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Characteristic Tests of High Damping Rubber Shear Specimens for Seismic Isolators of KALIMER

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ABSTRACT

The shear modulus and the equivalent damping of rubber shear specimens are investigated through various shear dynamic tests such as cyclical loading tests, loading rate tests, incremented shear strain tests, loading history tests, and recovery tests. The shear modulus and shear damping are decreased as the number of loading cycles increases, and increased as the loading rate increases. As the shear strain is larger than 100%, the shear modulus of rubber is increased due to the rubber hardening. Two types of loading history are applied to each rubber specimen and the affection on the rubber characteristic is estimated. From the recovery tests, it is revealed that the stabilized rubber mechanical properties are recovered after about 3 hours, and the rubber behavior approaches the initial properties after 1.5 years of relaxation.

1. INTRODUCTION

The seismic isolators fabricated for the seismic isolation design for KALIMER (Korea Advanced Liquid Metal Reactor) are shown in Fig.1. The manufacture and testing of these bearings have taken a lot of time and cost. Since rubber is the main deformable element in the bearing, the finite element analysis technique for rubber bearings based on the rubber specimen test data such as uniaxial, pure shear and compression has being developed[1,2]. Various shear dynamic tests for small specimens of rubber were performed to correlate the test results with the behaviors of the isolator, because the mechanical behavior are obtained quickly compared to full- and scale-sized bearing tests [3,4,5]. In this paper, extensive tests of small specimens of rubber used in seismic isolator for KALIMER are performed to obtain the mechanical characteristic responses of rubber compounds.

A testing facility for rubber specimens has been established in Argonne National Laboratory(ANL). High precision dynamic testing is performed on Instrons Corporation's 8500 series universal testing machine. This servo-hydraulic machine has a 55 kip load frame, a 5 kip actuator and can comfortably perform tests over the range of interest responses for rubber specimens, which is from 0.005Hz to 5Hz.

The 26 specimens made of high damping rubber used in the seismic isolators of the KALIMER, which is developed by KAERI, are 3 bar lap shear specimens of LTV type (Fig.2). The 26 specimens are sequentially named and many kinds of tests have been performed over the last 1.5 years. The test results for the several representative specimens named as SD9704A, SD9704B, K98-13, K98-17, K98-19 are presented in this paper. The dimensions of the LTV type rubber specimens are measured in Table 1. A comparison of test results for shear strain level tests between the specimen and the isolator is also briefly introduced.

Table 1. Dimensions of Rubber Specimens

	SD9704B SD9704A	K98-13	K98-17	K98-19
Steel Bar Thickness(cm)	0.445 x 3	0.813 x 3	0.800 x 3	0.805 x 3
Rubber Area (cm^2)	2.54 x 2.54	2.54 x 2.54	2.54 x 2.54	2.54 x 2.54
Rubber Thickness(cm)	0.686	0.635	0.640	0.643

