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Inelastic seismic performance of low-rise multi-story structure in hilly areas subjected to ground excitation: Controlling by TLD

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Abstract – *This study examines the inelastic seismic response of an idealized low-rise multi-story RC structural system in hilly regions under sloppy ground subjected to bi-directional ground motion. In this exertion, models have various degree of inelasticity, are subjected to a set of far-field ground motion with different characteristics for MDOF asymmetric structural system. The columns have varying height owing to sloping ground conducted different angle of slopes (θ) like 15° and 25°analyses on asymmetric system for evaluation the overall performance of load resisting elements and their mitigation technique due to uncontrolled vibration using beam-column joint (BCJ) and also essential modern technique of tuned liquid damper (TLD). The broad conclusions presented in this study help to fine tune the provisions in the seismic code.*

Key Words: **Inelastic response, Seismic performance, Sloppy ground, Bi-directional, Angle of slopes, Beam-column joint, TLD.**

1. INTRODUCTION

The deficiency of single-story buildings in hilly areas can be observed a major serious challenging issue throughout the globe due to ground motion [1]. The seismic performance of buildings depends on shape and plan of structural elements. In that case, hilly areas structures are constructed based on ground orientation makes the structure irregular with vertical and horizontal setback. Generally, ground motion behaves like a vector formation that is N-S and E-W direction. This bi-directional excitation created the vulnerability of structures for both configurations majorly that the eye-witness Nepal 2015, Sikkim 2011, Kashmir 2005 etc. were already recorded. The position of columns on sloppy ground terrains fabricate an irregular weak supporting frame work that induced a torsional effect in an inelastic region of load resisting structural elements owing to ground motion. This serious condition makes unease for developing the foundation strong for ages. Some new observations need should be made on keeping in mind the overall particular matter so that seismic safety mitigation techniques solve the problems and also favor the code provision more updated. Asymmetric structures are more vulnerable than the symmetric counterparts due to lateral and torsional coupling at different stiffness and mass eccentric conditions. Several earthquake phenomena indicate the elemental deformation causes due to low quality materials use and the proper designing program of structural construction with respect to the plan orientation in hilly region show in Fig. 1. Researchers have been developed some serious configuration on about single-story systems in hilly areas [1], where the construction of multi-story structure is limited to thinking. But because hilly stations have become tourist place now, multi-story structure is being constructed randomly. The survey showed that up to 4-story system has been developed in northern and north-east region in our country. Also, those multi-story structures have been constructed without following the story limit code guidelines and even recently. Apart from that, the limitation is not fixed in the code. Therefore, it is very important to provide a new safety guideline for all constructions now for control the major vulnerability of structural elements due to ground vibration. Even if necessary, to use damper [1] as a modern technique to see how much vibration control can be achieved for pre and post construction and for human life safety. Researchers have been differentiated the seismic response on multi-story building between different sloping ground angle and flat ground in seismic zone II that conclude the response of flat ground is suitable than sloping ground [2, 11]. Furthermore, assessment of seismic response for multi-story irregular building on different slope angles have been developed by some researchers recently that conclude the same result aspect of previous issue [2, 3]. Recently, a review study has been necessary on seismic performance of MDOF system in hilly areas [4, 7]. Moreover, the dynamic response has been conducted by some researchers on hilly stations in MDOF asymmetric system that clearly shown that the response has increased with increasing the sloping angle, as a result elemental deformation shows a major vulnerability [5, 6, 8-10]. The significant less amount of work has been done in this case, but the aperture indicates the judgmental response of sloppy ground structures due to seismic synthetic bi-directional ground motions of asymmetric multi-story systems in a critical seismic zone IV in India. In this backdrop, this case study reckons to estimate the inelastic seismic response of low-rise multi-story bi-directional asymmetric structural system owing to bi-directional ground motion at different angle of slopes in hilly terrain. Moreover, different parameters are considered and lies in a feasible range for this system under the inelastic range. It is also intended to investigate the effect of incorporation of bi-directional interaction for both systems in terms of displacement of edge lateral load resisting elements for the satisfactory of this effectiveness in critical phase that should be useful for practical and design purposes also believed to be new approach. Keep in mind the vulnerability of the structure, the controlling technique being

Fig. 1. Damage and collapse of multi-story buildings due to major earthquake in hilly areas.

shown in this study, BCJ can be considered as a significant technique by observe field survey which is shown in Fig. 1. TLD can be used along with BCJ for safety and resist the maximum deformation of load resisting elements of sloppy ground in hilly areas. For many years, researchers have been worked with TLD [1] that observed to control the dynamic loads. So, our observation is not considered to be beam-column joint only, parallelly the use of TLD and both cases cooperatively. In that case, observation not only consider the interior section of structural elemental deformation but also the serviceability of exterior section of structures that deal a serious challenging issue all over India.

