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CHARACTERISTICS OF MECHANICAL DAMPERS

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SUMMARY

Presented in this paper are the dynamic characteristics of four mechanical damping devices. Two of the devices tested were direct shear seismic dampers (DSSD) which utilize viscoelastic materials in pure shear as the mode of energy dissipation. The other two devices were of the steel plate added damping and stiffness (ADAS) type. These latter devices depend upon cyclic yielding of their steel plate elements for energy absorption. Dynamic characteristics of interest reported include the equivalent viscous damping coefficient, linear elastic stiffness and hysteretic stability of the devices. The influence of excitation frequency, displacement or strain amplitude and prior energy absorption on these parameters is also examined.

INTRODUCTION

For years it has been recognized that damping in building structures has been beneficial by limiting the maximum responses of the structures when subjected to earthquake induced ground motion. Recent analytical and experimental investigations suggest that it is possible to significantly increase damping in buildings through the use of mechanical damping devices (Refs. 1,2,3).

The development and characterization of these devices has lead to a new seismic design philosophy which relies upon increasing the energy dissipation capacity of a structural frame as opposed to relying upon increased stiffness and ductility (Ref. 4). In other words, the earthquake input energy can now be consumed by the deformation of these nonstructural mechanical dampers as opposed to being consumed by the yielding of and damage to main stuctural members.

Two basic types of mechanical damping devices have been tested extensively (Ref. 5). Partial results from the experimental investigation are reported and analyzed below.

EXPERIMENTAL PROGRAM

Device Descriptions The DSSD consists of two rectangular pads of viscoelastic material sandwiched between three steel plates. The DSSD is configured and installed in a building frame such that interstory drift causes the steel plates to move relative to each other, thus shearing the damping material. Specimen #4 was a DSSD with two pads of a polymer formulated by Minnesota Mining and Manufacturing (3M). Each pad was 0.5 inches thick by 4 inches wide by 10 inches long for a total viscoelastic volume of 40 cubic inches. Specimen #9 was a DSSD with two pads of a Lord Corporation elastomer. Each pad measured 0.5 inches by 4 inches by 4 inches for a volume of 16 cubic inches. The ADAS device is assembled from individual X-shaped steel plates and installed in a building frame such that interstory drift places the steel elements into reverse curvature bending. Yielding occurs at the top and bottom of the specimen and plasticity spreads to the middle of the steel elements due to the shape of their cross section. More detailed descriptions of the devices can be found in the literature (Refs. 2,4,5).

Tests Conducted The DSSD tests were conducted in a 110 kip Instron servohydraulic test frame. The individual tests consisted of cycling the specimen with a sinusoidal displacement signal of constant amplitude and frequency. For each of the twenty cycles per test forty load and corresponding displacement points were taken with a high speed digital data acquisition system. Temperature data was recorded with a digital thermometer. The ADAS tests consisted of the cyclic forced vibration of a single story frame in which an ADAS device had been added. Prior testing of the frame alone indicated that its hysteretic properties were negligible compared to that of the ADAS specimens. Again, 40 load and corresponding displacement points were taken for each cycle of excitation.

DYNAMIC CHARACTERISTICS

The data points taken for each test were used to generate hysteresis curves for the specimens. Some representative curves are shown in Fig. 1. The data was also used to determine the equivalent viscous damping coefficient, C_{eq}, which is proportional to the area enclosed by the hysteresis loop and the linear elastic stiffness, K, which is proportional to the slope of the major diameter of the force versus displacement ellipse.

Hysteretic data for DSSDs #4 and #9 are given in Tables 1 and 2, respectively. Included in the tables for each test are the frequency of excitation, f (cycles per second), the cyclic shear strain, SS (percent), the average material temperature and its change during the test, T_{ave} and ΔT (degrees Fahrenheit), the equivalent viscous damping coefficient, C_{eq} (kip-seconds per inch) and its coefficient of variation, cov and finally the stiffness, K (kips per inch) and its coefficient of variation. The coefficients of variation, calculated as the standard deviation divided by the mean value of the cyclic data, are indicators of the change in damping and stiffness of the device during one test.

