Effect of Near-fault Ground Motion on R/C Asymmetric Community Structures

Subhayan Bhaumik , Prithwish Kumar Das

Abstract- It is well established by different seismic damage surveys conducted all over the world that the asymmetric structures are more susceptible to seismic damage than their symmetric counterparts. Moreover, it is also pointed out by a number of previous research effort that such damage in asymmetric structures is more aggravated in R/C structures due to progressive strength and stiffness degradation of R/C structural elements. Community structures like auditoriums generally have load resisting elements distributed only near the boundary region of the structures leaving a large empty space at the central region. Seismic behaviour of such type of R/C asymmetric systems are investigated in a limited form (Dutta, 2001) considering only spectrum consistent far field ground excitations. However, study of such systems under near-fault ground excitations are also of great importance as there may be a huge gathering of people inside an auditoriums and amount of energy input to the structural systems will be much more in near-fault ground motions are than their far-field counter parts. On this aspect the present research effort investigates the responses of such auditorium like community structural systems with asymmetry under a number of real earthquake ground excitations of near-fault nature.

Keywords— stiffness degradation, strength deterioration, torsional response.

Introduction

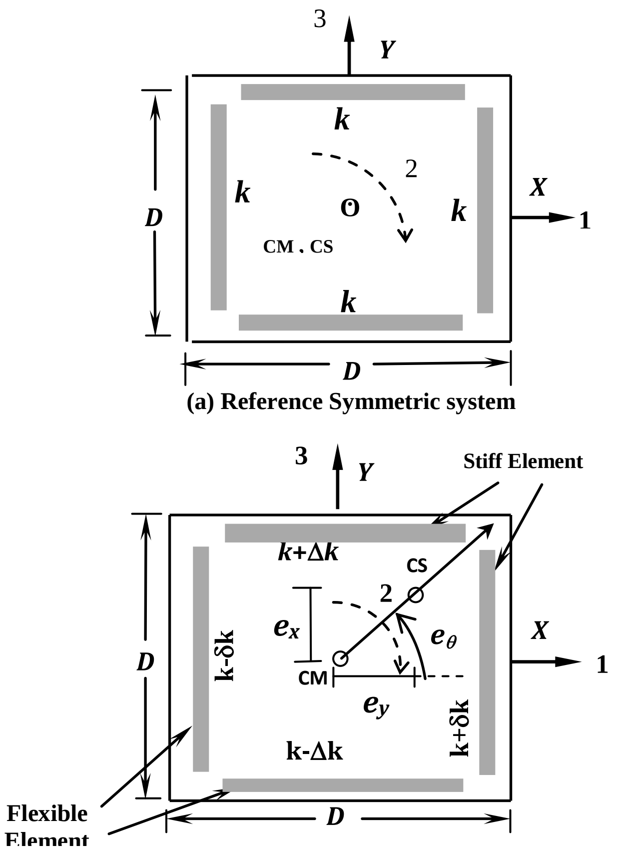
On the basis of different seismic damage surveys conducted all over the world pointed out that asymmetric structures are more susceptible to seismic damage than their symmetric counterparts Hence, over last few decades numerous investigations have been conducted on elastic as well as inelastic seismic behaviour of asymmetric structural systems to find out the cause of seismic vulnerability of such asymmetric structures. Most of the investigations considered bi-linear elasto-plastic load-deformation behavior for structural elements, which is suitable for steel-framed buildings constructed in developed countries. But in most of the developing countries like ours buildings as well as community structures like auditoriums are constructed with reinforced concrete structural elements. These R/C structural elements may undergo considerable amount of strength and stiffness degradation under nonlinear range repetitive loading during severe seismic excitations. These degrading features may aggravate severely displacement demand structural elements particularly in case of asymmetric structures. Few recent investigations studied the effect of strength and stiffness degradation (Das and Dutta, 2002, Dutta and Das 2002, Dutta et. al. 2005) on seismic response of idealized R/C structural system with unidirectional as well as bidirectional asymmetry. Most of these investigations considered spectrum consistent as well as real earthquake data of far-field nature. However, most of these investigations considered a general class of buildings having there lateral load resisting elements more or less uniformly distributed over their plan areas. On the other hand, auditorium like structures have their load resisting element distributed at the edge region of the structure. A previous study (Dutta, 2001) investigated the response of such system in a limited form using only spectrum consistent simulated far field ground excitations. However, these types of community structures are primarily made to accommodate huge gatherings. Moreover, the energy input by near-fault ground excitations are much more than that of far-field ground motions due to proximity of epicentre in case of the former type. Hence, there remains a possibility of huge casualty due to collapse of R/C community structures with unavoidable plan-asymmetry under severe near-fault ground excitations. In this viewpoint, the present research effort tried to investigate the response of such asymmetric structures under real near-fault ground excitations in a fruitful way.

