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Seismic Performance of Asymmetrical Building with TMD

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***Abstract:*— The Eccentricity in center of mass and the center of rigidity under the application of lateral loads causes different behaviour in flexible edge and stiff edge of an asymmetrical building when compared to the behaviour in edges of a symmetrical building. In this study, a typical ten storey RCC building with rectangular plan is considered with eccentricities introduced along the X-direction. Four different earthquakes are considered for linear time history analysis in Y-direction of the building. A tuned mass damper (TMD) with optimum tuning frequency and optimum damping ratio has been chosen with mass ratio 0.05 to control the edge displacements and base shear due to the application of earthquake time histories. The flexible and stiff edge response ratios in terms of peak displacements and normalized base shear with and without TMD are studied with respect to eccentricity ratio and frequency ratio of the building. The response ratios of flexible edge is higher than the response ratio of stiff edge with respect to both eccentricity ratio and frequency ratio for all four earthquakes considered. This study brings out the importance of including the effect of asymmetry in the design of TMD.**

***Index Terms* :-- Eccentricity ratio, flexible edge, frequency ratio, response ratio, stiff edge, tuned mass damper.**

I. INTRODUCTION

Performance of symmetrical building is uniform in all the edges of building during earthquakes. In asymmetrical buildings, the difference in position of center of mass and center of stiffness, known as eccentricity, causes torsional moment of rigid slab during applied lateral loads. Due to the torsional moment in the rigid slab, the behaviour of flexible edge and stiff edge are not similar i.e. joint displacements, storey shears and joint accelerations.

Many researchers studied to control the behaviour of asymmetrical building with dampers. Mevada and Jangid (2012) investigated the seismic response of single storey asymmetrical building with semi-active variable stiffness dampers. The parameters considered are eccentricity ratio, uncoupled time period and ratio of uncoupled torsional to lateral frequency. Mevada and jangid (2012) have concluded that the torsional, lateral and edge displacements decrease with the increase in stiffness ratio. Jangid and Datta (1997) investigated a simple one way eccentric model having two degrees of freedom with multiple tuned mass dampers by ignoring the effect of torsional coupling and concluded that the effectiveness of multiple tuned mass dampers is less for asymmetric system when compared with symmetrical system. In this paper, a ten storey RCC asymmetric building is investigated under four different earthquake ground motions. For controlling the behaviour of building during earthquakes, single Tuned Mass Damper (TMD) is arranged in the top storey of the building.

II. RESPONSE RATIOS

The behaviour of the building after installation of TMD is studied in terms of response ratios. The response ratios considered in the present study are: ratio of peak flexible edge displacement (u_f) with and without damper, ratio of peak stiff edge displacement (u_s) with and without damper and ratio of peak base shear with and without damper as given in equation (1), (2), (3). The response ratios are:

$$R_1 = \frac{u_{fd}}{u_{fud}} \quad (1)$$

$$R_2 = \frac{u_{sd}}{u_{sud}} \quad (2)$$

$$R_3 = \frac{B_{yd}}{B_{yud}} \quad (3)$$

Where,

u_{fd} = Peak flexible edge displacement with damper

u_{fud} = Peak flexible edge displacement without damper

u_{sd} = Peak stiff edge displacement with damper

u_{sud} = Peak stiff edge displacement without damper

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B_{yd} = Normalized base shear with damper

B_{yud} = Normalized base shear without damper

The response ratios are compared with respect to eccentricity ratio (v_1) and frequency ratio (v_2) as given in equation (4). (Bharti and Shrimali 2012)

$$v_1 = \frac{e_x}{\rho}\ ; \qquad v_2 = \frac{\omega_\theta}{\omega_y} \qquad (4)$$

Where

ρ = mass radius of gyration= $\sqrt{\frac{a^2+b^2}{12}}$

e_x = eccentricity in x-direction

a= length of building along x-direction

b= breadth of the building along y-direction

ω_θ =torsional frequency

ω_y =translational frequency

III. MODELLING OF TUNED MASS DAMPER

Tuned mass damper is an auxiliary mass-spring- dashpot system anchored to the building to control the vibrations exerted during earthquake ground motions.(Chang and Yang 1995; Constantinou et al. 1998; Rana 1996). According to Sadek et.al (1997), the parameters for designing a TMD is mass ratio (μ), damping ratio (ξ), tuning ratio (f) and mode shapes of the building. For a MDOF system, mass ratio (μ) is defined as the ratio of TMD mass to generalized mass for the fundamental mode for unit modal participation factor. The parameters are given in the equations (5), (6) & (7).