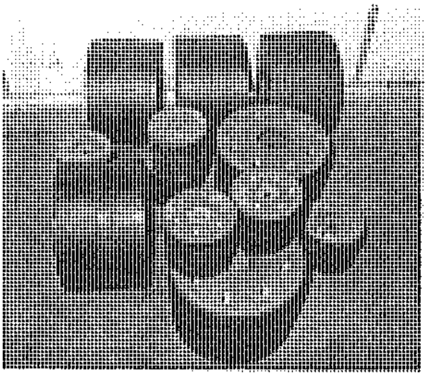


Fig. 1 Scaled Laminated Rubber Bearings

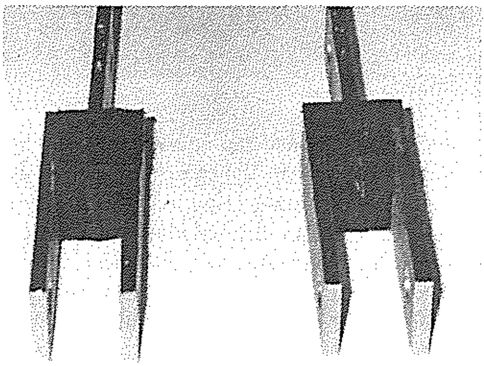


Fig. 2 Rubber Specimen for Shear Dynamic Test

2. TEST ITEMS FOR RUBBER SPECIMENS

The cyclical test, which is consecutively cycled for twenty-six fully reversed cycles at 100% strain and 0.5 Hz, is performed with the specimen SD9704B. After 3 days relaxation, loading rate tests are performed on the same specimen to find its sensitivity to the loading rate in which each loading rate has six cyclical loads at 100% shear strain. The applied loading rates are of 0.005, 0.025, 0.05, 0.10, 0.5, 1.0, 2.5 and 5.0Hz. After another 2 days relaxation, shear strain level tests of six cycles of fully reversed loading at 0.5 Hz are applied at the shear strain levels of 5, 10, 20, 50, 75, 100, 150, 200, and 250%.

For ascertaining the loading history effects of rubber specimens, two types of test sequence are defined and applied to the two specimens of K98-13 and K98-17, respectively.

Using the K98-19 specimen, recovery tests using the 26-cycles loads at 100% shear strain are performed with test intervals of 15 minutes and three hours. And the 26-cycles test for the SD9704A specimen taken at a large shear strain 1.5 years ago is performed to compare the results with those of 1.5 years ago.

3. TEST RESULTS OF RUBBER SPECIMENS

The shear modulus and the effective damping per cycle for all six kinds of tests are calculated and represented in Figures 3 to 9.

3.1 Cyclical test

A cyclical test was performed on an unscragged (virgin) specimen. The specimen was subjected to 26 cycles of sinusoidal shear strain of 100% at 0.5 Hz. Fig.3 shows the variations of shear modulus and damping with cycle numbers. The main decrease of shear modulus and damping occurs within a few cycles, and relatively small changes occur after a few cycles.

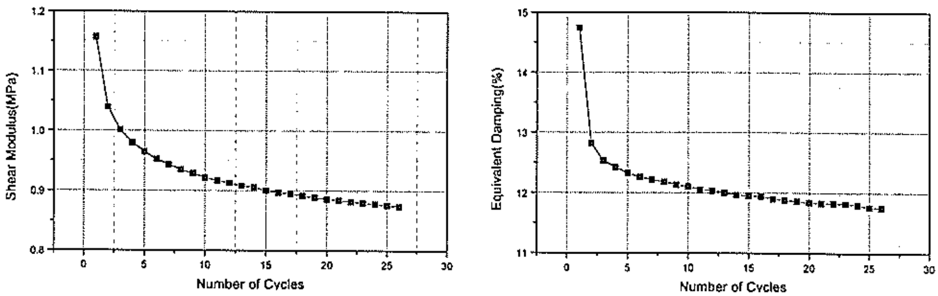


Fig. 3 Cyclical Test of 100% Shear Strain for SD9704B

3.2 Loading Rate Tests

The loading rate tests of 100% shear strain with 6 cycles and 8 different test frequencies were performed using the same specimen(SD9704B) which had taken the shear cyclical test with 100% strain 3 days ago. Fig. 4 shows the variations of shear modulus and damping with loading rate over the frequency range of 0.005 Hz to 5.0 Hz. The shear modulus and the damping values increase as the loading rate increases. The shear modulus and damping at 0.005 Hz are smaller than those at 0.5 Hz by about 30% and 15%, respectively.

