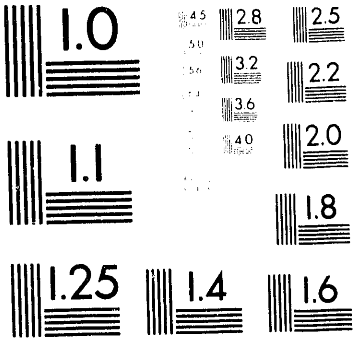
1.0
2.8
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FREQUENCY AND TEMPERATURE DEPENDENCE OF HIGH DAMPING ELASTOMERS

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1 INTRODUCTION

High damping steel-laminated elastomeric seismic isolation bearings are one of the preferred devices for isolating large buildings and structures. In the United States, the current reference design for the Advanced Liquid Metal Reactor (ALMR) uses laminated bearings for seismic isolation. These bearings are constructed from alternating layers of high damping rubber and steel plates. They are typically designed for shear strains between 50 and 100 percent and are expected to sustain two to three times these levels for beyond design basis loading conditions. Elastomeric bearings are currently designed to provide a system frequency between 0.4 and 0.8 Hz and expected to operate between -20 and 40 degrees Centigrade.

Over the past several years, the Engineering Mechanics Program of the Reactor Engineering Division of Argonne National Laboratory has been actively involved in research and development efforts related to the use of laminated elastomeric bearings for seismic isolation. An important area of this R&D effort is testing elastomer specimens. An Elastomer Testing Facility has been established at Argonne to perform high precision dynamic testing of small elastomer test specimens. Results from earlier research efforts were reported by Kulak and Hughes (1991), Kulak, Wang and Hughes (1991) and Kulak and Hughes (1992).

To assure proper performance of isolation bearings, it is necessary to characterize the elastomer's response under expected variations of frequency and temperature. We must characterize the dynamic response of the elastomer within the frequency range that spans the bearing acceptance test frequency, which may be as low as 0.005 Hz, and the design frequency. Similarly, the variation in mechanical characteristics of the elastomer must be determined over the design temperature range, which is between -20 and 40 degrees Centigrade. This paper reports on (1) the capabilities of a testing facility at ANL for testing candidate elastomers, (2) the variation with frequency and temperature of the stiffness and damping of one candidate elastomer , and (3) the effect of these variations on bearing acceptance testing criteria and on the choice of bearing design values for stiffness and damping.

2 DEFINITION OF SHEAR STIFFNESS AND DAMPING RATIO

Two quantities that characterize the behavior of an isolator are the shear stiffness and the energy dissipation. The shear stiffness of the isolator is a quantity that governs the fundamental horizontal frequency of a base isolated system, and the energy dissipation controls the amplitude of the system, primarily at the fundamental system frequency. Because of the relatively high shear modulus of the steel, it is the shear modulus of the elastomer that determines the shear stiffness of the bearing. There are several different definitions being used for this quantity. In this paper the effective shear modulus, G_{eff}, is used, and it is given by

$$G_{eff} = \frac{\Delta\tau}{\Delta\gamma} = \frac{\tau^{+}_{max} - \tau^{-}_{max}}{\gamma^{+}_{max} - \gamma^{-}_{max}} \tag{1}$$

where τ^{+}_{max} and τ^{-}_{max} are the maximum positive and negative shear stresses, respectively, and γ^{+}_{max} and γ^{-}_{max} are the maximum positive and negative shear strains, respectively. Energy dissipation is an important property of isolation systems, and it can be characterized as the energy dissipated during a cycle, W_D. For elastomeric isolation systems, linear analysis is often performed to evaluate performance for strain levels of 100 percent or less. For linear analysis, a damping ratio is useful and we are using an effective damping ratio , β, that is given by

$$\beta = \frac{W_D}{2\pi W_S} \tag{2}$$

where W_S is the energy stored during a cycle.