2. STRUCTURAL IDEALIZATION

In this study, two typical idealized multi-story structures are developed under the sloping ground terrain in different slope angle show in Fig. 2, where the columns are free from each other situated below the basement slab show in Fig. 2(a). On the other hand, another system is developed with beam-column joint show in Fig. 2(b) with same idealization for assessing the overall response for both cases and their serviceability due to ground excitation. Fig. 2(a) shows the passive vibration control device consist a rigid square steel liquid (water) container with concrete support basement which is connected to the top-mid of the structure that reduce structural vibration by sloshing of liquid inside the tank. The mass of TLD with liquid is m. The liquid sloshing can move in a coupled horizontal (x-direction) and rotational (θ_b) direction. This horizontal force (F) developed due to sloshing of liquid in TLD with stiffness of K_t. The length (l) and width (b) of system are considered 3m × 3m, also the depth of liquid (h_0) = 0.5m and sloshing liquid depth (h) = 1m at a section in TLD. The rotational motion of TLD with liquid is specified by θ_t for density of liquid (ρ). The average velocity of liquid at x-direction considered V_{avg}. Therefore, the governing equations are adopted by previous case study [1, 17] to assess the reducing percentage of vibration. All parameters are considered in a specific limit from past issue [1]. The simplified model even can used to at least to grossly understand the seismic performance in inelastic region. In this study, idealized three story structural system is represented namely bi-directionally asymmetric system where the eccentricity is caused by the stiffness and mass eccentricity at each story show in Fig. 3. The same six-element system was also developed by some researchers in earlier studies [12, 14]. Generally, building structures have load resisting elements scattered over the plan of building. Accepting the same for the purpose of analysis an idealized system of six load resisting elements have been considered with details variation of stiffness and mass distribution, whereas mid two elements are considered in one specific element at each story. The system has three degrees of freedom at each story and contemplate of a rigid deck supported by three lateral load-resisting structural elements in each of the two translations in two orthogonal directions and one rotational.