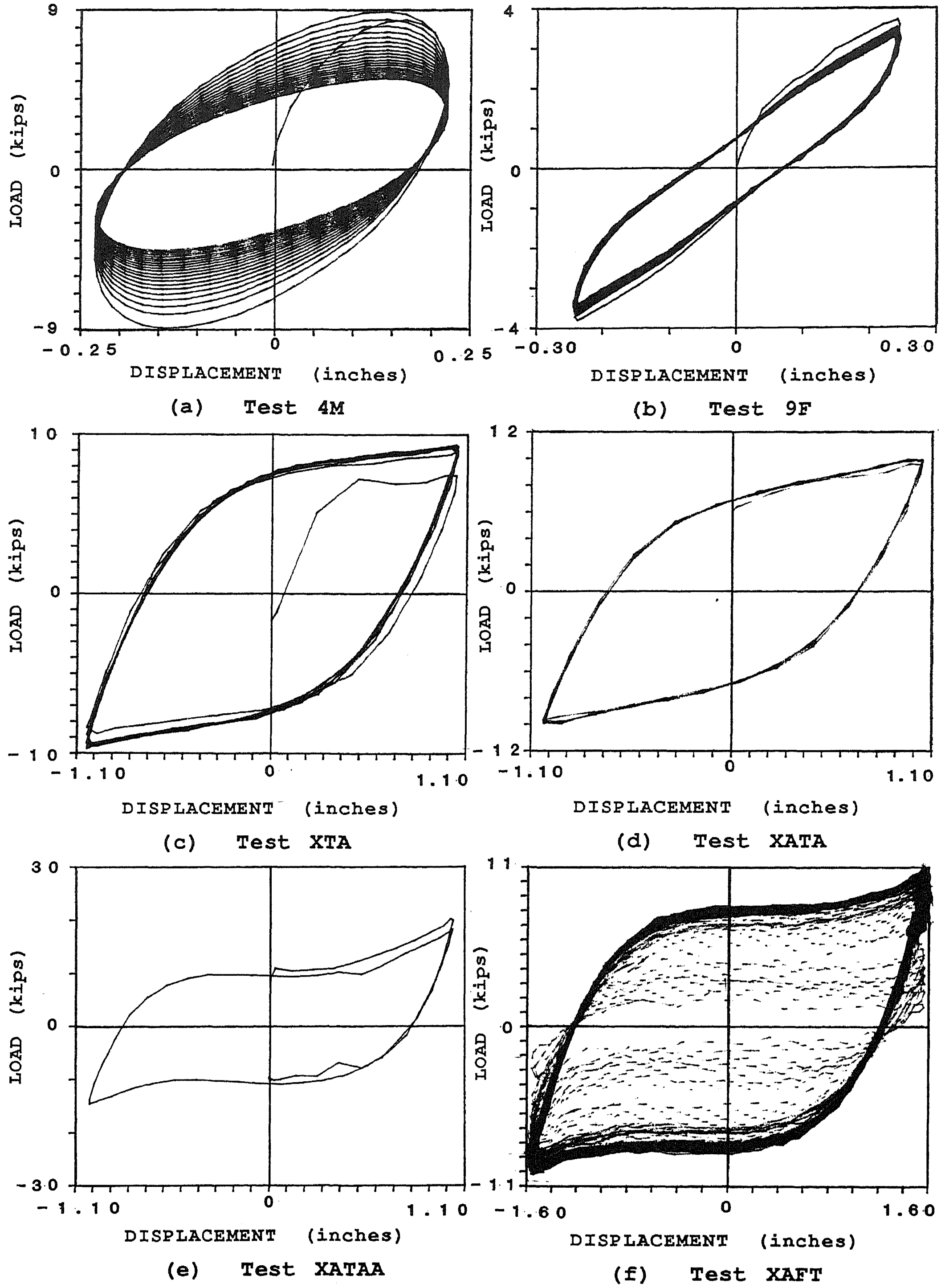

Fig. 1 Hysteresis Curves for Mechanical Dampers

Table 1 Hysteretic Data for Direct Shear Seismic Damper #4

Test	f (Hz)	SS (%)	T_{ave} (Fahrenheit)	ΔT	C_{eq} (kip-sec/in)	cov	K (kip/in)	cov
4A	0.10	50	79.0	1.9	10.70	0.02	6.88	0.02
4B		100	81.7	6.3	8.66	0.09	5.76	0.08
4C		200	87.2	15.3	5.60	0.23	3.68	0.22
4J	0.50	50	77.1	5.6	5.91	0.14	14.56	0.12
4K		100	81.1	13.8	3.46	0.32	9.44	0.27
4L		200	89.7	23.3	1.32	0.50	4.16	0.42
4M	1.00	50	79.0	4.2	3.57	0.15	16.80	0.18
4N		100	83.0	14.1	1.94	0.42	10.24	0.36
4O		200	89.0	24.1	0.71	0.64	4.64	0.55

