RESPONSE OF IDEALIZED 6- ELEMENT R/C ASYMMETRICAL STRUCTURAL SYSTEMS UNDER NEAR-FAULT SEISMIC MOTIONS

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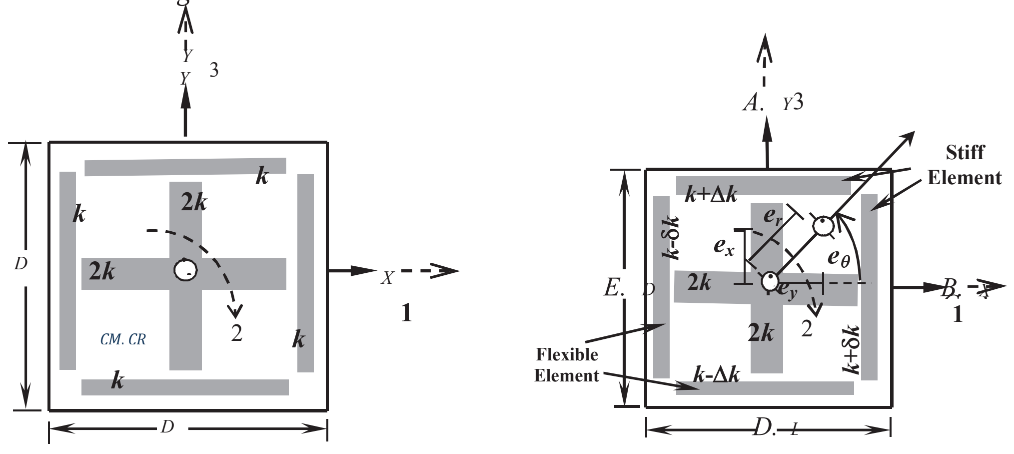
Abstract: At the time of Earthquake a structure may experience strength degradation. If the structure is asymmetric and is built with Reinforced concrete then the response of this R/C structure is more than the elastoplastic asymmetric structural system. During this seismic motion this asymmetric structures leads to larger lateral displacement in the load resisting elements located at on edge, compared to other resisting elements and cause earlier yielding of that edge elements in localized form. Due to successive inelastic excursions of these R/C elements at one edge make these elements more flexible and and weaker as compared to those at the opposite edge by strength and stiffness degradation. This may cause gradually shifting of stiffness and strength centers away from this flexible edge, creates bidirectional eccentricity in successive seismic loading cycles and causes a progressive increase in torsional effect in R/C structures.

Keywords: strength degradation, elastoplastic degradation, inelastic dispalcement,stiffness, degradation, torsional response.

Introduction: The objective of this paper is to investigate response of this one-story idealized asymmetric buildings, under the action of bi directional horizontal seismic motions with an emphasis on the response of the resisting element under inelastic range .Near-fault ground motions impose large demands on structures compared to far-fault ground motions. Buildings will be subjected to bi-directional seismic motion and may have asymmetry for nominal or accidental reason, in both principal directions. This asymmetric buildings under earthquake excitations have a greater vulnerability compared to symmetric buildings. 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 behaviour for structural elements, which is suitable for steel-framed buildings constructed in well developed countries. But in most of the 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 cyclic 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, the responses of structural systems under near-fault motion are found to be crucial particularly when the duration of ground motion pulses is very large. Moreover, the energy input to the structural systems is huge in this type of ground motion as they only found in near location of epicentre of quake. These near-fault motions behave like a single pulse of large amplitude having very less number of zero crossings and consist of fault-parallel and fault-normal ground motions. Few recent investigations (Dutta and Das, 2002; Das and Dutta, 2003) had considered responses under simulated near-fault ground excitations. These simulated near-fault ground motions were of very simplified form and are generated considering some crucial values of ratio of lateral period of structural system and pulse duration of simplified motion.

Structural System : 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 the residential or office buildings, lateral load-resisting structural members are found to be uniformly spaced over its plan. Thus, in the present investigation, to represent the plan-wise distribution of the stiffness, structure has been idealized with six-element system as also used in a few other studies (Dutta and Das 2002, Dutta et. al. 2005 Das and Dutta, 2003) attributing 50% (2k)of the total lateral stiffness (4k) to the middle element and the rest 50% (2k)is distributed between four edge elements. Fig. 1(a) represents the schematic diagram of such idealized symmetric structural system. A very small amount of eccen-tricity is introduced by increasing the stiffness of the lateral load-resisting



(a) Reference symmetric system **(b) Bi-directionally eccentric asymmetric system**

Fig1. 6-Element Structural System

element of one edge by a calculated amount and decreasing the same of the opposite edge element by the equalamount. The lateral load-resisting edge elements with lesser stiffness are designated as flexible elements (*k-δk or k-Δk)* and the opposite edge elements having greater stiffness are referred to as stiff elements(*k+δk or k+Δk)*.Three represent-tative 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 e_x or e_y .This e_x and e_y is the eccentricity with respect x and y axis respectively 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 unequal values of eccentricities in *x* and *y* direction are presented.