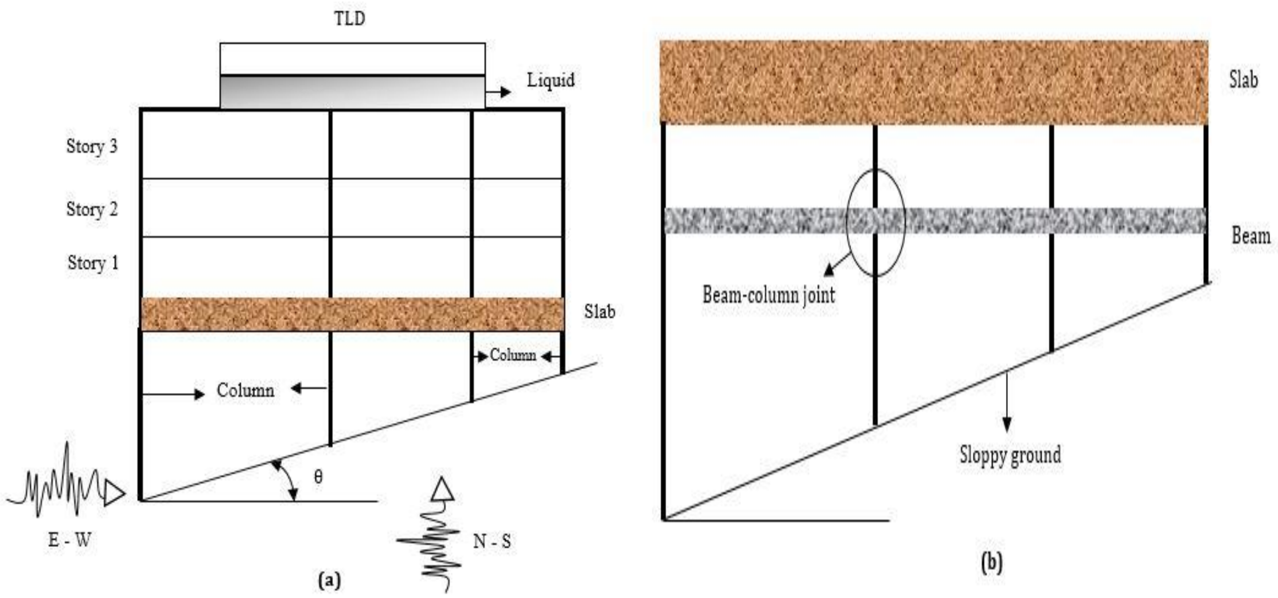

Fig. 2. Idealized multi-story irregular model Structure.

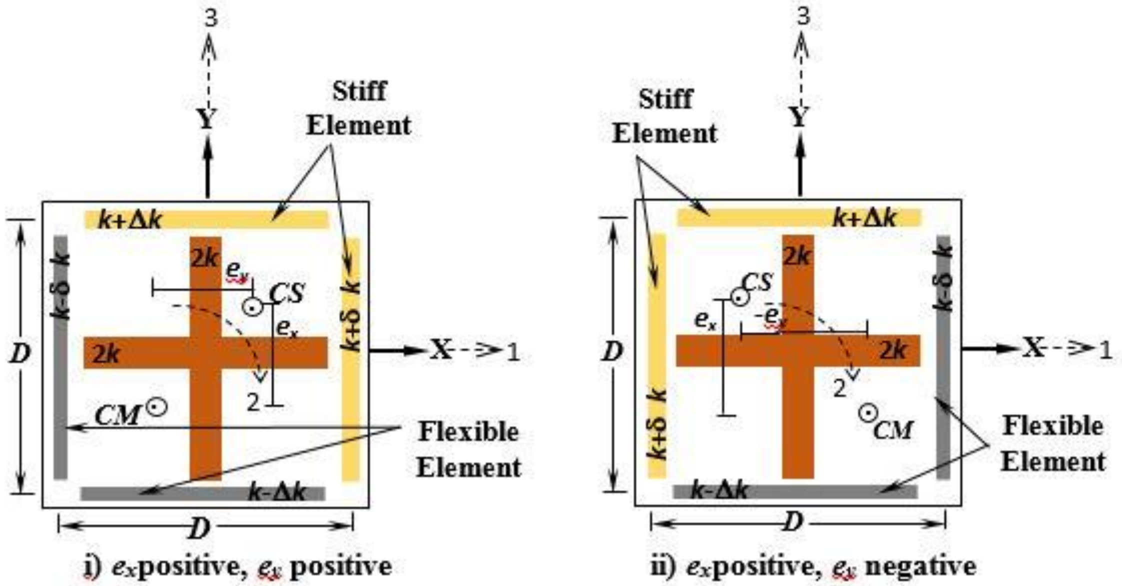

Fig. 3. Bi-directionally asymmetric system.

The frames or walls having strength and stiffness are represented by the lateral load-resisting structural elements in their planes only. The distribution of both the orthogonal directional is perfectly accounted for the reference asymmetric system as shown in Fig. 3 by assigning stiffness is 2k to the middle Element 5 (ME) that is 50% of the total stiffness 4k, represent through Element 5. The remaining 50% is equally distributed between two edge elements thus each of them has stiffness k, represent through Element 1 (Flexible, Flexible (FF)), Element 2 (Flexible, Stiff (FS)), Element 3 (Stiff, Stiff (SS)) and Element 4 (Stiff, Flexible (SF)). In this model structure, the location of the center of mass (CM) and center of stiffness (CS) recline at the different eccentric location in opposite position towards the principal axis of system for each story. Although the CM can be explained at each story for such structures, whereas the definition of CS is much more complicated due to the load resisting elements are connected to the upper to lower of the stories. In this case study, the position of CM and CS lies in a two different vertical axis at each story connection and by the by connected on a single common axis. The lateral load-resisting edge elements with less stiffness were considered like flexible elements and the opposite edge elements having greater stiffness were represented to as stiff elements. The distance D is same between two extreme lateral load resisting elements in two orthogonal direction. The specific bi-directionally asymmetric system eccentricity is initiated by increasing the stiffness of one edge element and decreasing that of the element at the opposite edge. In such bi-directionally multi-story asymmetric systems, eccentricities are symbolized by e_x and e_y that lies between the distance of CM and CS with respect to principal axis of system for both conditions. Distribution of stiffness and mass eccentric conditions are balanced for both eccentricities' e_x and e_y with the positive sense where CS lies in the first quadrant and CM lies in third quadrant as shown in Fig. 3(i). Another system shows that the negative eccentric sense that is e_x and $-e_y$ where CS lies in the second quadrant of the principal axis of the system and CM lies in forth quadrant as shown in Fig. 3(ii). The two possible cases for bi-directionally eccentric system is taken depending on as also found in the previous literature that the combination of eccentricity e_x and eccentricity e_y in different quadrant may alter the result considerably [12, 14]. The stiffness eccentric system is chosen as few literatures in this particular field has only considered asymmetric system for mass eccentricity [14]. Such this study gives an idea about the nature of eccentricity makes any difference or not in the behavior.

