# Seismic Control of Asymmetric Structures

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## Abstract

This paper presents results of an investigation on how supplemental viscous damping can be used to control excessive deformations in asymmetric-plan buildings. It is shown that symmetric distribution of supplemental damping devices in the building plan is not necessarily the best way to control excessive deformations in an asymmetric-plan building; a value of the damping eccentricity equal to the structural eccentricity in magnitude but opposite in algebraic sign leads to higher reduction.

## Introduction

The performance of structures during past earthquakes has shown that asymmetric-plan buildings are especially vulnerable to earthquake damage. Therefore, numerous investigations in the past have investigated the earthquake behavior of asymmetric-plan buildings. As a result, procedures to account for undesirable effects of plan asymmetry, such as increased force and ductility demands on lateral load-resisting elements, have been developed and incorporated into seismic codes of many countries. However, there remains a need for additional research to develop techniques that will control excessive earthquake-induced deformations in asymmetric-plan buildings.

Although, the control of earthquake-induced vibrations in symmetric-plan buildings through the use of supplemental damping has been a subject of numerous recent studies (e.g., Aiken and Kelly, 1990; Hanson, 1993; Reinhorn et. al., 1995), there has been a lack of efforts toward developing a fundamental understanding of how these devices and their plan-wise distribution influence the lateral-torsional coupling in asymmetric-plan systems. Therefore, the objectives of this investigation were to (1) to identify the system parameters that control the seismic response of

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asymmetric-plan buildings with fluid viscous dampers; and (2) to investigate the effects of the controlling parameters on edge deformations in asymmetric-plan buildings. This paper focuses on the effects of one of the most important parameters related to the supplemental damping, namely the damping eccentricity.

## System and Ground Motion

The system considered was the idealized one-story building of Figure 1 consisting of a rigid deck supported by structural elements (wall, columns, moment-frames, braced-frames, etc.) in each of the two orthogonal directions. Supplemental damping is provided by fluid viscous dampers in the building's bracing system. The mass is assumed to be distributed symmetrically in the system plan. Therefore, center of mass (CM) is located at the geometric centroid of the plan area. The stiffness eccentricity is denoted by the distance, $e$, between the CM and the center of rigidity (CR), and the damping eccentricity is denoted by the distance, $e_{sd}$, between the CM and the center of supplemental damping (CSD).

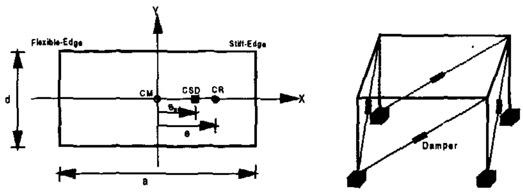


Figure 1. System considered.

The ground motion considered is the North-South (360°) component recorded at the Sylmar County Hospital parking lot during the 1994 Northridge earthquake. The peak values of the ground acceleration, velocity, and displacement recorded at this site were $826.8\,\mathrm{cm/s^2}$, $128.9\,\mathrm{cm/s}$, and $32.55\,\mathrm{cm}$, respectively.

## System Parameters and Response Quantities

The parameters that control the system response are (Goel, 1998): (1) transverse vibration period, $T_y = 2\pi/\omega_y$ ($\omega_y$ = transverse vibration frequency) of the reference symmetric building; (2) normalized stiffness eccentricity, $\bar{e}$; (3) ratio of the torsional and transverse frequencies, $\Omega_\theta$; (4) aspect ratio, $\alpha$; (5) mass and stiffness proportional constants, $a_0$ and $a_1$, which in turn depend on the natural damping ratio in the two vibration modes of the system; (6) supplemental damping ratio, $\zeta_{sd}$; (7) normalized supplemental damping eccentricity, $\bar{e}_{sd}$; and (8) normalized supplemental damping radius of gyration, $\bar{\rho}_{sd}$. In this study, the

following system parameters were fixed: $\Omega_\theta = 1$, $\bar{e} = 0.2$, $\alpha = 2$, and constants $a_0$ and $a_1$ were selected such that $\zeta_1 = \zeta_2 = \zeta = 5\%$.