Method of Analysis: The coupled equa-tions of motion for considered the asymm-etric structural system can be written by two translational as well as one rotational degrees of freedom as :

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

where *m* is the mass of the rigid deck; *r* is the radius of gyration of mass of the rigid deck about a vertical axis passing through the centre of mass (*CM*). [*C*] is the damping matrix; u_x, u_y, and are the translations of the centre of mass (*CM*) along X and Y axis, and rotation of *CM* in horizontal plane, respectively; $\ddot{u}_{gx}$ and $\ddot{u}_{gy}$ are ground accelerations along two mutually perpendicular principal axes, respectively. $\{f_s\}$ is the spring force vector which can be calculated considering the current status of each load-resisting element with the help of hysteresis models. However, in the linear elastic range $\{f_s\}$ can be given as:

$$\{f_s\} = \begin{bmatrix} 4k & 4ke_x & 0 \\ 4ke_x & kD^2 & -4ke_y \\ 0 & -4ke_y & 4k \end{bmatrix} \begin{Bmatrix} u_x \\ \theta \\ u_y \end{Bmatrix}$$

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 γ = 0.5 and β = 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. Here Five uncoupled lateral time periods T_l in 0.1 sec,0.2 sec and 0.5 sec were used to represent natural period ranges in a asymmetric structural system. However, results only corresponding to short period stiff systems are presented here as they found to be more susceptible to seismic damage due to asymmetry. 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.Here,For R/C lateral load resisting structural element strength detoriation is considered as δ= 0.05 and for elasto plastic structural element it is considered as zero.

Hysteresis Model and Ground Motions: 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. 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 (Dutta et. al, 2005; Das and Dutta, 2003).

Real ground motions of near-fault nature are considered in the present investigations are collected from strong motion data base available from PEER stronge motion database. 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 Three set of real ground acceleration time history is considered and each set consists of two ground acceleration data in two mutually orthogonal direction has been use as input ground motion. One component of data with maximum peak ground acceleration considered as fault parallel motion, arbitrary assumed acted 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 below:

Results: Displacement responses of bi-directionally eccentric structural systems with different unequal values of eccentricities are presented in normalized form. Normalization is done by the displacement responses of similar but symmetric structural systems to investigate only the effect of asymmetry. Fig. 2 – Fig.5 show response of degrading structures (δ= 0.05) representing buildings with reinforced concrete structural elements and also shows variation of displacement of elasto plastic steel structural elements under three different seismic events with different time period and eccentricities. In each of the figure normalized maximum displacement response is plotted against torsional to lateral period ratio τ (TAU). Four different curves in each figure represent normalized maximum displacement response of a) Flexible element in *x* direction (NDSPFLX), b) Stiff element in *x* direction (NDSPSTX), c) Flexible element in *y* direction (NDSPFLY) and d) Stiff element in *y* direction (NDSPSTY)

Seismic Events	Station	Date	Distance	M
Coyot Lake	Girloy Array	06. 08. 1979	7.95 km	5.9
Mammoth Lakes	Convict Creek	25. 5.1980	10.91 km	6.2
West-Morland	West- moorland fire sta.	24. 11. 1987	19.51 km	6.54