3. METHODOLOGY

The non-linear equation of motion show in eq. 1. is numerically solved in time domain using Newmark's β-γ method and by the by modified Newton-Raphson technique is used for iteration. The Newmark's parameters are chosen as $\gamma = 0.5$ and $\beta = 0.25$ [12-16]. The results are computed with various sizes of time step given by T_x/N, where T_x is the uncoupled lateral period and N is an integer number which is gradually increased by doubling it to obtain the results with better accuracy. For this purpose, considered time step of $T_x/400$ for appropriate determination of values [12-16]. Seismosignal V. 5.1.0 – A computer program that constitutes an easy and efficient way for signal processing of strong-motion data [online]; 2018, ed: available from URL: (http://www.seismosoft.com) and also added the essential parameters that is moment magnitude, closest site-to-fault-rapture distance, shear wave velocity, mean time period [12]. Using this essential software investigating the ultimate characteristic of ground acceleration motion capacity that has been acted on the structural members. Where, m, c and k are mass, damping matrices and stiffness matrices respectively. Here, $\{\ddot{u}\}, \{\dot{u}\}, \{\ddot{u}_g\}$ denote the acceleration, velocity and seismic ground acceleration vectors respectively.

$$m\left\{\ddot{u}\right\} + c\left\{\dot{u}\right\} + k\left\{u\right\} = -m\left\{\ddot{u}_g\right\} \quad \text{.........[1]}$$

4. GROUND MOTION

For the multi-story structural model an enhanced nonlinear dynamic analysis has been used which is capable to capture progressive seismic damage of structures under inelastic range. As scaled far-field (FF) ground motions are considered from Pacific Earthquake Engineering Research (http://peer.berkeley.edu) Center for the performance analysis. The ground motion is generated on a structural system like a vector formation, often oriented in north-south (N-S) and east-west (E-W) directions whereas the strong motion database for horizontal components of motions are generally available along orientations of recording which are often arbitrary. This recorded component is applied along two principal axes of the structure. Thus, it is often deduced that the arbitrarily placed recording sensors are aligned with the principal axes of structure. In this way, overall structural response of the MDOF system is estimated subjected to bi-directional FF synthetic ground motion history under hilly areas in India. The case studies in this paper are investigated for a set of fifteen bi-directional synthetic ground motions to resist any variability arising subjected to the particular characteristic of any specific ground motion [12]. Details of the ground motions are shown in Table 1. Selected ground motions in terms of geophysical parameters, viz., magnitude-distance-soil conditions triads. Motions are scaled appropriately to introduce a uniform level of inelastic action. For each component of a motion, this scale factor is decided observing the spectral acceleration of each original record component at the fundamental period of vibration of element in relation to the element capacity. Scale factors of two components of a record so computed are compared and the average factor is applied to the components. The peak ground acceleration (PGA) values are depends on about the moment magnitude (M_w), closest site-to-fault-rupture distance (r), shear wave velocity (V_s30) and mean time (T_m) [12]. All recoded parameters are considered in a justified range.

