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AN EXPERIMENTAL STUDY OF THE DYNAMIC CHARACTERISTICS OF VISCOUS FLUID DAMPERS FOR BASE ISOLATED BUILDING

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SUMMARY

This study was performed to obtain a numerical model for a viscous fluid damper from an experimental testing. The input signals for displacement were chosen as two types: a triangular and a sinusoidal forms. The performing test parameters were the area of the resistant plate, relative velocity between resistant plate and base plate, oil film thickness of the viscous fluid, but the temperature effect was neglected. The numerical model was established by assuming an non-Newtonian fluid behavior. The test results were summarized by the equation of $F = 0.0308A(V/d)^{0.5125}$. Using the obtained formula, the procedure to apply the viscous fluid damper for a real structure design was introduced. And, the developed models were considered to resolve the problem that was taken place at the dynamic characteristic test for the first model.

INTRODUCTION

The idea that buildings can be protected from the damaging effects of earthquakes by using some type of support that uncouples it from the ground is an appealing one, and many base isolation systems have been invented over the past century to produce this effect.

There are two basic types of isolation systems: elastomeric bearings and sliders, and elastomeric bearing is the most widely adopted system. The concept of this bearing is followed; it gives the structure a fundamental frequency that is much lower than both its fixed-base frequency and the predominant frequencies of the ground motion. The first dynamic mode of the isolated structure involves deformation only in the isolation system and the structures above the isolation system behaves a rigid body motion. The higher modes that produce deformation in the structure are orthogonal to the first mode and to the ground motion, and do not participate in the isolated system motion. Therefore, the isolation bearing alters the earthquake energy at higher frequencies through the dynamics of the system.

But, the flexibility given by isolation system produces a large seismic deformation in the isolation system, the damping devices are additionally needed to reduce the displacement. The internal damping of bearing, hydraulic damper, steel bar, or lead plug within the bearing itself have been used to give the damping to the isolated structures. In this paper, a viscous fluid damper was devised following the procedure specified in Figure1.

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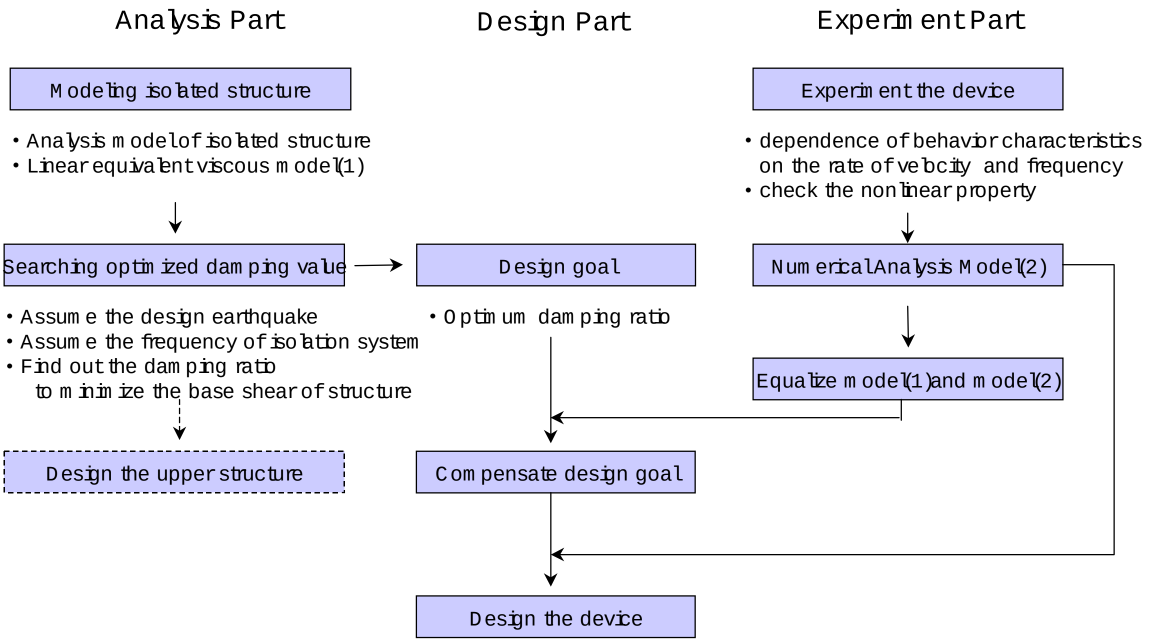