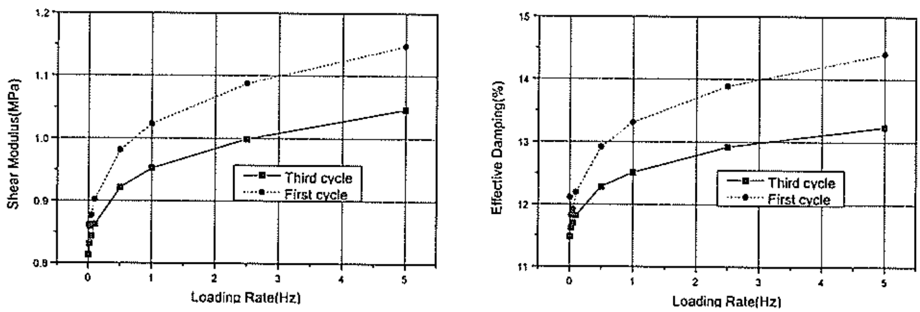


Fig. 4 Loading Rate Tests of 100% Shear Strain after 26-Cycles Test for SD9704B

3.3 Shear Strain Level Tests

The tests were performed with various shear strains of 5%, 10%, 25%, 50%, 75%, 100%, 150%, 200% and 250% at 0.5Hz. The results for the effective shear modulus and the equivalent damping for the first and the third cycles for the SD9704B specimen are given in Fig.5. As the shear strain increases, the shear modulus decreases until 100%, and after that is increased by rubber hardening. The damping monotonically decreases according to the shear strain level. The characteristic values of the third cycle are decreased compared with the first ones because of the rubber softening.

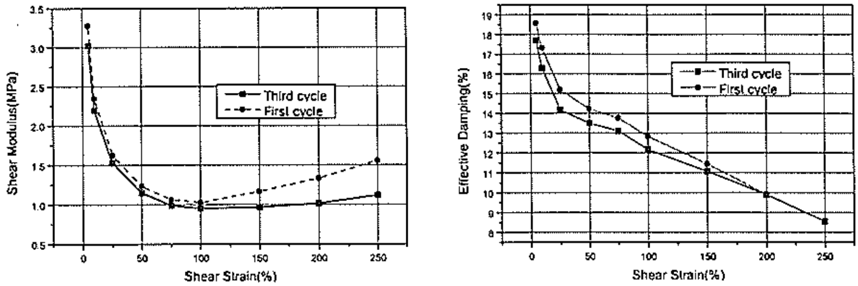
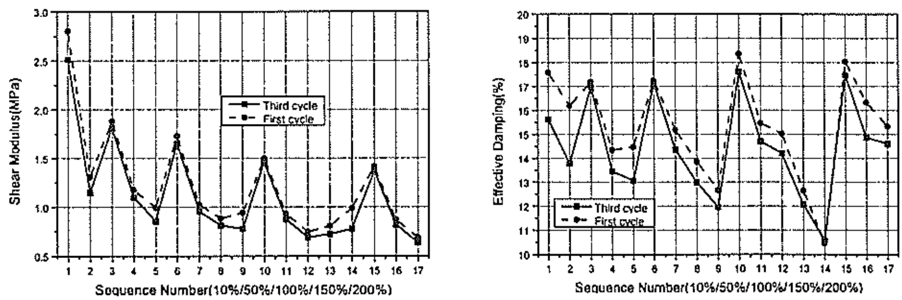


Fig. 5 Shear Strain Level Tests after 26-Cycles and Loading Rate Tests for SD9704B

3.4 Loading History Effect Tests

A characteristic test sequence (Type I), referred to as strain-buildup tests, involves the shear strains of 10/50%, 10/50/100%, 10/50/100/150%, 10/50/100/150/200%, and 10/50/100% to assess the change in modulus at lower shear strains due to cycling at higher shear strains. If these effects are great, then there can be significant implication on analytical models for bearing response, particularly for analyses of response to long-duration earthquakes where repeated cycling at a wide range of strains could occur.

As the historical shear strain taken by the rubber specimen is larger, the reduction of the shear modulus values at 10% strain is larger. The equivalent damping at 10% shear strain is not greatly affected by the shear strain magnitude experienced by the rubber specimen. The shear modulus values at 50% are slowly decreased, but the equivalent damping is slightly



increased.