5. SYSTEM PARAMETERS

The variation of maximum displacement response may be influenced by several system parameters as well as loading considerations for valuable conclusions. These primarily considerable two dynamic control parameters namely the lateral natural period (T_x) and the uncoupled torsional-to-lateral period ratio (τ). This lateral periods (T_x) are considered for this

Table 1: Details of ground motions (FF) used.

Sl no.	Event (Year)	Record ID	Magnitude (M_W)	r(km)	Vs30(m/s)	PGA(m/s²)	
						X - Component	Y - Component
1.	Big Bear-01, 1992	RSN905	**6.46**	78.91	367.54	0.33	0.37
2.	Northwest China-01, 1997	RSN1748	**5.9**	24.06	240.09	2.68	2.29
3.	Northwest China-01, 1997	RSN1749	**5.9**	52.36	341.56	0.35	0.43
4.	Northwest China-02, 1997	RSN1750	**5.93**	37.26	240.09	1.22	1.41
5.	Northwest China-02, 1997	RSN1751	**5.93**	46.24	341.56	0.70	0.73
6.	Northwest China-03, 1997	RSN1752	**6.1**	17.73	240.09	2.94	2.68
7.	Northwest China-04, 1997	RSN1754	**5.8**	27.86	240.09	1.84	2.34
8.	Northwest China-04, 1997	RSN1755	**5.8**	40	341.56	1.32	0.82
9.	Kozani_ Greece-01, 1995	RSN1126	**6.4**	19.54	649.67	2.03	1.37
10.	Hector Mine, 1999	RSN1763	**7.13**	89.98	724.89	0.35	0.26
11.	Tottori_ Japan, 2000	RSN3950	**6.61**	74.62	284.59	0.79	0.80
12.	Tottori_ Japan, 2000	RSN3957	**6.61**	96.93	650	0.55	0.71
13.	FtPayne, 2003	RSN963	**4.62**	85.04	720	0.03	0.06
14.	RiviereDuLoup, 2005	RSN1794	**4.65**	176.32	665.9	0.12	0.08
15.	ValDesBois, 2010	RSN4039	**5.1**	138.29	591	0.18	0.24

MDOF asymmetric system 1.0sec, 2.0sec and 3.0sec in short to long period ranges. On the other hand, for most real buildings, the values of uncoupled torsional-to-lateral period ratio (τ) are varied within the range of 0.25-2.0 with an interval of 0.05 with 5% damping also used in previous research [1, 12, 14]. Influence the torsional effect for asymmetric system eccentricity is important criteria to observe the critical response of structural elemental deformation with respect on τ. Furthermore, the present study attempts to incorporate the analysis of the bi-directional asymmetric system into a feasible range of eccentric variation. The stability of a structure depends on the plan orientation where the stiffness and strength vary in many parts of interior and exterior section. On the other hand, the displacement and settlement of the soil masses can be displacing the position of the foundation and CG point of the structure. In this case study, the three typical eccentric parameters of this system are classified in terms of small, intermediate and large eccentric systems as represented as e/D = 0.05, 0.1 and 0.2 used in previous literature [1, 12, 14]. The combination of eccentric conditions in Table 2. have been considered at each level (up to three stories) due to which the critical response overwhelmed by each level has been highlighted in this paper. Hence, standard three combinations of eccentricity are considered along two principal directions as listed in Table 2. Asymmetric systems with stiffness and mass eccentricities are considered in this present study. On the other hand, beside of stiffness eccentric condition, strength eccentricity also influence the torsional behavior of buildings that varies as a fraction of stiffness eccentricity. A typical value of strength eccentricity (e_{st}) = e is considered in this study for observing the effect of asymmetry that is ignored in code design. All design parameters related to TLD are considered from previous literature [1] and others in practical observation. Generally, common buildings like residential building, hotel, office etc. are being built day after day without proper testing of construction materials. So, getting properly high stiffness and strength of load resisting elements is very difficult due to ground excitation causes stiffness and strength degradation. The three different values of ductility reduction factor (R_μ) = 4, 6 and 8 are chosen for this system only. These values are highly recommended by the different codes, such as ASCE 7-05 [18] and NEHRP [19].

Table 2: Combinations of eccentricity considered along two principal directions (***Note:*** e_x and e_y are eccentricity in x and y-axis respectively).