Subhayan Bhaumik
Post Graduate student
Department of Aerospace Engineering and Applied Mechanics
Bengal Engineering and Science University,Shibpur Howrah -711103
West Bengal, INDIA

Prithwish Kumar Das
Associate Professor
Department of Aerosapce Engineering and Applied Mechanics
Bengal Engineering and Science University,Shibpur Howrah,-711103
West Bengal,INDIA

I. Structural Systems and Method of Analysis

The idealized one-storied structural systems considered in the present investigation are idealized as single story rigid diaphragm model with three degrees of freedom, two translations in two mutually orthogonal directions and one in-plane rotation. Masses are assumed to be lumped at the floor, which is considered as rigid in its own plane as well as in flexure. Generally, in case of community structures like auditorium, lateral load-resisting structural members are found to be distributed near the boundary region of the structures. Thus, in the present investigation, to represent such a plan-wise distribution of the stiffness, structure has been idealized with four element system as also used in a previous investigation (Dutta, 2001). The total lateral stiffness in one direction is distributed between two edge elements in that direction. Fig. 1(a) represents the schematic diagram of such idealized symmetric structural system.



(a) Reference Symmetric system

(b) Bi directioal Eccentric system

Fig. 1: Idealized structural model.

The stipulated amount of eccentricity is introduced by increasing the stiffness of the lateral load-resisting element of one edge by a calculated amount and decreasing the same of the opposite edge element by the equal amount The lateral load-resisting edge elements with lesser stiffness are designated as flexible elements and the opposite edge elements having greater stiffness are referred to as stiff elements. Three representative values of normalized eccentricities namely $e/D = 0.05$, $e/D = 0.1$, $e/D = 0.2$ are considered in this investigation where e is the eccentricity in either x or y direction (e_x and e_y) and D is distance between two edge element in x or y direction. In the limited scope of the present paper, results corresponding to only bi-directionally eccentric systems (as presented in Fig. 1(b)) with different or same values of eccentricities in x and y direction are presented The coupled equations of motion for the considered asymmetric structural system can be written by two translational as well as one rotational degrees of freedom as

$$\begin{bmatrix} m & 0 & 0 \\ 0 & mr^2 & 0 \\ 0 & 0 & m \end{bmatrix}\begin{Bmatrix} \ddot{u}_x \\ \ddot{\theta} \\ \ddot{u}_y \end{Bmatrix}+[C]\begin{Bmatrix} \dot{u}_x \\ \dot{\theta} \\ \dot{u}_y \end{Bmatrix}+\{f_s\}=-\begin{bmatrix} m & 0 & 0 \\ 0 & mr^2 & 0 \\ 0 & 0 & m \end{bmatrix}\begin{Bmatrix} \ddot{u}_{gx}(t) \\ 0 \\ \ddot{u}_{gy}(t) \end{Bmatrix}$$

The equations of motion are numerically solved in the time domain by Newmark's β - γ method likewise previous investigations. (e.g., Dutta and Das 2002, Dutta et. al. 2005, Das and Dutta, 2003) using modified Newton-Raphson technique. The Newmark's parameters are chosen as $\gamma = 0.5$ and $\beta = 0.25$. The time step of integration is taken as $T_s/400$ sec., where T_s is the lateral natural period of asymmetric idealized system. This time step of integration is found to be sufficiently small from sample convergence studies.