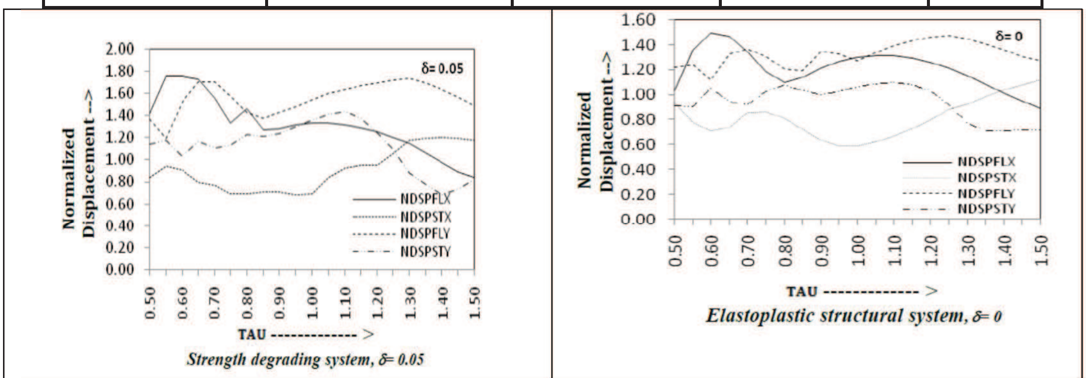
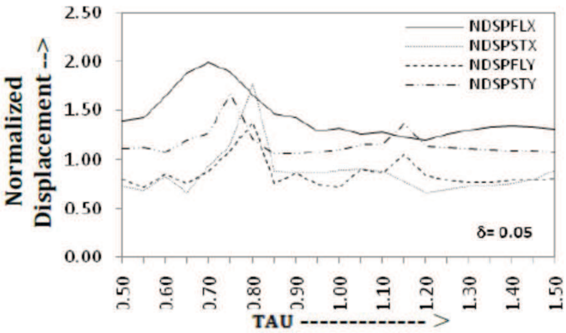
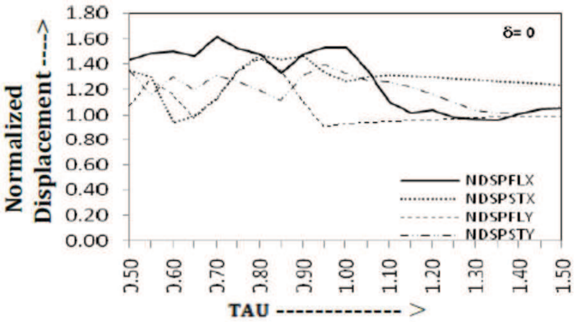


Fig2. Response for T_l **=0.1s,** e_x, e_y/D **= 0.05 (Coyot Lake Eq.)**

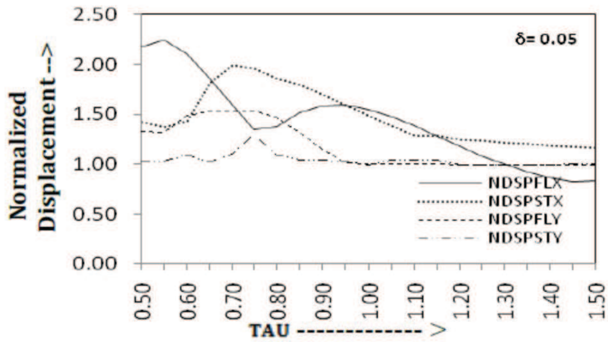


Strength degrading system, δ= 0.05

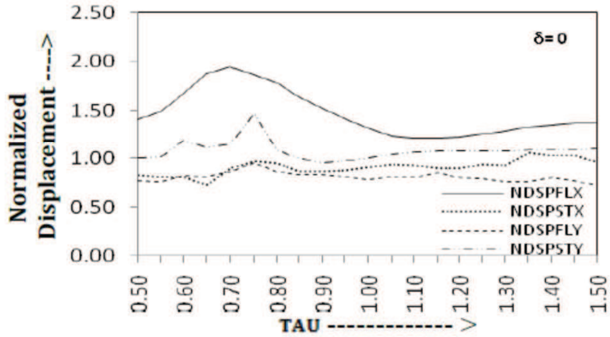


Elastoplastic structural system, δ= 0

Fig3. Response for T_l =0.1s, e_x/D= 0.2 e_y/D= 0.05 (Mammoth Lake Eq.)