Sl. No.	e_x/D	e_y/D
1.	0.05	0.05
2.	0.05	0.1
3.	0.05	0.2

6. RESULTS AND DISCUSSION

The nonlinear dynamic analysis of multi-story structural system through mean element displacement under critical inelastic sense for standard two angle of slopes (15° and 25°) are presented with plotting as representative of the trend with the time variation lies between small to large lateral periods (T) that is 1.0sec to 3.0sec for asymmetric MDOF systems. Mean displacement response, as mentioned earlier [1], are presented and computed for the corner elements as these elements are more vulnerable owing to torsional and also lateral coupling in single-story asymmetric structures in hilly regions. In this study, the idealized low-rise multi-story asymmetric system has represented with four corner elements for each story (up to three stories). These elements are represented the overall seismic response for developing to the physical understanding of the behavior of bi-directionally multi-story asymmetric systems. Further, the mean maximum responses for fifteen FF ground motions are presented in a graphical formation. In the graphs, the mean maximum displacement response is plotted at ordinate and torsional to lateral period ratio (τ) at abscissa. Fig. (4) to Fig. (39) shows the ultimate scenario with three sets of graphs for the variation of response reduction factor (Rμ) and the angle of slopes (θ) at different lateral times. Further, each graph exhibits the response with different combination of bi-directionally eccentric system and for standard strength eccentricity (e_{st}) = e. Fig. (4) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 1.0sec where element 1 may leads to an increase in the dynamic maximum response with the value of τ up to 36.41, 49.18 and 80.65 times in story1, story2 and story1 for Rμ= 4 respectively. Additionally, element 2,4 for small, element 3,4 for medium and element 2,3 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness and mass eccentricities. On the other hand, Fig. (5) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 2.0sec where element 3 may leads to an increase in the dynamic maximum response with the value of τ up to 197.44, 179.94 and 239.62 times in story1, story2 and story2 for Rμ= 4 respectively. Additionally, element 1,2 for small, element 2,3 for medium and element 1,2 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness and mass eccentricities. The bi-directional eccentric combinations are represented through story wise stiffness and mass eccentric variations that influence stiffness degradation for connecting of each story level. Influence of ground motion characteristics on the nonlinear dynamic analysis, the response of asymmetric multi-story structural system is examined to achieve a fair insight into the behavior of such systems. These responses are easily compared to the previous case study [1] for understanding the better accuracy and the percentage of progressive damage of load resisting elements in sloppy ground conditions subjected to bi-directional ground motion excitation.

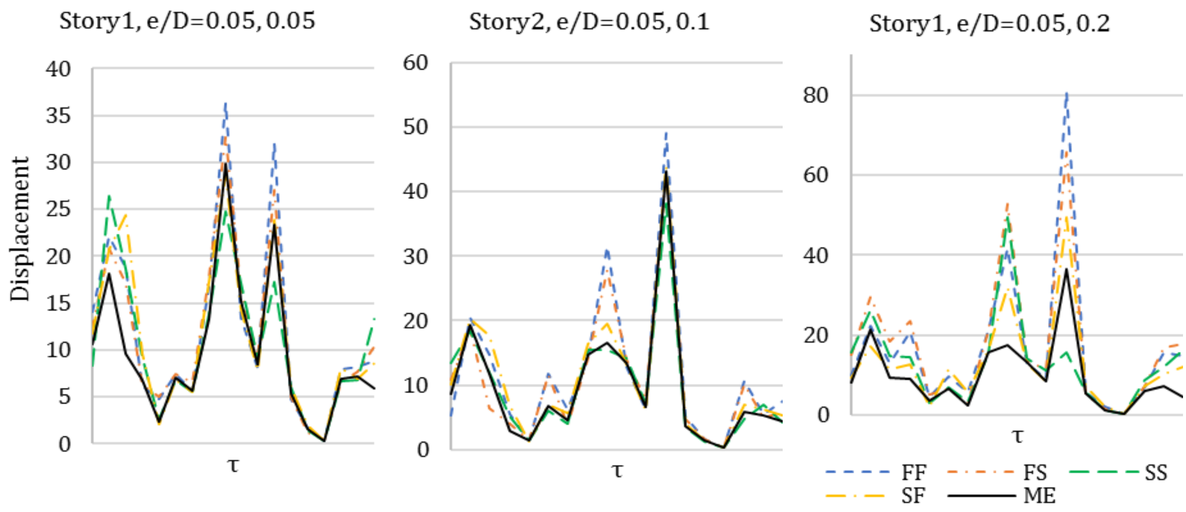

Fig. 4. Maximum displacement response of MDOF asymmetric system for T=1sec at 15° (Rμ=4).