3 TESTING FACILITIES

The experimental work performed at the Elastomer Testing Facility of Argonne National Laboratory is on small specimens in the three-bar-lap configuration. The tests are performed on one of Instron Corporation's new generation of 8500 series universal testing instruments which use a computer-based system to provide full digital control of the machine. The servohydraulic machine has a 5kip actuator and sufficient hydraulic supply to test at frequencies up to 100 Hz. The machine is connected to a 386DX computer that has been programmed for test control, data acquisition and data processing. A small environmental chamber only large enough to contain the specimen and its holder is mounted on the testing machine to carry out the testing at temperatures that can range from -73 to 204 degrees Centigrade. The chamber is heated by electrical resistance heaters and cooled using the vaporization of liquid CO_2.

To obtain data useful for earthquake type loading, fully reversed cyclical testing must be performed. The determination of the shear response of the elastomer requires the use of a three-bar -lap shear specimen (Fig. 1) that retains stability during reversed cyclical loading. There are two rubber pads in the specimen each being, nominally, 1 × 1 × 0.2 inches. ANL currently uses this design for all its elastomer testing and requires this type of specimen in the specifications for procurement of full-sized isolators.

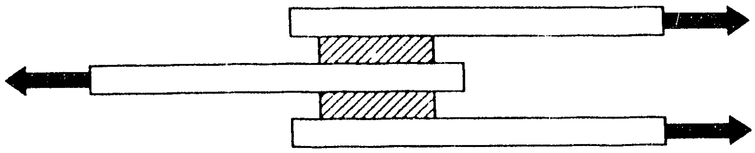

Fig. 1. Three-Bar-Lap Shear Specimen

4 FREQUENCY TESTS

Recent experience has shown that the frequency range for performance evaluation must consider the manufacturing process and the type of bearing testing equipment available at the plant as well as the isolation system design frequency. For example, the design frequency of a typical isolated structure is between 0.4 and 0.8 Hz. Bearing manufacturers, however, do not have test machines that can operate in this frequency range with full-size bearings. Typically, manufacturers perform stiffness tests at a frequency of approximately 0.005 Hz, which is two decades lower than current design frequencies. Currently, technical specifications for bearing procurement require that the effective modulus of the elastomer be within 10 percent of the design value. However, should an elastomer compound have a frequency dependance greater than 10 percent, then bearings that would satisfy the design performance values at the design frequency would fail during the acceptance test. Therefore, all candidate elastomers must be tested to determine their sensitivity in a frequency band that includes the bearing acceptance-test frequency and the design frequency.

All results presented in this paper are from tests on a single specimen of a candidate elastomer for the ALMR project. The specimen is one of a group of six purchased by ANL from the Oil States Industries Division of the LTV corporation in September, 1989. The compound is denoted as 243-62. The values of effective modulus are strongly influenced by the amount of time between tests and the amount of preliminary loading (scragging) immediately prior to a test. In order to get consistent results that isolate the effect of variation in frequency, all tests were performed at room temperature to 100% strain with a sinusoidal loading. All results presented here are for the sixth load cycle. Figure 2 displays the values of effective modulus for a group of tests from 0.002 Hz to 5 Hz. The curves on the figure connect data points from a series of tests that were separated by 24 hours. The lower curve shows the reduction in modulus caused by 30 cycle scragging immediately prior to the 6 cycle test. The individual

