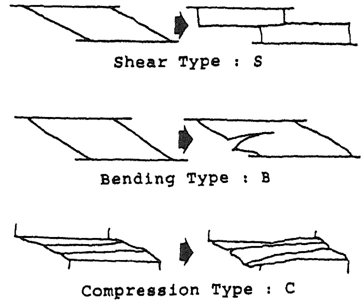


Fig.6 Types of failure mode

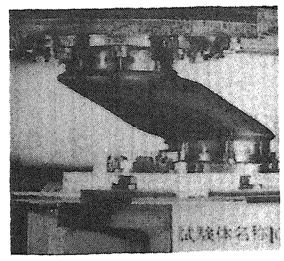


Fig.7 Typical buckling mode (S-20-2, Loading pattern ③)

3.2 *Characteristics of Failure Limit*

In Fig. 5, the failure limits of the entire test samples are plotted on the σ - γ plane by using the shape factors as parameters for comparison. In the figure, both the maximum load points and the rubber rupture points are indicated, since the rupture of rubber does not always occur at the maximum load point.

Failure modes for shear loading under constant axial force differ depending on the shape of the rubber bearings and compression force applied. The failure mode may be classified into (1) shear type : S, (2) bending type : B, and (3) compression type : C as shown in Fig. 6. The results of classification are shown in Fig. 5, where the intermediate modes are shown in combined form such as SC or BC. From these results, the following can be pointed out concerning the failure limit characteristics:

1. In the shear loading under compression force, deformation capacity decreases as S1 and S2 become smaller. The reason lies in that the maximum shear strength is determined by the buckling which occurs at an early stage. A typical buckling mode of rubber bearing is shown in Fig. 7.
2. For the deformation capacity against tensile and inclined loadings, no remarkable differences were found due to the difference in shapes.
3. It is found that failure mode S (shear type) is dominant under low axial force, and modes B and C (bending and compression types) become dominant when high axial force is applied. For bearings with thick rubber layers whose S1 is small, mode C becomes dominant.

4 CONCLUSION

From the results of failure tests of laminated rubber bearings, it was shown that the failure limits and the restoring force characteristics of the bearings are strongly influenced by their geometric shapes under some loading conditions. That is, as the primary and secondary shape factors (S1 and S2) become smaller, shear deformation capacity under high compression force is drastically reduced due to early occurrence of the buckling. These results suggest that when designing a seismic isolation structure, care should be taken in the following:

1. When using laminated rubber bearings under high axial stress conditions, the secondary shape factors should be selected to be large to ensure an enough deformation capacity.
2. When estimating the safety margin of a seismic base isolation structure against seismic forces, variation in the limit characteristics of the laminated rubber bearings due to their geometric shapes should be taken into account.

These findings should be properly reflected to the design guidelines for the base-isolated buildings in the future.

REFERENCES

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