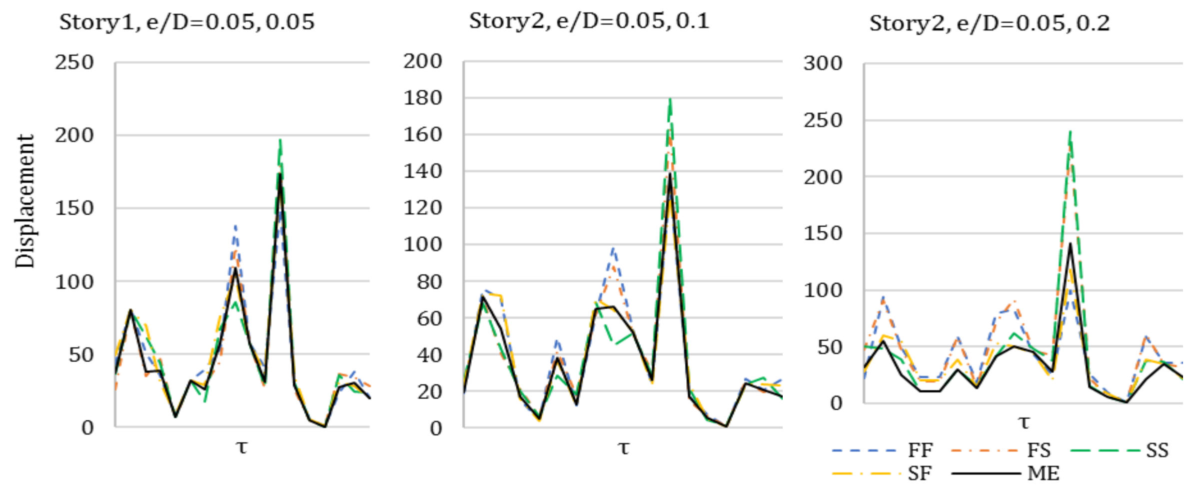

Fig. 5. Maximum displacement response of MDOF asymmetric system for T=2sec at 15° (Rμ=4).

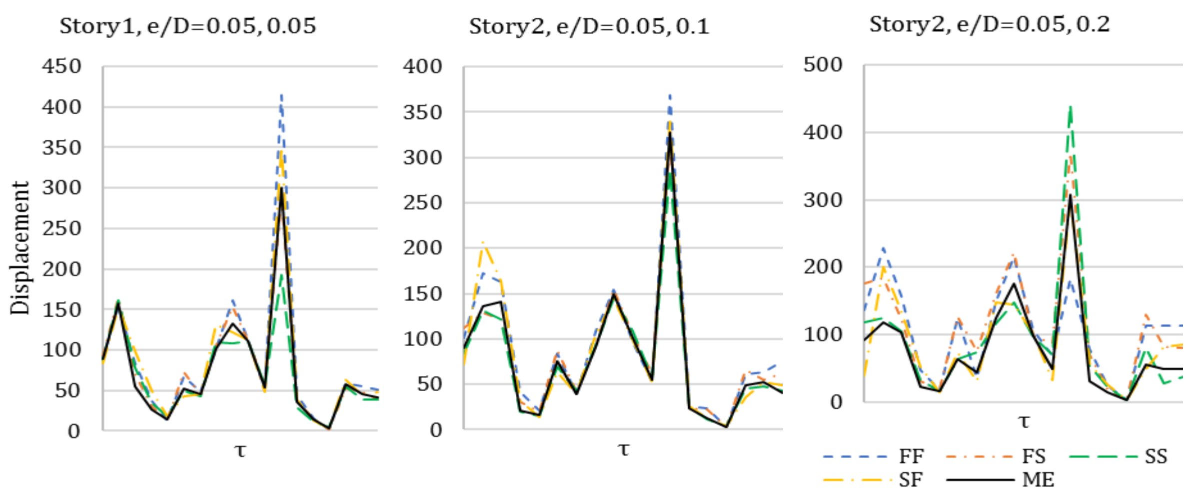

Fig. 6. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° (Rμ=4).