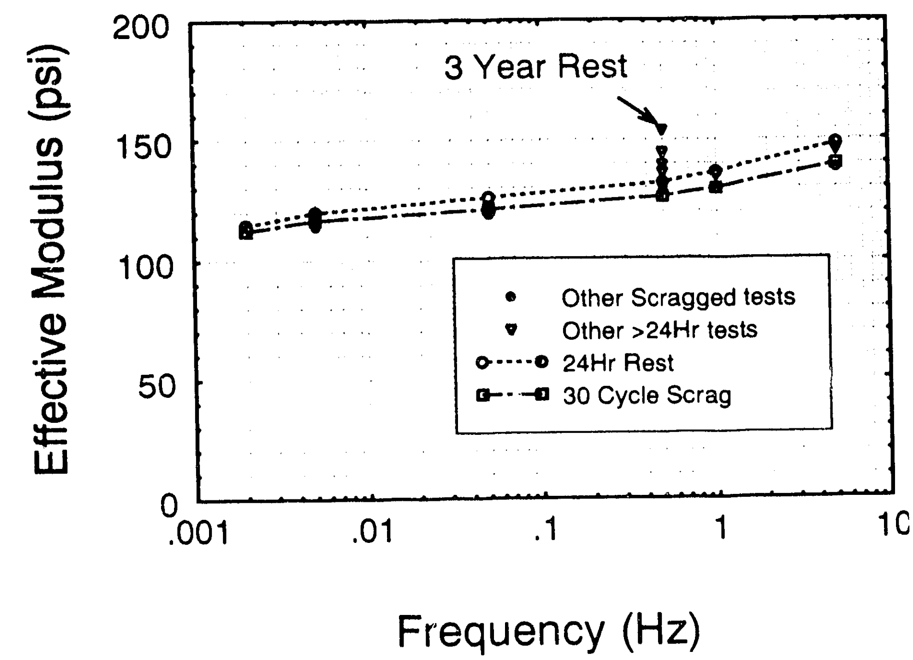

Fig. 2. Variation of Effective Modulus with Frequency

points plotted on the figure are for other tests with various rest periods prior to the test. It is interesting to note the point at .5 Hz and 154 psi is for the very first test ever performed on the specimen about three years after it was fabricated. Figure 3 shows the effective damping ratio for these same tests. The close clustering of the data points for each frequency demonstrates that the amount of rest time prior to the test has insignificant effect on the damping. Even the initial test on the virgin specimen gave a value in the middle of all the other tests at 0.5 Hz.

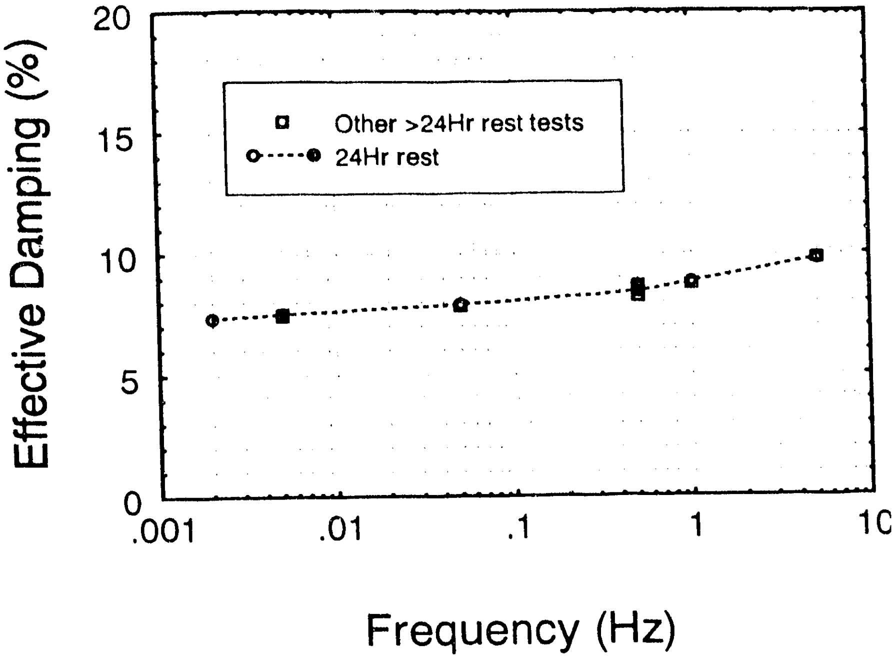

Fig. 3. Variation of Damping with Frequency

5 TEMPERATURE TESTS

Seismic isolation bearings in service are often exposed to the full range of environmental temperatures. The influence of temperature on stiffness and damping was determined for the same specimen used in the frequency variation tests. All tests were performed at 0.5 Hz and at both 50% and 100% strain. Because of the expense of cooling the environmental chamber a group of tests at a particular strain were conducted in one day over the entire temperature range. The results are presented in Figs. 4 and 5. The effective modulus values show a significant