The maximum displacement demand for extreme edge load resisting element of an asymmetric structural system were studied for a feasible range of dynamic characteristics of the system. Uncoupled lateral period T_l and torsional to lateral period ratio τ are the two primary dynamic characteristic of that structural systems under seismic excitation. As most of the auditorium like community structures generally have low heights in comparison with multi-storeyed general residential or official buildings, systems with small uncoupled lateral time period namely T_l equal to 0.1 second is used to represent natural period range of such low-rise stiff asymmetric structural system. The torsion to lateral time period ratio τ is varied within a range of 0.5-1.5 as torsional to lateral period ratio τ for most of low-rise buildings lies within this range.

II. Hysteresis Model and Ground Motion.

In the present investigation two types of hysteresis behaviours namely, i) strength and stiffness degrading and ii) elasto-plastic are considered. First type of hysteresis behavior may be considered for represent the characteristics of RC structural members, while the second one represents the characteristics of steel frame structural members. For obtaining most critical physible response for R/C structural system , the value of strength and stiffness degradation are kept as 10 % of the initial value per yield excursion. The first types of hysteresis model are incorporated through the algorithm developed and explained as in (Dutta and Das 2002). These simple hysteresis models are also used in some previous investigations (Das and Dutta, 2003, Dutta et. al, 2005, Bhaumik and Das, 2013).

Real ground motions of near-fault nature are considered in the present investigations are collected from strong motion data base available from PEER strong motion database (www.peer.berkeley.edu/smcat/search.html).

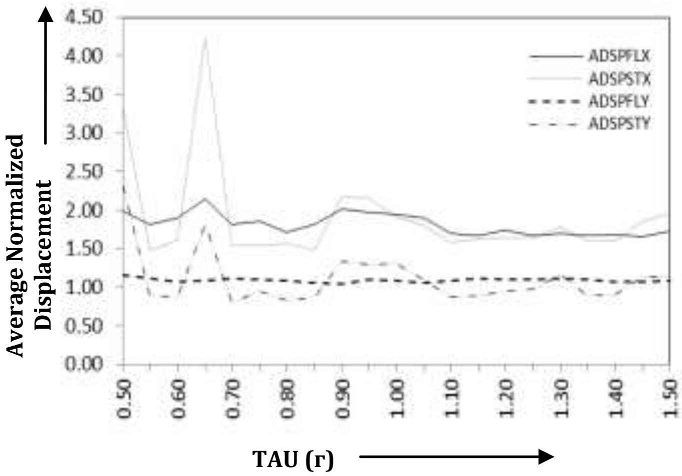
TABLE 1

Sl. No.	Seismic Events	Station	Date	Magnitude in Richter Scale	Distance from epicentre (km)
1	Chalfant Valley	Zack Brothers ranch	07.20.86	5.8	6.4
2	Coyote Lake	Gilroy Array #3	06.08.79	5.7	7.4
3	Imperial Valley	El Centro Array #3	10.15.79	6.5	12.9
4	Imperial Valley	Sahop Casa Flores,	10.15.79	6.5	9.6
5	Loma Prieta	Saratoga – Aloha Ave	10.18.89	6.9	8.5
6	Mammoth Lakes	Convict Creek	5.25.80	6.1	6.6
7	Morgan Hill	Halls Valley	4.24.84	6.2	3.5
8	West of Westmorl and	Westmor land Fire Sta.	04.26.81	5.9	6.5

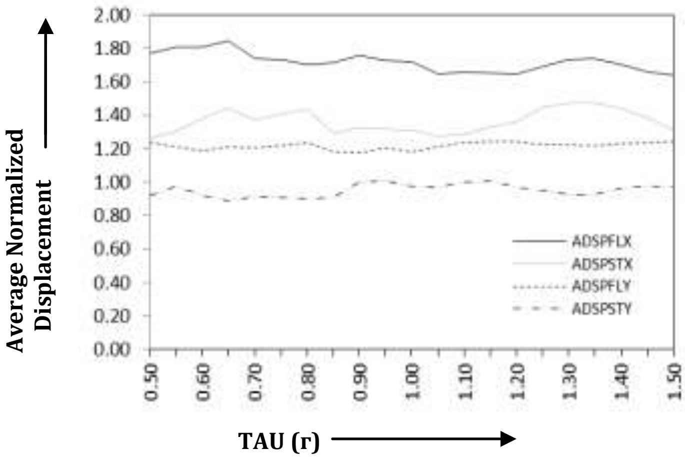
The ground motions are selected in such a way that they are considered at measuring stations which are only few kilometres away from respective epicentres. In this present study an ensemble of and each set consists of two sets of ground acceleration data in two eight set of real ground acceleration time history is considered orthogonal directions in horizontal plane has been use as input ground motion. One component of data with maximum peak ground acceleration considered as fault parallel motion and applied along x direction and the other component of data is considered as fault normal ground motion, acted along y direction. The main characteristics of the selected records are reported in Table 1.