$$\mu = \frac{m}{\phi_1^T[M]\phi_1} \qquad (5)$$

$$f = \frac{1}{1+\mu\phi}\left[1-\beta\sqrt{\frac{\mu\phi}{1+\mu\phi}}\right] \qquad (6)$$

$$\xi = \phi\left[\frac{\beta}{1+\mu}+\sqrt{\frac{\mu}{1+\mu}}\right] \qquad (7)$$

Where, β is damping ratio of the structure and ϕ is amplitude of mode shape at the TMD location.

NUMERICAL STUDY

A typical ten storey RCC building with plan dimension of 35mx15m is modelled in SAP2000 as shown in Fig. 1. The plan consists of 5m bay length in both x-direction and y-direction. A 200mm thick rigid slab is considered along with an additional load of 1ton/m^2 on it. In symmetrical building, all the columns are assumed to be size 0.4mx0.4m. For asymmetrical building, the eccentricity in x-direction is varied by changing the column sizes in the frame. Table 1 shows the variation of frame moment of inertia for given eccentricities. For studying seismic behaviour of building, four different earthquake ground motions viz., El Centro, Loma Prieta, Northridge and spectrum compatible artificial ground motion consistent with Zone-V medium soil for design basis earthquake are applied to the building in y-direction (perpendicular to the direction of eccentricity in the building). A TMD is designed at the top of the building using link element in SAP2000.

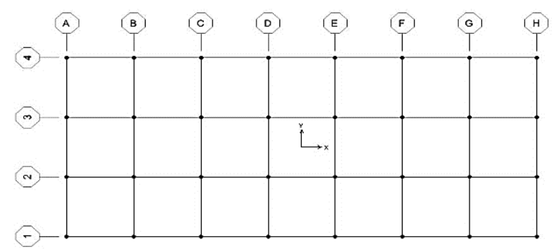

Fig. 1. Plan of building

The tuned mass damper parameters are calculated to control the deformation behaviour are: μ=0.05, β=0.05, ϕ=1.27 (Merin Ross et al. 2014; Sadek et al. 1997). Effective stiffness and effective damping are calculated for all eccentricity cases considered.

Table 1 Moment of Inertia for the frames

Eccentricity (%)	Frame moment of inertia(m^4)				
	A,B,C,D	E	F	G	H
0	0.0341	0.0085	0.0085	0.0085	0.0085
1	0.0341	0.0137	0.0085	0.0085	0.0085
2	0.0341	0.0208	0.0085	0.0085	0.0085
3	0.0341	0.0085	0.0137	0.0085	0.0085
4	0.0341	0.0208	0.0137	0.0085	0.0085
5	0.0341	0.0085	0.0085	0.0137	0.0085
10	0.0341	0.0085	0.0085	0.0208	0.0085
15	0.0341	0.0085	0.0085	0.0085	0.0208
20	0.0341	0.0085	0.0137	0.0137	0.0208
25	0.0341	0.0085	0.0208	0.0208	0.0208

V. RESULTS & DISCUSSIONS

The response ratios (R1 & R2) of an asymmetrical building with one TMD in top floor is computed with linear time history analysis of four earthquake ground motions with respect to eccentricity ratio (v1) and frequency ratio (v2). For Elcentro earthquake (Fig 2(a)), the response ratios R1 is higher than R2 with respect to eccentricity ratio (v1). From

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Fig. 2(b), the response ratios R1 and R2, for Lomaprieta earthquake, is having a difference of 0.4 with increase in eccentricity ratio (v1). In case of Northridge earthquake (Fig. 2(c)), the response ratio (R1) is unchanged for all eccentricity ratios (v1) when compared to response ratio (R2). Response ratio (R2) is decreasing with increase in eccentricity ratio (v1). In Zone-V spectrum compatible medium soil earthquake (Fig. 2(d)), the response ratio (R1) is unaltered for all eccentricity ratios (v1) i.e. equal to 1.0. The change in response ratio (R2) is large with increase in eccentricity ratio (v1).