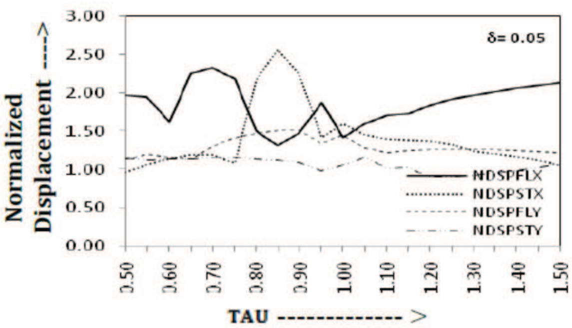


Strength degrading system, δ= 0.05

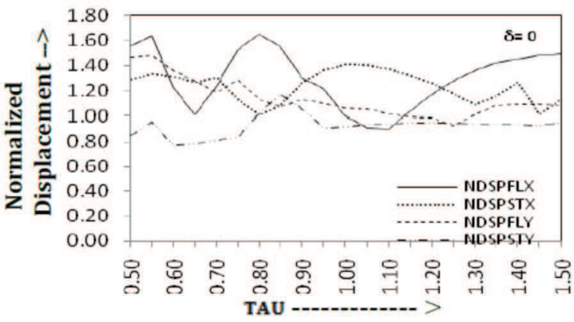


Elastoplastic structural system, δ= 0

Fig 5. Response for T_l =0.2s, e_x/D= 0.1, e_y/D= 0.2 (Coyot Lake Eq.)

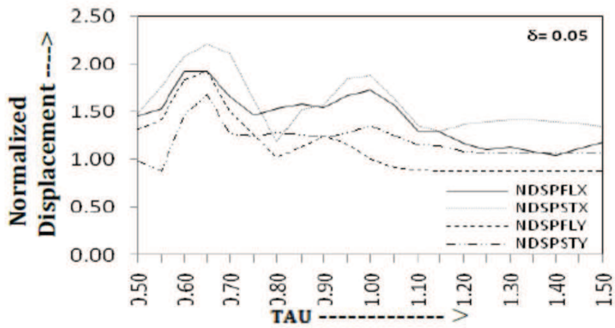


Strength derading system, δ= 0.05

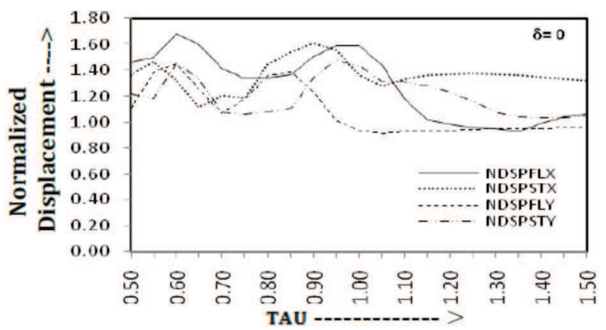


Elastoplastic structural system, δ= 0

Fig4. Response for T_l =0.1s, e_x/D= 0.2, e_y/D= 0.05 (Westmorland Eq.)



Strength degrading system, δ= 0.05



Elastoplastic structural system, δ= 0

Fig6.. Response for T_l =0.2s, e_x/D= 0.1, e_y/D= 0.2 (Mammoth Lake Eq.)

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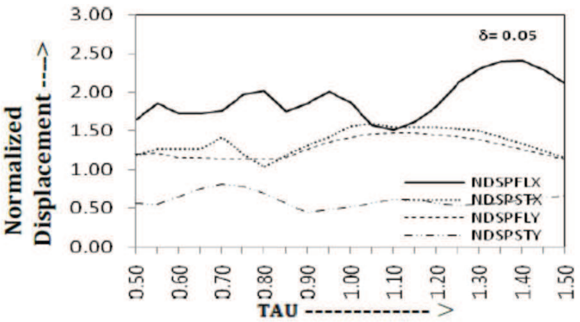
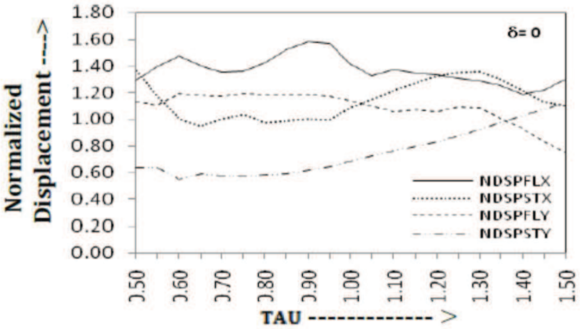
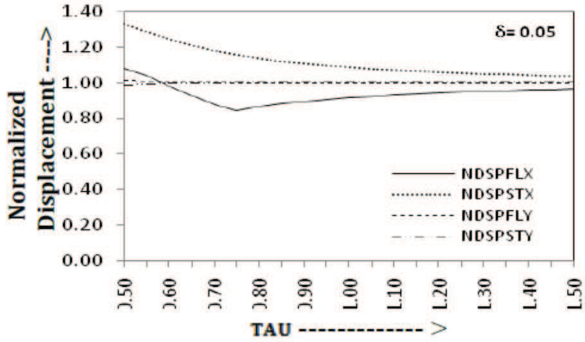


