FLUID VISCOUS DAMPER FOR IMPROVING THE EARTHQUAKE RESISTANCE OF BUILDINGS

by

M.C. Constantinou and M.D. Symans

Department of Civil Engineering
State University of New York
Buffalo, NY 14260

and

D. Taylor

Taylor Devices, Inc.
90 Taylor Drive
North Tonawanda, NY 14120

Structures Congress 93
Irvine, CA, April 1993

FLUID VISCOUS DAMPER FOR IMPROVING THE EARTHQUAKE RESISTANCE OF BUILDINGS

M.C. Constantinou,[1] M.D. Symans[2] and D.P. Taylor[3]

Abstract

Experimental results are presented which demonstrate that the use of fluid dampers as add-on devices in moment resisting frames substantially increases damping and reduces seismic story drifts, story shear forces, and floor accelerations.

Introduction

Various damping devices have been proposed as add-on devices to buildings for improving earthquake resistance. Most notable of these devices are mild steel dampers, frictional dampers and constrained-layer viscoelastic shear dampers (Whittaker 1989, Aiken 1990, Chang 1991). Experimental studies demonstrated that these dampers are effective in reducing drifts while maintaining shear forces at the same lever or, under certain conditions, less than those of structures without dampers. However, due to their hysteretic or strong viscoelastic behavior, these devices introduce a substantial axial force component which is in phase which the maximum bending moment in columns.

Fluid dampers may be designed to behave as linear viscous devices and, thus, they introduce damping forces which are out-of-phase with drifts and column bending moments. Accordingly, they can be very effective in reducing both drifts and shear forces without introducing axial column forces which are in-phase with column bending moments. These significant properties of fluid viscous dampers have been confirmend in shake table testing of a series of 1-story and 3-story model structures (Constantinou 1992). The experimental results demonstrated reductions of

1,2 Assoc. Professor and Graduate Student Dept. of Civil Engrg., State Univ. of New York, Buffalo, NY 14260

3, President, Taylor Devices, N. Tonawanda, NY 14120

drifts and shear forces of the order of 2 to 3 in comparison to the response of the models without dampers for a wide range of earthquake input motions. This paper presents a summary of the shake table testing of the 3-story structure with and without fluid dampers.

Description of Fluid Damper

Hydraulic damping devices which utilize fluid flow through orifices have found numerous applications in shock isolation of military hardware, shock and vibration isolation of vehicles and in the wind vibration control of military structures such as missile launching platforms.

The construction of this device is shown in Figure 1. It consists of a stainless steel piston with bronze orifice head and an accumulator. It is filled with silicon oil. The orifice flow is compensated by a passive bi-metallic thermostat that allows operation of the device over a temperature range of -40°C to 70°C. This construction originated within a product used in a classified application on the U.S. Air Force B-2 Stealth Bomber. The performance characteristics of the device are considered as state-of-the-art in hydraulic technology.

The tested fluid dampers utilized an orifice called Fluidic Control Orifice, a design which is capable of delivering damping forces linearly proportional to the velocity. Thus, the devices behaved as linear viscous dampers. This behavior dominated for frequencies of motion below a predetermined cutoff frequency (related to the characteristics of the accumulator valves). Beyond this frequency (set at about 4 Hz), the fluid dampers exhibited strong stiffness in addition to substantial ability to dissipate energy. The existence of the cutoff frequency is desirable, since the lower modes of vibration are only damped while the higher ones are both damped and stiffened so that their contribution is completely suppressed.