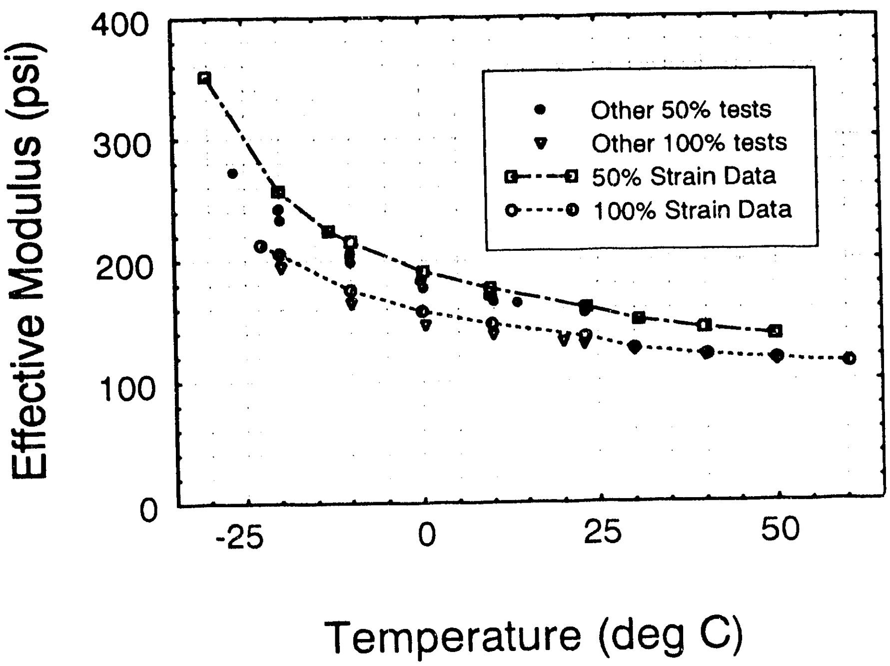

Fig. 4. Variation of Effective Modulus with Temperature

increase as the temperature is reduced. Although we have not had time to perform many tests below -20°C, our results suggest that the crystallization temperature for this compound is below the design range. It is important to determine this value and we will be performing such tests since our equipment can go down to -70°C. The unconnected data points (triangles) for the 100% tests illustrate the effect of temperature on recovery. The tests denoted by triangles had short rest times and at temperatures below room temperature yielded lower values of effective modulus while the material recovers rapidly at temperatures above 30°C yielding identical values of modulus. The effective damping ratio shows a significant increase with lower temperatures and this is very evident in the shape of the hysteresis loops. The hysteresis loops for the sixth cycle at two different temperatures are shown in Fig. 6.