Fig. 6 Results of Loading History Effect Tests – Type I of K98-13

Similar sequence (Type II), intended to capture load-history effects in the bearings, involves alternating strains of 10% and 150% with five cycles. The objective of this group of tests is to examine the change in the effective modulus at 150% strain due to repeated cycling and recover. As shown in Fig. 7, the shear modulus and damping values remains similar values except the first cycle at the 10% and 150% both.

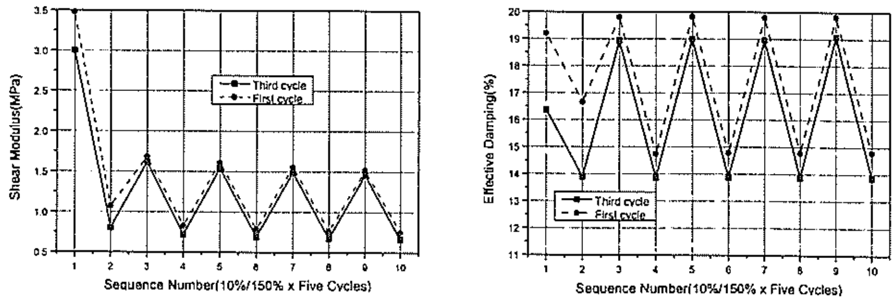


Fig. 7 Results of Loading History Effect Tests –Type II for K98-17

The shear modulus of the shear strain range of 10% to 150% varies 1.7 - 0.7 MPa for Type I and 1.6 - 0.7 MPa for Type II. The equivalent damping varies 17.5 – 12% for Type I and 19 – 14% for Type II. This means that the rubber behavior is almost independent of loading history Type.

3.5 Recovery Tests

To investigate the recovering of the mechanical performance of rubber after shear dynamic loading, two times of 26-cycles test at 100% shear strain for K98-19 specimen are carried out at 15 minutes and at 3 hours after initial 26-cycles test. Fig. 8 shows that the shear modulus and the damping have not recovered to the initial mechanical performance, but the test results of 3 hours are very close to the 15 minutes test ones. It means that the rubber mechanical characteristics are recovered after 3 hours after initial deformation.

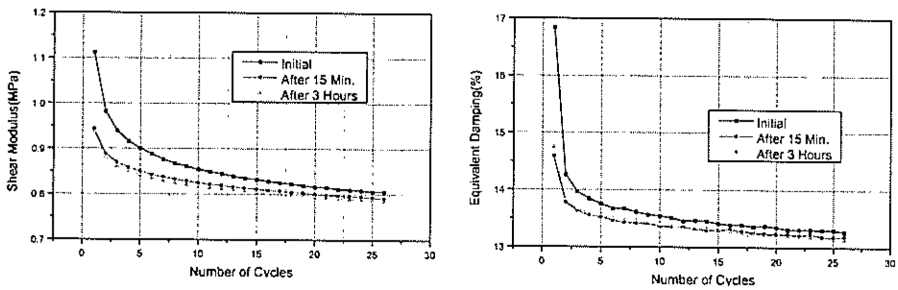


Fig. 8 Recovery Tests for K98-19

An interesting 26-cycles test was performed to check the recovering ability of rubber for the SD9704A specimen, which had taken the shear strain level tests of the strain range of 5% to 300%, loading rate tests of 100% shear strain, and shear cyclical tests 1.5 years ago. The comparison of the shear cyclical test results is represented in Fig. 9. The results show that the shear modulus of the rubber specimen taken 3 different kinds of tests 1.5 years ago can be recovered exceedingly by about 110% of those in the 1st cyclical test, but the damping by about 90% of those in the 1st cyclical test.