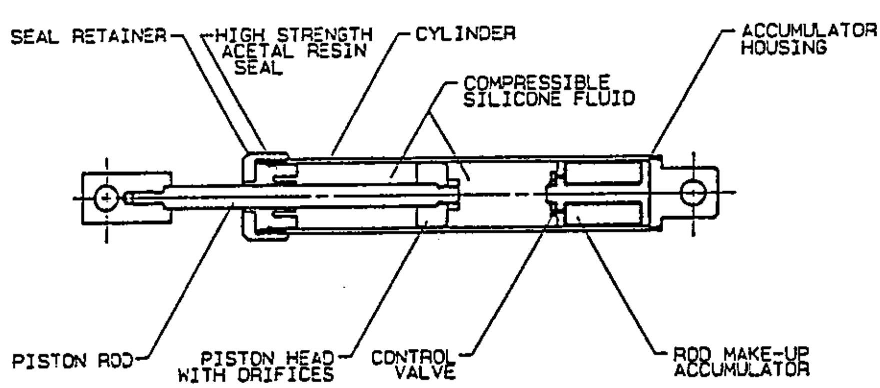

Figure 1. Construction of Fluid Damper

A mathematical model capable of describing the behavior of fluid dampers is the simple Maxwell model:

$$P + \lambda \dot{P} = C_0 \dot{u} \qquad (1)$$

where P = force, $\dot{u}$ = velocity, C_0 = damping constant at zero frequency and λ = relaxation time. The term $\lambda\dot{P}$ accounts for the stiffening of the device at frequencies above the cutoff limit. Typically, λ is very small (6 msecs in the tested device), and the cutoff frequency is larger than the frequencies of the significant modes so that the term $\lambda\dot{P}$ may be neglected for practical purposes.

The fact that the behavior of the tested fluid dampers is essentially linear viscous, is demonstrated in the test results of Figure 2. The peak force needed to maintain harmonic motion of the piston is plotted against the peak velocity of motion for three different temperatures. Evidently, the behavior is linear viscous to large velocities. Furthermore, the device exhibits this behavior over a wide range of temperatures. Apparently, temperature has a minor effect of the mechanical properties of the device.

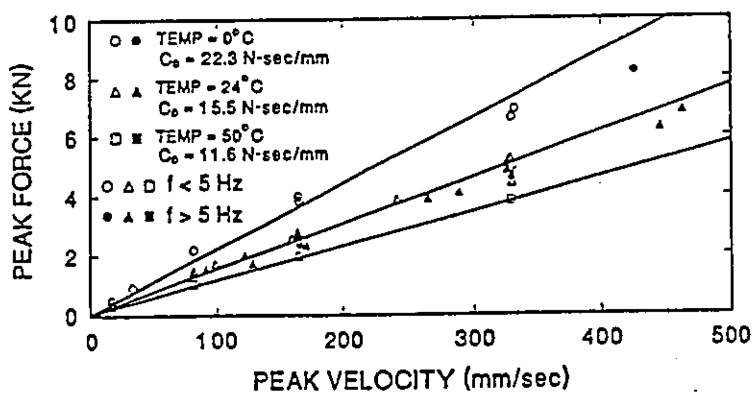

Figure 2 Mechanical Properties of Fluid Damper

Shake Table Test Results

The 3-story model structure used in the testing is the same one which was previously used in active control tests. At quarter length scale, the model had total weight of 28.5 kN, which was equally distributed to the three floors. The model was tested without dampers and with dampers installed as braces at an angle of about 35°. Tests were conducted with four dampers installed at the first story and with six dampers installed in pairs at each story. The dynamic characteristics of the structure were determined in small vibration amplitude tests and are listed in Table 1. Evidently, the addition of fluid dampers substanitally increased the damping ratio of the structure and also stiffened the higher modes (damper cutoff frequency about 4 Hz).

Table 1. Properties of Tested Structure under Elastic Conditions

Frequency and Damping Ratio	Without Dampers	With 4 Dampers	With 6 Dampers
Mode 1	2.00 Hz, 0.018	2.11 Hz, 0.177	2.03 Hz, 0.194
Mode 2	6.60 Hz, 0.008	7.52 Hz, 0.319	7.64 Hz, 0.447
Mode 3	12.20 Hz, 0.003	12.16 Hz, 0.113	16.99 Hz, 0.380

Table 2 presents a sample of recorded peak response values of the tested structure. The excitation consisted of recorded earthquakes which were time compressed by a factor of 2 and scaled in peak acceleration by the shown percentage figure. An examination of the results in Table 2 reveals that the addition of fluid dampers resulted in a two-fold to three-fold reduction of the peak response of the bare frame. Particularly interesting is the reduction in story shear forces. It should be noted that the shear forces include the contribution from the damper forces.