Fig. 3 represents response ratios (R1 & R2) with frequency ratio (v2) for four earthquake ground motions. From the Fig. 3, the response ratios with frequency ratio (v2) are similar to the plots with eccentricity ratio (as shown in Fig. 2) for increase of eccentricity in the building.

Fig. 4 shows the normalized base shear response ratio (R3) with eccentricity ratio (v1) for four earthquake ground motions. Base shear response for Elcentro earthquake is 0.55 for zero eccentricity ratio (v1) and increased to 0.8 for maximum eccentricity ratio. The response ratio (R3) is constant with eccentricity ratio for Northridge earthquake For Zone-V medium soil spectrum compatible earthquake, the response ratio is 1.0 with respect to increasing eccentricity ratio. At maximum eccentricity ratio (v1), the response ratio (R3) is 0.48(lowest) among all the considered earthquake ground motions.

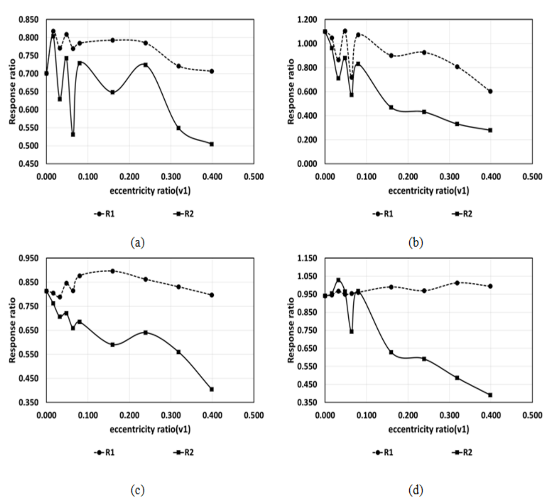

Fig. 2 Response ratios (R1 & R2) with eccentricity ratio (v1)
(a) El Centro (b) Loma Prieta (c) Northridge (d) spectrum compatible zone-V earthquake

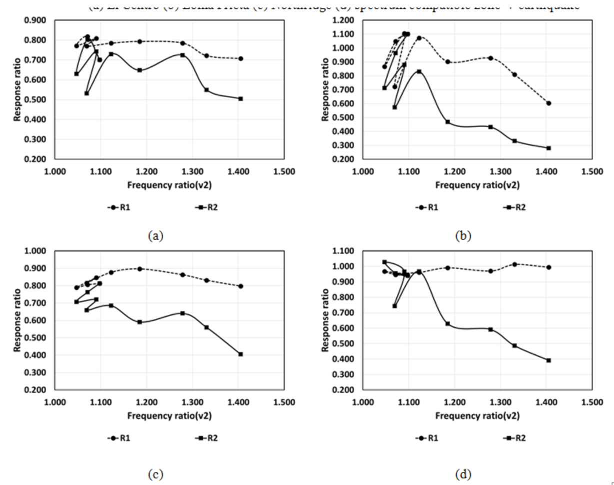

Fig. 3 Response ratios (R1 & R2) with frequency ratio (v2) (a) El Centro (b) Loma Prieta (c) Northridge (d) spectrum compatible zone-V earthquake

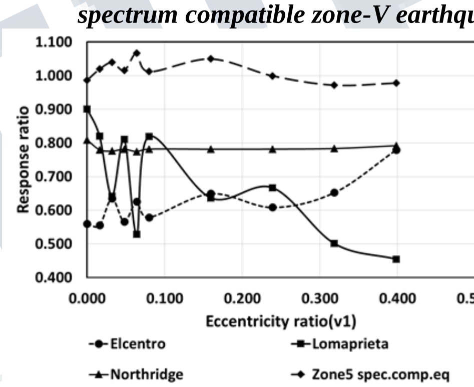

Fig. 4 Response ratio (R_3) with eccentricity ratio (v_1)

VI. CONCLUSION

From the studies made, following are the main observations.

1. Response reduction in flexible edge and stiff edge peak displacements are different and reduction in response at flexible edge is lesser compared to stiff edge in all the cases considered.
2. Sensitivity of displacement response reduction to variation in eccentricity ratio and frequency ratio of stiff edge is more compared to flexible edge.
3. Response reduction in base shear for different earthquakes are different and response reduction for spectrum compatible earthquake is lesser among the four earthquakes considered.
4. Hence it is important to include the effect of eccentricity in the design of TMD for asymmetrical building.

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