Table 2 Hysteretic Data for Direct Shear Seismic Damper #9

Test	f (Hz)	SS (%)	T_{ave} (Fahrenheit)	ΔT	C_{eq} (kip-sec/in)	cov	K (kip/in)	cov
9A	0.10	25	71.0	1.1	8.35	0.02	17.79	0.02
9B	0.10	50	72.4	3.1	5.70	0.04	13.18	0.03
9C	0.50	25	72.6	1.8	1.71	0.01	17.02	0.01
9D	0.50	50	74.6	5.4	1.20	0.02	13.63	0.02
9E	1.00	25	73.4	1.7	0.88	0.01	17.41	0.01
9F	1.00	50	75.2	5.9	0.62	0.02	13.82	0.02

The hysteretic data for ADAS specimens X and XA are found in Tables 3 and 4, respectively. All of the ADAS tests were conducted at the same frequency due to the relative insignificance of strain rate affects on the hysteretic behavior of steel. For each test the cyclic amplitude, Δ (inches), the product of equivalent viscous damping and test circular frequency, $C_{eq}\omega$ (kips) and linear elastic stiffness, K (kips/inch) are listed. The parameter $C_{eq}\omega$ is meaningful due to the frequency independence of the hysteretic behavior of the ADAS device. In order to determine the equivalent viscous damping coefficient at a frequency different from the one used in the test, one simply divides $C_{eq}\omega$ by the desired circular frequency.

OBSERVATIONS

Due to the relatively large amount of data presented an exhaustive analysis is not practical, however some important observations can be made.

Table 3 Hysteretic Data for ADAS Specimen X

Test	f (Hz)	Δ (inch)	$C_{eq}\omega$ (kips/inch)	K (kips/inch)
XTA	0.33	±1.04	6.38	9.18
XTB		±0.84	6.48	10.68
XTC		±0.63	6.69	12.97
XTD		±0.42	6.29	17.21
XTE		±0.21	3.11	24.38
XTF		±0.11	1.59	30.91
XFT*		±1.56	5.41	7.74

*Average of all fatigue cycles

Table 4 Hysteretic Data for ADAS Specimen XA

Test	f (Hz)	Δ (inch)	$C_{eq}\omega$ (kips/inch)	K (kips/inch)
XATA	0.33	±1.03	5.98	9.65
XATAA		±1.03	10.51	16.87
XATBB		±0.82	10.92	15.57
XATCC		±0.62	12.25	16.17
XATDD		±0.42	14.05	20.54
XATEE		±0.21	12.61	33.45
XATFF		±0.11	7.18	46.73
XAFT*		±1.57	4.89	7.94

*First 40 cycles of 70 total

Examination of the data in Table 1 indicates that both the damping and stiffness of DSSD #4 are greatly affected by the test frequency and strain amplitude. The large coefficients of variation of the mean values of damping and stiffness indicate a significant change in these properties as the test progresses or as more and more energy is dissipated. However, the data in Table 2 indicates that only the damping of DSSD #9 is highly dependent upon frequency and strain amplitude. The low values of the coefficients of variation in Table 2 indicate that the properties of DSSD #9 are unaffected by the amount of energy absorbed.

Examination of the data in Tables 3 and 4 indicates that the damping and stiffness of both ADAS devices are relatively constant within the range of displacement amplitudes of ±0.6 to ±1.0 inches.

The tremendous fatigue resistance of ADAS specimen XA can be seen in Fig. 1(f) in which the device survived approximately forty cycles of severe cyclic excitation before its hysteretic behavior began to deteriorate.

CONCLUSIONS

The following conclusions can be drawn from the experimental data reported herein:

1. Mechanical damping devices exist which can be used to introduce significant amounts of damping to building frames for improved structural response to earthquake input.
2. The damping and stiffness of some viscoelastic DSSDs can be strongly dependent upon excitation frequency, shear strain level and cumulative energy dissipated while other DSSDs may be less affected by these variables.
3. The damping and stiffness of steel plate ADAS devices appear to be independent of displacement amplitude over a relatively broad range of this variable. The hysteretic behavior of the ADAS devices was unaffected by the cumulative energy dissipated. The fatigue resistance of the devices would be adequate for even the most severe seismic applications.

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