Figure 3 shows side by side the response of the bare frame without dampers under El Centro 50% and of the frame with 6 dampers under El Centro 150%. Apparently, the addition of dampers increased the ability of the structure to resist this earthquake by a three-fold. Furthermore, the results of Figure 3 demonstrate that the addition of dampers had no effect on the stiffness of the structure. Rather, they only increased its energy dissipation capacity.

Figure 3 includes also analytical results on the response of the damped structure. In the analysis (see Constantinou, 1992 for details), the model of (1) was employed. Almost identical results were obtained in analyses in which the simpler viscous model (λ=0) was used. Evidently, the analytical results are in excellent agreement with the experiment.

Conclusions

Experimental results have been presented which demonstrate that fluid dampers are very effective in reducing the seismic response of structures to which they are added.

These dampers are characterized by the following properties: essentially linear viscous behavior, insensitivity to substantially temperature changes, and reliability and longevity as already demonstrated by several years of continuous use in the harsh environment of military applications.

Table 2. Peak Response of Tested Structure (Number in Parenthesis is Floor or Story at Which Peak was Recorded).

Excitation	No. Dampers	Accelera-tion (g)	Shear Force / Total Weight	Story Drift / Height (%)
El Centro 33%	0	0.417 (3)	0.220 (1)	1.069 (2)
El Centro 50%	0	0.585 (3)	0.295 (1)	1.498 (2)
Taft 100%	0	0.555 (3)	0.255 (1)	1.161 (1)
El Centro 50%	4	0.282 (3)	0.159 (1)	0.660 (2)
El Centro 100%	4	0.591 (3)	0.314 (1)	1.279 (2)
Taft 100%	4	0.246 (3)	0.130 (1)	0.638 (2)
El Centro 50%	6	0.205 (3)	0.138 (1)	0.510 (2)
El Centro 100%	6	0.368 (3)	0.261 (1)	0.998 (2)
El Centro 150%	6	0.534 (3)	0.368 (1)	1.492 (2)
Taft 100%	6	0.178 (3)	0.120 (1)	0.463 (2)
Taft 200%	6	0.348 (3)	0.235 (1)	0.921 (2)
Pacoima Dam 50%	6	0.376 (3)	0.275 (1)	1.003 (1)
Hachinohe 100%	6	0.334 (3)	0.256 (1)	0.963 (2)
Miyagiken 200%	6	0.342 (3)	0.254 (1)	0.963 (2)

References

Aiken, I.D. and Kelly, J.M. (1990). Earthquake Simulator Testing and Analytical Studies of Two Energy-Absorbing Systems for Multistory Structures. Report No. UCB/EERC-90/03, Earthquake Engineering Research Center, Berkeley, CA.

Chang, K.C., Soong, T.T., Oh, S-T and Lai, M.L. (1991). Seismic Response of a 2/5 Scale Steel Structure with Added Viscoelastic Dampers. Report No. NCEER-91-0012, National Center for Earthquake Engineering Research, Buffalo, NY.

Constantinou, M.C. and Symans, M.D. (1992). Experimental and Analytical Investigation of Seismic Response of Structures with Supplemental Fluid Viscous Dampers. Report No. NCEER-92-XXXX. National Center for Earthquake Engineering Research, Buffalo, NY.

Whittaker, A., Bertero, V., Alonso, J. and Thompson, C. (1989). Earthquake Simulator Testing of Steel Plate Added Damping and Stiffness Elements. Report No. UCB/EERC-89/02, Earthquake Engineering Research Center, Berkeley, Ca.