IV. Results and Conclusions

Maximum displacement responses of edge elements (flexible and stiff) of bi-directionally eccentric structural systems with different values of eccentricities are computed in normalized form. Normalization is done by the maximum displacement responses of edge elements of similar but symmetric structural systems to investigate only the effect of asymmetry. Such normalized responses, computed for all eight real earthquake ground excitations of near-fault nature, are averaged and represented in Fig. 2 to Fig. 4. Each of these figures consist two set of graphs showing responses of degrading structures representing buildings with reinforced concrete structural elements and response of similar but elasto-plastic structural system representing buildings having steel structural elements. In each of the figure averaged normalized maximum displacement response is plotted against torsional to lateral period ratio τ (TAU). Four different curves in each figure represent averaged normalized maximum displacement response of a) Flexible element in *x* direction (ADSPFLX), b) Stiff element in *x* direction (ADSPSTX), c) Flexible element in *y* direction (ADSPFLY) and d) Stiff element in *y* direction (ADSPSTY). Careful comparison betweentwo sets of graphs presented in each figures (Fig. 2, Fig. 3 and Fig. 4) clearly reveal that though for the structural systems with elasto-plastic structural elements responses are not so much magnified due to asymmetry, but for strength and stiffness degrading structural systems representing R/C structures, the responses are magnified significantly due to incorporation of asymmetry. Hence, comprehensive study of R/C asymmetric community structural systems under near-fault ground motions considering different aspect of such systems is the need of the hour.

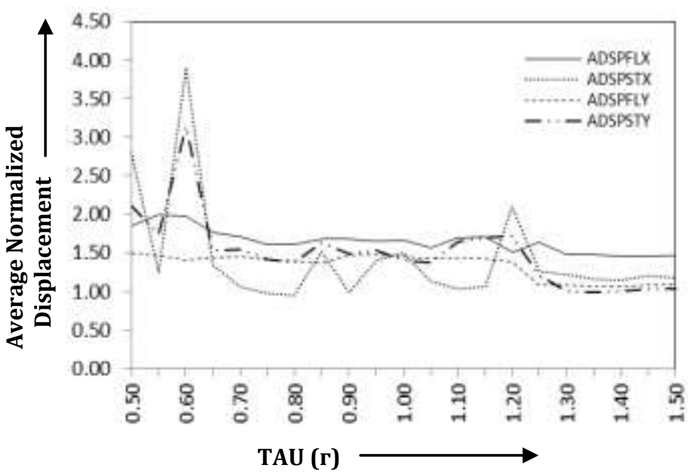


Degrading System Response (δ= 0.05)

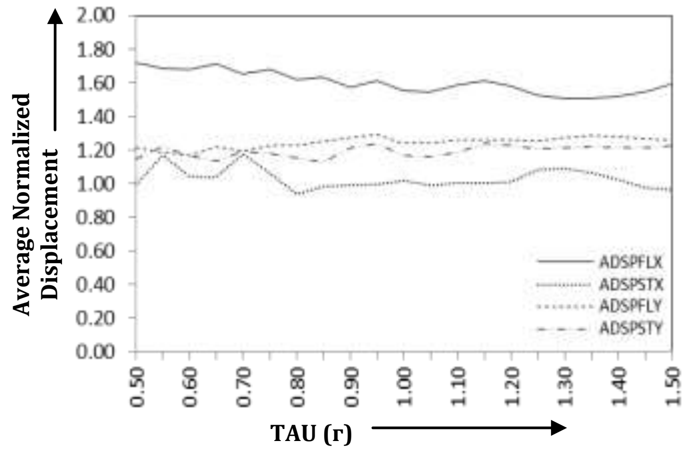


Elastoplastic system Response (δ= 0)

Fig.2: Average normalized displacement response of structural systems with T_l =0.1s, e_x/D= 0.2 and e_y/D = 0.1

