FAILURE CHARACTERISTICS OF BONDED RUBBER BLOCKS UNDER TENSILE LOADS

University of Tokyo　Student Member　Chamindalal Sujeewa LEWANGAMAGE
University of Tokyo　Fellow　Yozo FUJINO

1. Introduction

The use of seismic isolation rubber bearings for bridges and buildings provide a very effective passive method to suppress hazard from earthquake-induced vibrations. The bearings are not loaded in tension, but tensile force can be caused by horizontal acceleration during a strong earthquake. It is generally known that such tensile forces in rubber bearings can developed hydrostatic tensile stresses and can cause internal ruptures leading to failure[1, 2]. Bonded rubber blocks are one layered small-scale rubber bearings, which can be used to study behavior of the bearings. Gent et al.[1] has studied sudden appearances of internal cracks in bonded rubber cylinders at comparatively small tensile load but ultimate failure characteristics of bonded rubber blocks have not been studied. This paper presents experimental studies and modeling of failure characteristics of bonded rubber blocks under tensile loads.

2. Experimental outline

The specimen used for the study is shown in Fig. 1. Uniaxial tension tests were conducted until failure for different strain rates of loading for the specimens with different rubber thickness. The details of the tests are given in Table 1.

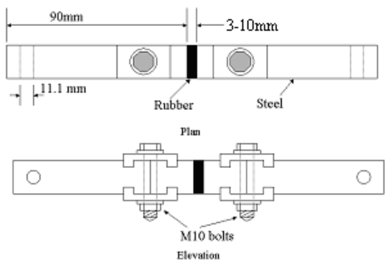

Fig. 1. Bonded rubber block for tensile test (specimen)

Table 1. Material test descriptions (tensile test for bonded rubber blocks)

	Uniaxial tension
Type of rubber (Shear modulus in Mpa)	Natural (0.98)
Specimen thickness (mm)	3,5,6,8,10
Loading velocity [mm/sec]	0.01,0.1,1,10
Specimen tested per case	3
Temperature [°C]	18~25

3. Experimental results

From the results of test series, three kinds of failure modes were observed; bond failure (30%), failure near the steel part (almost at the edge) (50%) and failure at the middle (20%). After careful observation of the specimens and the results at failure, it can be assumed that failure at the edge may have occurred either due to large deformation of rubber at the edge or formation of internal rupture near to the edge. Failure at the middle part may be due to formation of internal rupture. Internal rupture of rubber occurred due to development of hydrostatic tensile stresses.

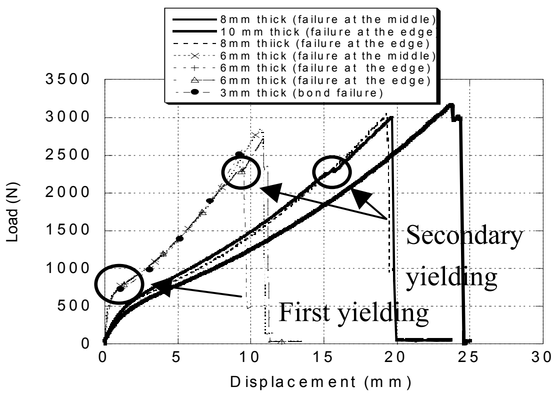

Fig. 2. Load-displacement relations

For the cases which were forming an internal rupture at either edge or middle, the point at which cracking occurred was, in general, clearly shown by a marked discontinuity in the load-displacement relation in Fig. 2. When the specimen thickness is 3mm discontinuity of load-displacement relation was observed at small tensile strain. However, when specimen thickness increases (>3mm) such a behavior was not observed at small tensile strain. Thus, it can be assumed that when the specimen thickness is small, negative hydrostatic pressure components of the applied stress reaches a critical value and forms internal rupture. Further, secondary