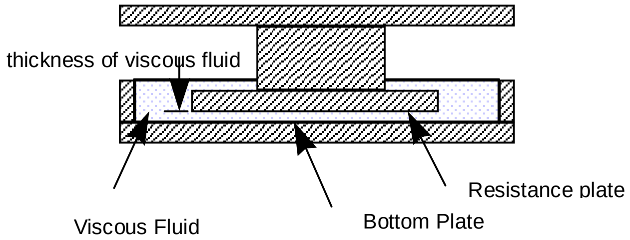
Figure 1 : The procedures to design a viscous fluid damper for a base isolated structure

SINGLE LAYER DAMPER

Design procedure

The first viscous damper model, as shown in Figure 2, was designed with a single resistance plate to establish a pure shear behavior between the viscous material and resistance plate.

$$\mathbf{F = 0.42\, e^{-0.043T}\, A\, (V/d)^{0.59}} \qquad \mathbf{(1)}$$



A : Area of resistance plate(cm^2)
F : Shear Resistance Force (Kgf)
T : Viscous fluid temperature(c^o)
V : Relative velocity of resistance and bottom plate (cm/sec)
d : Thickness of viscous fluid (cm)

Figure 2 : The schematic and numerical model of the first viscous damper model

Test procedure

The damping force of the viscous damper is dependent on the horizontal relative velocity between the bottom plate and resistance plate, the area of the plate, viscosity, and the thickness of the viscous fluid film. Therefore, the test procedure was established as tabulated in Table 1 so that the effect on the design parameters of the viscous damper is evaluated to make a numerical model. The viscous material is silicon-based oil, and the viscosity was 10,000 poise. The temperature effect was ignored.

TABLE 1 : TEST PROGRAM

Test model	Diameter of the resistance plate(cm)	Input signal for the displacement		Input displacement (cm)
		Sin(Hz)	Saw-tooth(cm/s)	
R16D10	φ 16	1	1, 5, 10, 15, 20	3, 5
R16D5	φ 16	1	1, 5, 10, 15, 20	3, 5
R22D10	φ 22	1	1, 5, 10, 15, 20	3
R22D5	φ 22	1	1, 5, 10, 15, 20	3

Test result and numerical model

Experimental approach

When two parallel plates in the viscous fluid make relative movement in the direction of their surface, velocity gradient occurs between the two plates in the direction perpendicular to their movement. If the viscous fluid material is Newtonian fluid, the relationship between the velocity gradient and viscous shear stress is represented by Eq(2). But, the silicon oil shows Non-Newtonian behavior that apparent viscosity (η) varies with velocity gradient (dv/dy), as shown Eq(3).

$$\tau = \eta \frac{dv}{dy} \tag{2}$$

Therefore, relations between resisting force and velocity are given by Eq(3) and Eq(4)

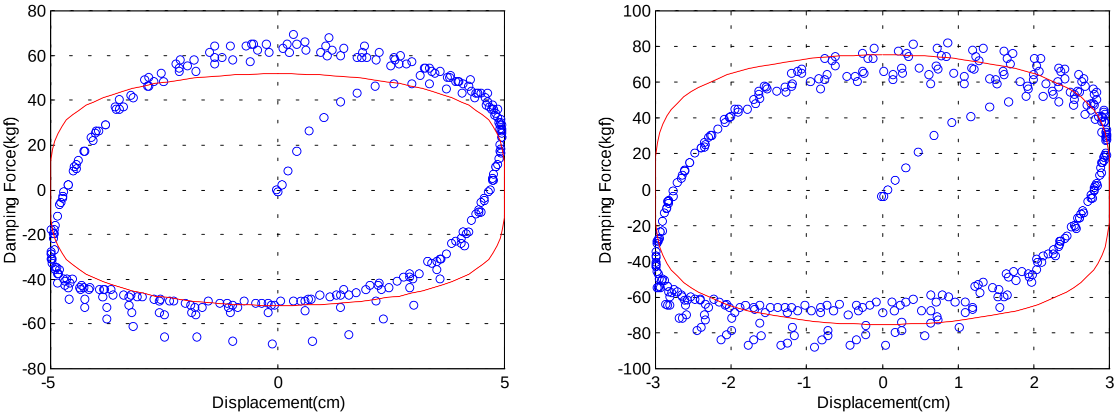
$$\eta \propto \left(\frac{dv}{dy}\right)^{-n} \tag{3}$$

$$F \propto \left(\frac{v}{d}\right)^{\alpha} \tag{4}$$

where, τ is viscous shear stress, η is viscosity, n < 1, F is damping force.