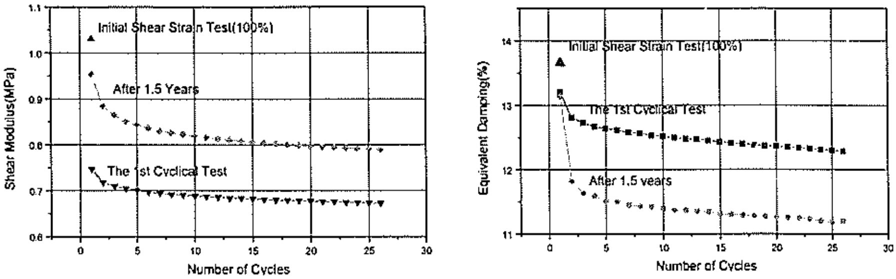


Fig. 9 Recovery Tests for SD9704A

3.6 Correlation between Specimen Tests and Bearing Tests

The characteristic test results of the rubber specimen are compared with those of the 1/8 scaled-bearing [6]. As shown in Fig.10, the shear modulus of the specimen is higher than those of the bearing by about12%, but the equivalent damping is smaller than those of the bearing by about 17%.

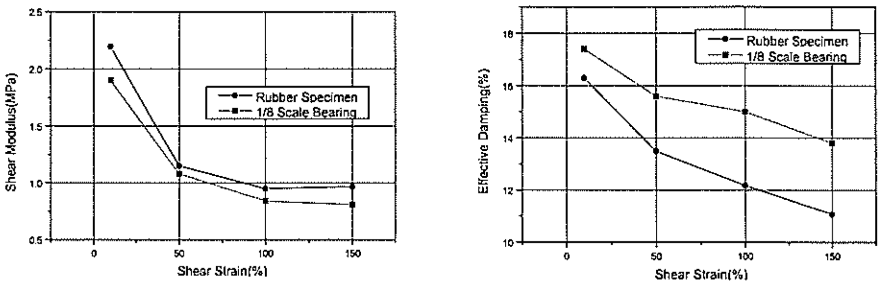


Fig. 10 Correlation between Specimen Tests and Bearing Tests

4. CONCLUSIONS

Through the various shear dynamic tests such as cyclical loading, loading rate, shear strain level, loading history effect, and recovery tests, the shear modulus and the equivalent damping decreases as the number of loading cycles increases, and increases as the loading rate increases. As the shear strain is larger than 100% shear above, the shear modulus of rubber is increased due to the rubber hardening.

From two types of loading history effect tests, the reduction magnitude of the shear modulus values at 10% strain is larger as the experienced shear strain is larger, while the equivalent damping at 10% shear strain is not affected by the shear strain magnitude experienced by rubber specimen. The shear modulus and the equivalent damping are mostly dependent on the maximum shear strain experienced by the specimen rather than the loading history types.

From the recovery tests, the stabilized mechanical properties of rubber are recovered after about 3 hours, and after 1.5 years of relaxation, which approach the initial virgin properties.

The shear modulus of specimen test is higher than those of 1/8 scaled bearing by about12%, but the equivalent damping is smaller than those of the bearing by about 17%.

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REFERENCES

1. Yoo, B., Lee, J.H. and Koo,G.H., IAEA Research Co-ordination Meeting (RCM) on "Intercomparison of Analysis Methods for Seismically Isolated Nuclear Structures," Hertford, UK, May 26-27, 1998.
2. IAEA Research Co-ordination Meeting(RCM) on "Intercomparison of Analysis Methods for Seismically Isolated Nuclear Structures," St. Petersburg, Russian Federation,1996.
3. Kulak, R.F. and Hughes, T.H., "Correlation of Elastomer Material Properties from Small Specimen Tests and Scale-size Bearing Tests," Proceedings Fifth National Conference on Earthquake Eng., Chicago, IL, 1994.
4. Kulak, R.F. and Hughes, T.H., "Mechanical Behavior of a Suite of Elastomers Used for Seismic Base Isolation," PVP Vol.319,Seismic, Shock and Vibration,ASME,1995, pp211-214
5. Kulak, R.F., "Key Findings from R&D Activities at Argonne National Laboratory for Seismic Isolation Bearings," ASME PVP 96, 1996.
6. Aikan, Ian D., Clark, Peter W. and Kelly, James M., Experimental Testing of Reduced-Scale KAERI Seismic Isolation Bearings, EERC, Univ. of California at Berkeley, August 1996.