Strength degrading system, δ=0.05

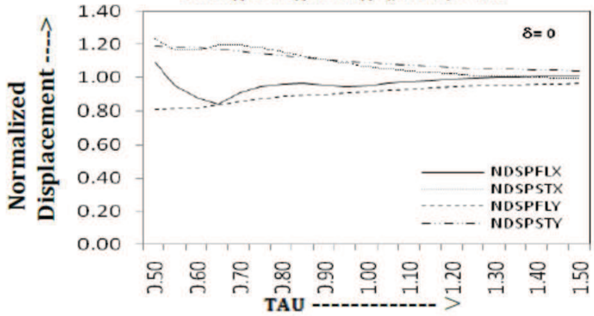


Elastoplastic structural system, δ= 0

Fig7.. Response for T_l =0.2s, e_x/D= 0.1 , e_y/D= 0.2 (Westmorland Eq.)

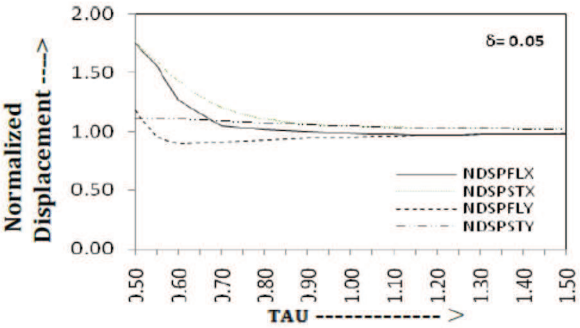


Strength degrading system, δ=0.05

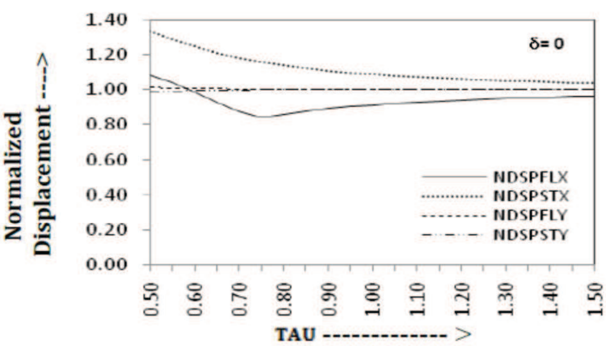


Elastoplastic structural system, δ= 0

Fig9 . Response for T_l =0.2s, e_x/D= 0.1 e_y/D= 0.2 (Mammoth Lake Eq.)

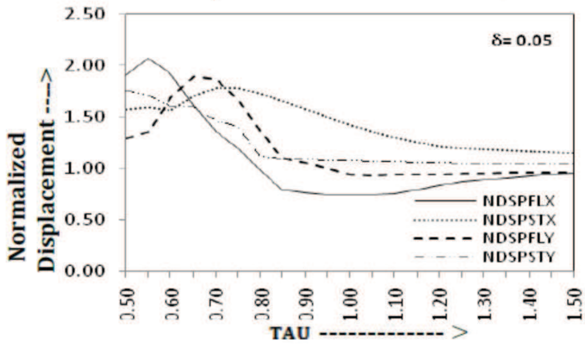


Strength degrading system, δ=0.05

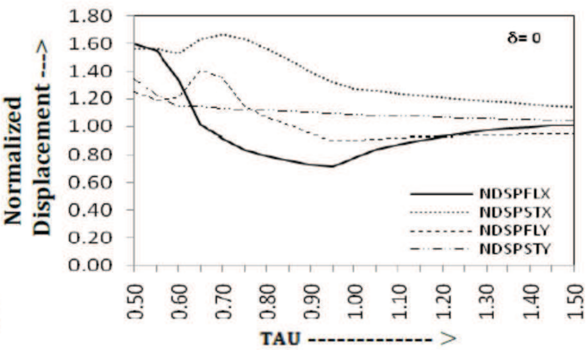


Elastoplastic structural system, δ= 0

Fig8 : Response for T_l =0.5s, e_x/D= 0.1 , e_y/D= 0.2 (Coyot Lake Eq.)



Strength degrading system, δ=0.05



Elastoplastic structural system, δ= 0

Fig10 : Response for T_l =0.5s, e_x/D= 0.1 e_y/D= 0.2 (Westmorland Eq.)

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Conclusions: Careful comparison of strength degrading graph (d= 0.05) and elasto plastic (d= 0) graph of Fig.2 – Fig. 10for three different seismic events 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 structural systems under near-fault ground motions considering variations in different dynamic characteristics is the need of the hour.

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