The damping force of the viscous fluid damper is assumed by the equation of ($C \cdot A \cdot (v/d)^{\alpha}$) and the curve fitting is performed for the test result of a constant velocity (saw-tooth) about the design parameters. The Eq(5) represents the regression analysis result and the comparison between the experimental and numerical damping force is indicated in Figure 3.

$$F = 0.0308A(v/d)^{0.5125} \quad \text{(kgf)} \tag{5}$$



(a) R16D5 **(b) R22D5**

Figure 3 : Comparison between the damping forces of the experiment and numerical model

Design approach

The equivalency of non-linear characteristics to linear ones was performed so that the linear analysis of a structure has relationship to the numerical model developed by the experimental approach. It is assumed that a cyclic energy for a sine-wave is equivalent to the consumed energy per cycle by the damper, which is specified by Eq(6). Substituting **α** into Eq(6) gives the equivalent damping coefficient C_{eq} as shown in Eq(7).

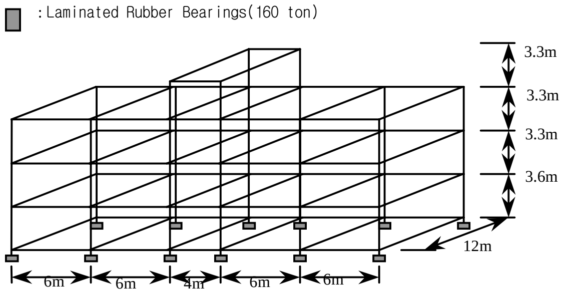
$$\oint K v^{\alpha}\, dx = \oint C_{eq} v\, dx \tag{6}$$

$$C_{eq} = 1.1095\, K (v_{\max})^{-0.4875} \tag{7}$$

Design example

The example building is a steel structure building of three stories and it is supported by the elastomeric bearings.

The arrangement and shape of the bearings is shown in Figure 4 and Figure 5. The design vertical load of each bearing is 160 ton and the frequency of the base isolation system is designed to be 0.5Hz.



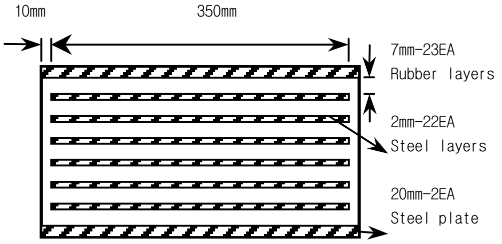


Figure 4 : Arrangement of base isolation system **Figure 5 : Shape of the bearing**

Time history analysis

The ground motion for El Centro 1940 NS was used as the input signal, and time history analysis with a linear model was performed along with the damping ratio ranges of 0% ~ 50%.

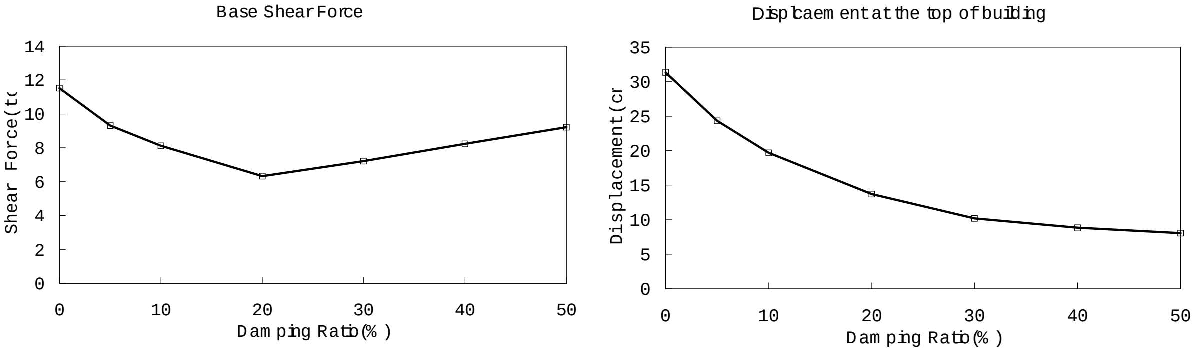


Figure 6 : Time history analysis results of the building

With the increase of the constant damping ratio, the calculated displacement at the top of building was decreased. However, the base shear force was showed in a different pattern with the minimum value at the damping ratio of 20%. For the damping ratio 20%, the maximum displacement and velocity of the isolation system were calculated as 12.03cm and 44.57 cm/s respectively.

Dimension of damper

From the time history analysis result for the example building the optimum damping ratio was obtained 20%. The required size of a damper for 20% damping ratio can be obtained from Eq(5) and it is designed as thickness of the viscous fluid film 0.5 cm and the diameter of the resistant plate 18 cm.

HIGH PERFORMANCE DAMPER

High viscous fluid

There are several ways to increase the damping force of a damper and one method is to use higher viscous fluid. This method is still under development it is expected that the results will be presented in some other paper.