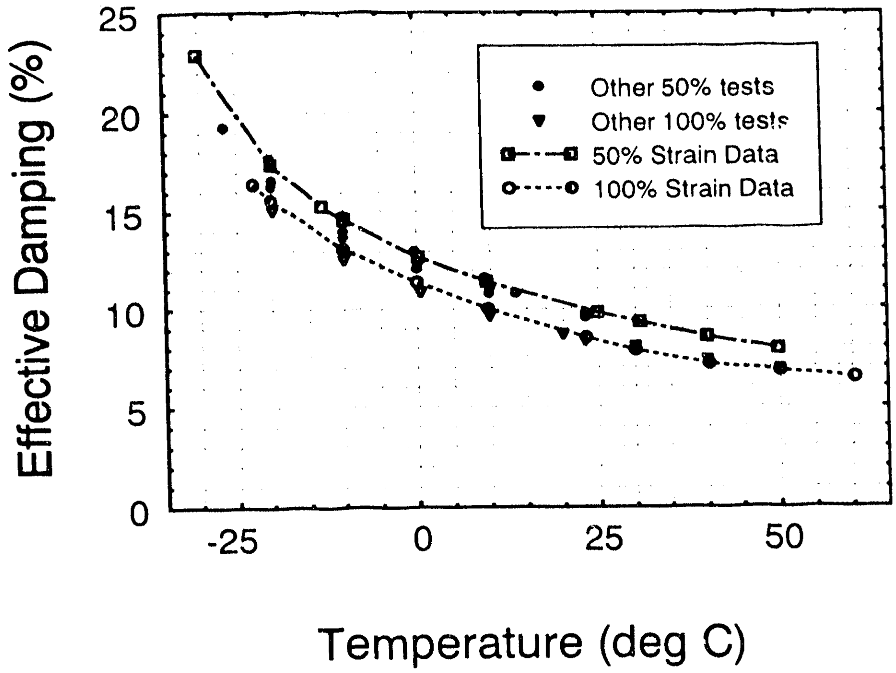

Fig. 5. Variation of Damping with Temperature

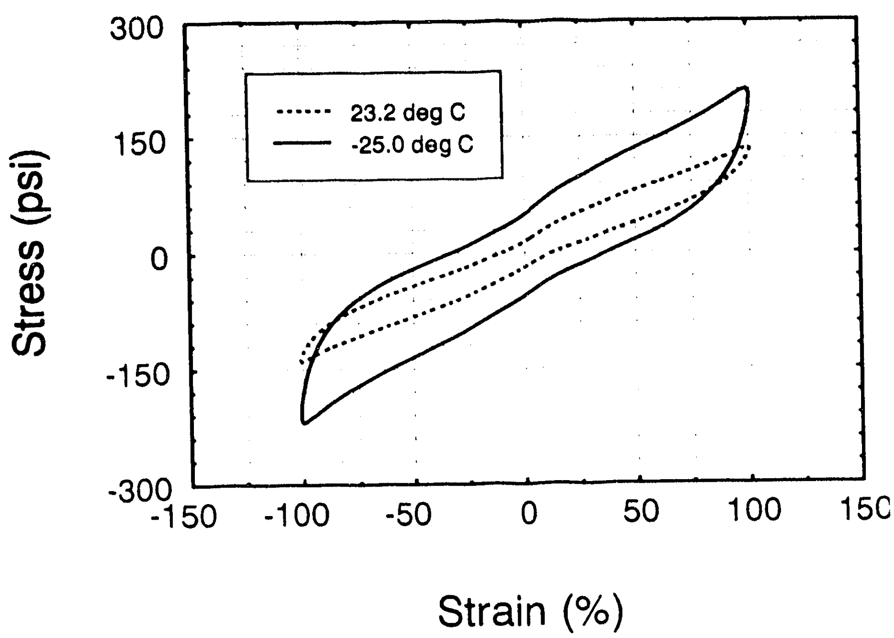

Fig. 6. Hysteresis Loops for 100% Shear Strain

6 CONCLUSIONS

Some key findings of the research are summarized below. The frequency dependence of the tested elastomers was insignificant for the range of frequencies relevant to seismic isolation. But, a significant variation exists over the frequency range that includes the bearing acceptance-test frequency and the design frequency. This result has lead to a modification of the acceptance testing procedure to assure that bearings are produced with the required values of stiffness and damping at the design frequency. The tested elastomers exhibit variations in both stiffness and damping over the design temperature range. By accounting for the temperature variation of the elastomer in the design process, seismic isolation system designer can optimize the performance over the design temperature range.

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