Keywords: Bonded rubber blocks, rubber bearings, failure criteria, internal rupture, large strains
Address: Hongo 7-3-1, Bunkyo-ku, Tokyo 113-8656, Japan; Tel: 03-5841-6099, Fax: 03-5841-7454
Email: sujeewa@bridge.t.u-tokyo.ac.jp, Fujino@bridge.t.u-tokyo.ac.jp

formation of such a rupture at large tensile strain was observed (Fig. 2). This was observed even in specimens with a larger thickness (>3mm). The phenomenon behind such a behavior can be assumed, it is similar to the formation of rupture with small tensile strain due to hydrostatic pressure effect[1]. After formation of such a secondary rupture, failure of the specimen occurred without much further deformation but in cases where rupture occurred at small tensile strains, it withstood larger deformation. However, ultimate failure loads were independent of formations of such a rupture[2]. When the specimen thickness is larger (>8mm), internal rupture of rubber was not observed. This may be an indication that bearings with large shape factors (small thickness) have higher possibility to generate internal rupture of the rubber.

4. Modeling

Two failure criteria are proposed to evaluate the failure of bonded rubber blocks; one is to estimate the rubber failure under large stains (Eq. 1) and the other is to estimate the internal rupture of rubber (Eq. 2). The details of the modeling have been discussed in ref. 2.

$$(I_c - 3)(II_c - 3) - \alpha_f (II_c - 3)^2 \geq \beta_f \quad \textbf{(1)}$$

$$p_f \geq S p_m \quad \textbf{(2)}$$

$$p_m = -k(J - 1) \quad \textbf{(2a)}$$

where I_C, II_C, α_f, β_f, p_f, p_m, k, J, *and* S are the first, second invariants of the right Cauchy green deformation tensor, material constants, critical negative hydrostatic pressure value at rupture, pressure from assumed hydrostatic pressure-deformation relation for rubber with slightly compressible[2], bulk modulus of rubber material, determinant of deformation gradient tensor and a material constant related to shape factor[2] of bearing respectively.

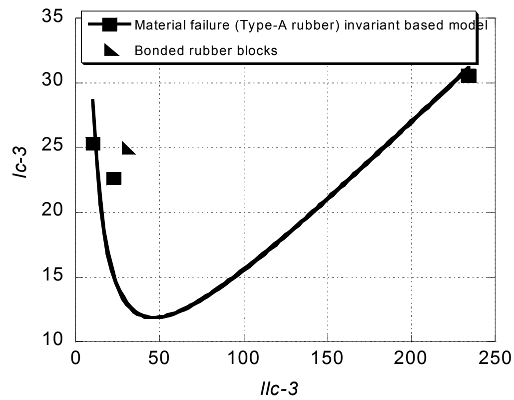

Fig. 3. Rubber failure- results comparison

The material failure criteria are introduced into a finite element model[2], and then the experimental failure tests were simulated. Finally, results of the numerical analysis were compared with the results of the failure experiments. Fig. 3 shows the comparison results: material model and failure results of bonded rubber blocks under large strains. The FEM result shows that at the rupture level, average hydrostatic pressure value calculated by FEM (10 Mpa) is closely related, which is calculated by Equation (2) when slightly compressibility is assumed (average J =1.02 under tension). Bulk modulus for the rubber material is used as 600 Mpa, which is estimated using an inverse analysis[2]. Finally, it can be concluded that internal rupture of rubber due to high tensile loads and complete rubber failure due to a large deformation in bonded rubber blocks can be estimated by proposed failure criteria.

5. Conclusions

Experimental investigations on failure characteristics of bonded rubber blocks under tensile loads have performed. Two criteria are proposed to estimate failure values due to large deformations (large strains) and due to hydrostatic pressure, and verified.

References

1. Gent A.N., Lindley P.B., (1959). “Internal rupture of bonded rubber cylinders in tension.” *Royal Society of London Proceedings*, Series A, Vol.249, PP.195-205.
2. Lewangamage C.S., Abe M., Fujino Y., Yoshida J., “Modeling on rubber failure in seismic isolation rubber bearings under large deformations.” *Journal of Earthquake Engineering and Structural Dynamics*, (submitted).