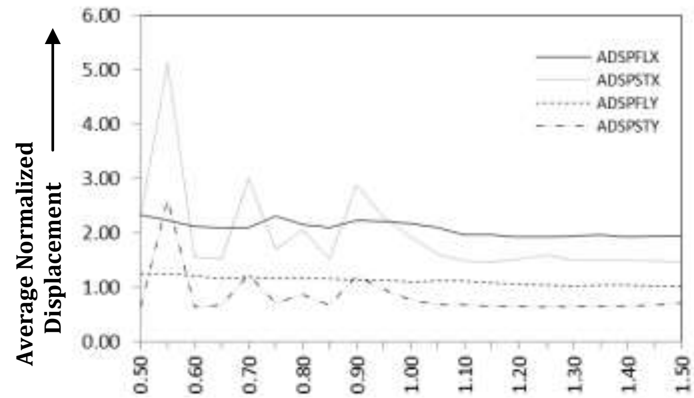


Degrading System Response (δ= 0.05)

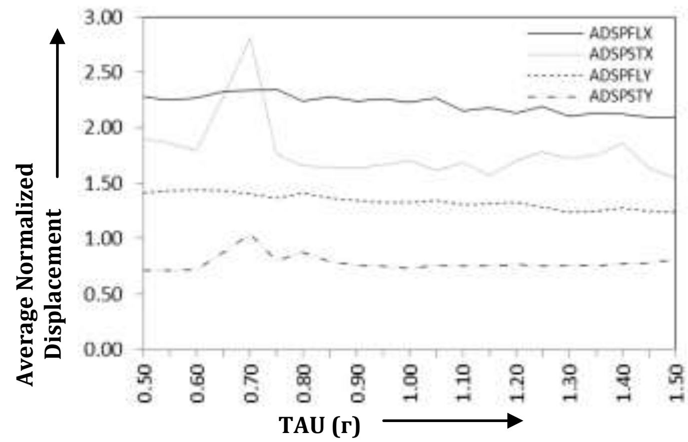


Elastoplastic system Response (δ = 0)

Fig. 3: Average normalized displacement response of structural systems with T_l =0.1s, e_x/D= 0.2 and e_y/D= 0.05



Degrading System Response (δ = 0.05)



Elastoplastic system Response (δ = 0)

Fig.4: Average normalized displacement response of Structural systems with T_l =0.1s, e_x/D= 0.2 and e_y/D= 0.2

References

[1] Bhaumik, S. and Das, P. K. (2013), "Response of Idealized R/C Asymmetric Structural Systems under Near-fault Ground Motion," Paper no.: *58-istam-sm-fp-43*, **58TH Congress of The Indian Society of Theoretical and Applied Mechanics (ISTAM)**, An An International Meet, December 18-21, Bengal Engineering and Science University, Shibpur, West-Bengal, India.

[2] Das, P. K. and Dutta, S. C., (2002), "Effect of Strength and Stiffness Deterioration on Seismic Behaviour of R/C Asymmetric Buildings," **International Journal of Applied Mechanics and Engineering**, Vol. 7, No. 2, pp. 527-564.

[3] Das, P. K. and Dutta, S. C., (2003), "Inelastic Seismic Behaviour of R/C Structures with Bi-directional Asymmetry under Near-fault Motion", Proc. of **Structural Engineering Convention (SEC 2003)**, An International Meet, December 12-14, I.I.T. Kharagpur, INDIA. 475-483.

[4] Dutta, S. C., (2001), "Effect of Strength Deterioration on Inelastic Seismic Torsional Behaviour of Asymmetric RC Buildings," **Building and Environment**, Vol. 36, No. 10, pp. 1109-1118.

[5] Dutta, S. C. and Das, P. K., (2002), "Validity and Applicability of Two Simple Hysteresis Models to Assess Progressive Seismic Damage in R/C Asymmetric Buildings," **Journal of Sound and Vibration**, Vol. 257, No. 4, pp. 753-777.

[6] Dutta, S. C., Das, P. K., and Roy, R, (2005). "Seismic Behaviour of Code-Designed Bi-Dectionally Eccentric Systems", **Journal of Structural Engineering, ASCE**, Vol. 131, No. 10, pp. 1497-1514.