Multiple layers viscous fluid damper

Design procedure

Another method to increase the damping force is to use multiple layers of resistance plates and it was designed the second model as shown in Figure 7. The extension of the numerical model for a single layer damper in Eq(5) gives the numerical model for multiple layers damper as given in Eq(8).

$$F = 0.0488e^{-0.023t}(A_b + N \times A_l)(v/2d)^{0.5125} \quad kgf \qquad (8)$$

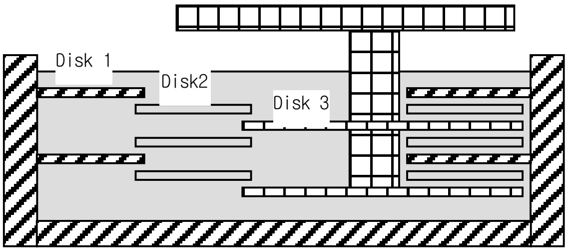


Figure 7 : Schematic design of a multiple layers viscous damper

A_b : Projective area between disk 3 and housing plate(cm^2)
A_l : Effective projective area of the disk 2
t : Viscous fluid temperature(c^o)
v : Relative velocity of disk 3 and housing (cm/sec)
d : Thickness of viscous fluid (cm)
N : Number of the disk 2(ie, 3,5,7,·······)

EXPERIMENTAL PROCEDURE

Test Program

Assuming that all the test conditions are the same as the single layer viscous fluid damper, the tests were performed according to the test procedure specified in Table 2.

Table 2 : Test program for the multiple layers viscous fluid damper

Test type	Input signal for the displacement		Input displacement(cm)
	Frequency(Hz)	Saw-tooth(cm/s)	
Dependency of the frequency	0.1, 0.2, 0.3, 0.4, 0.5, 0.6 0.7, 0.8, 1.0, 1.2, 1.6, 2.0	-	
Dependency of the velocity	-	0.5, 1, 2, 4, 8, 10, 12, 16	4

Test Result and Numerical Model

From the same procedure as the previous model, the Eq(9) represents the regression analysis result and the compression between the test and numerical damping force is indicated in Figure 8.

$$F = 0.2489\,(A_b + N \times A_l)(v/2d)^{0.5156} \qquad \text{(kgf)} \qquad (9)$$

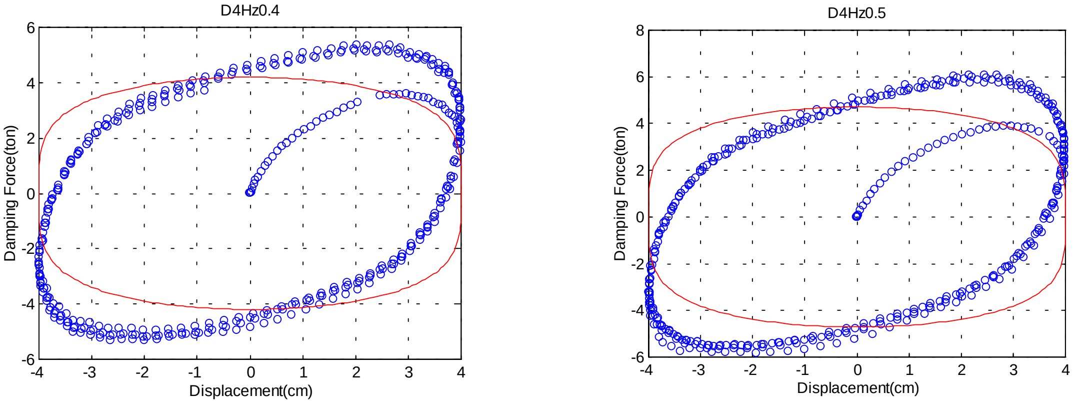


Figure 8 : Comparison between the damping forces of the experimental and numerical model

CONCLUSION

To reduce the displacement of a base isolated building viscous fluid dampers were designed and tested. The design procedure of a viscous damper was established and the parameters to affect the damping force were identified.

(1) The numerical model of a single layer viscous damper model neglecting the temperature effect was obtained from the experimental regression analysis process as

$$F = 0.0308A(v/d)^{0.5125} \qquad \text{(kgf)}$$

(2) The design procedure of a viscous fluid damper was established, and an example calculation was performed for the application of damper to a steel structure building of three stories.

(3) A multiple layers viscous damper model was presented to increase the damping force.

$$F = 0.2489\,(A_b + N \times A_l)(v/2d)^{0.5156} \qquad \textbf{(kgf)}$$

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