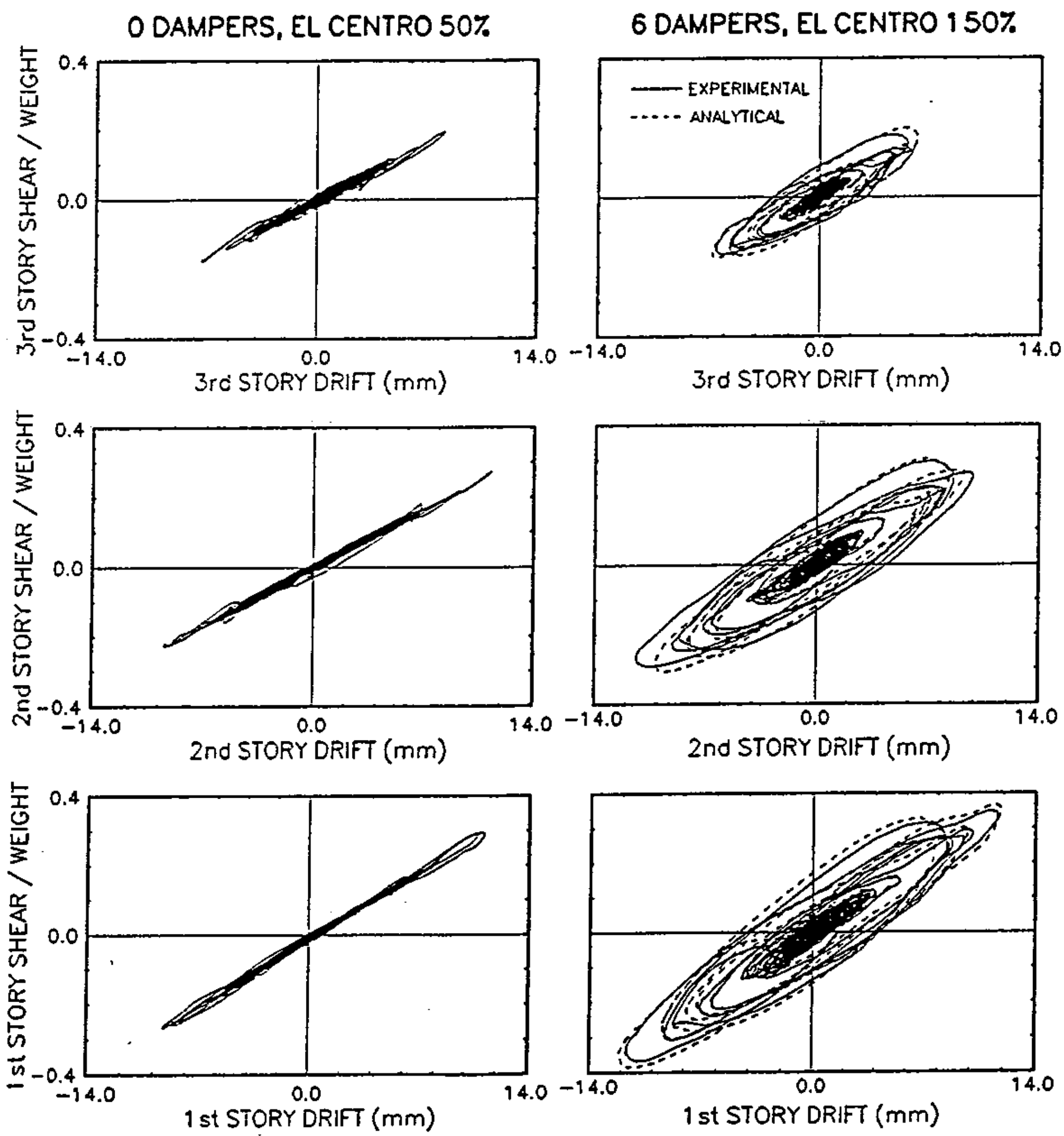

Figure 3. Response of Model without and with Fluid Dampers