The response quantities selected in this investigation were the deformations of the flexible and stiff edges in asymmetric-plan building normalized by the deformation of the reference symmetric building, $\bar{u}_f = u_f \div u_o$ and $\bar{u}_s = u_s \div u_o$. A value of the normalized edge deformation by more than one indicates a larger edge deformation in the asymmetric-plan building as compared to the reference symmetric building; conversely, a value of normalized edge deformation smaller than one implies a smaller edge deformation in the asymmetric-plan building.

**Effects of Supplemental Damping**

This paper summarizes the effects of one of the three important system parameters related to the supplemental damping, namely the damping eccentricity, $\bar{e}_{sd}$. Presented in Figure 2 are the normalized edge deformations computed for a range of $\bar{e}_{sd}$ values between –0.5 and 0.5 for buildings with $T_y$ = 1 s; the extreme values of $\bar{e}_{sd}$ = –0.5 and 0.5 correspond to all dampers located either at the flexible or at the stiff edge, respectively.

The presented results (Figure 2) show that the supplemental damping eccentricity significantly affects the edge deformations. In particular, deformation of the flexible edge decreases and that of the stiff edge increases as $\bar{e}_{sd}$ varies from 0.5 to –0.5, i.e., the CSD moves from the right to the left of the building plan (Figure 1). These results also show that $\bar{u}_f$ is the smallest for $\bar{e}_{sd}$ = –0.5 indicating that the largest reduction in deformation of the flexible edge would be obtained by concentrating all dampers at the flexible edge. The stiff edge deformation, on the other hand, is the smallest for $\bar{e}_{sd}$ = 0.5, implying that the largest reduction would be obtained by locating all dampers at the stiff edge. Furthermore, asymmetric distribution of supplemental damping results in much higher reduction in the edge deformation compared to the symmetric distribution as apparent from deformation of the flexible edge being much smaller for $\bar{e}_{sd}$ = –0.5 compared to $\bar{e}_{sd}$ = 0.

It is apparent from the presented results that the same distribution of dampers does not lead to the most reduction in deformations of both edges: the distribution that results in the largest reduction in the flexible edge deformation leads to the smallest reduction in the stiff edge deformation and vice versa. For asymmetric-plan buildings, the flexible edge is generally the most critical edge because of higher earthquake-induced deformations. Therefore, dampers should be distributed such that the CSD is as far away from the CM, on the side opposite to the CR, as physically possible -- a distribution that leads to the largest reduction in deformation of the flexible edge. Although this distribution does not lead to the largest possible

reduction in deformation of the stiff edge, it none the less reduces deformations as compared to deformation of the same edge in buildings without dampers.

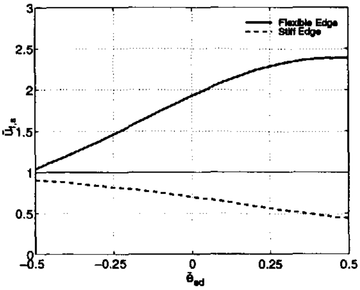


Figure 2. Response of asymmetric-plan buildings with supplemental damping: $\bar{e} = 0.2; \Omega_\theta = 1; \alpha = 2; \zeta = 5\%; T_y = 1\,\mathrm{s}$; and $\zeta_{sd} = 10\%$.

## Conclusions

It is shown that the response reduction in asymmetric buildings strongly depends on the plan-wise distribution of the supplemental damping. In particular, it was found that (1) asymmetric distribution of the supplemental damping led to a higher reduction in edge deformations as compared to symmetric distribution; and (2) the largest reduction in the critical edge, i.e., flexible edge, deformation occurred when the CSD was as far away as physically possible from the CM and on the side opposite to CR.

## References


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