Fig. 7. Maximum displacement response of MDOF asymmetric system for T=1sec at 25° (Rμ=4).

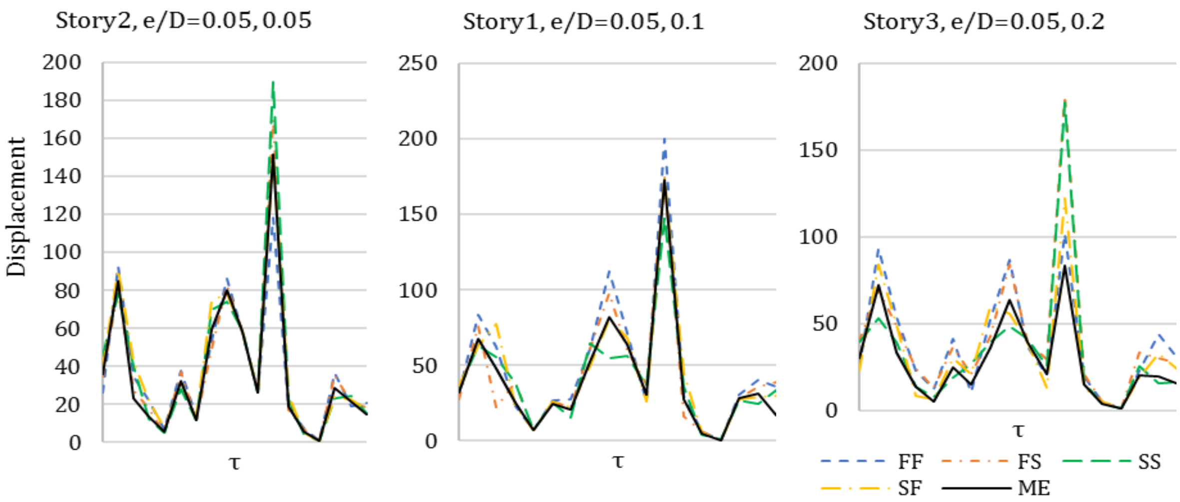

Fig. 8. Maximum displacement response of MDOF asymmetric system for T=2sec at 25° (Rμ=4).

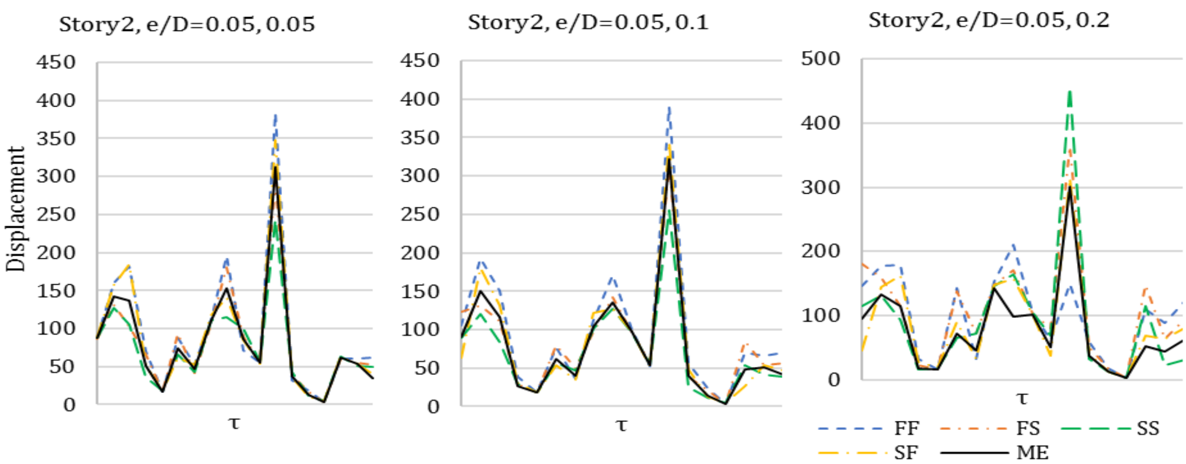

Fig. 9. Maximum displacement response of MDOF asymmetric system for T=3sec at 25° (Rμ=4).

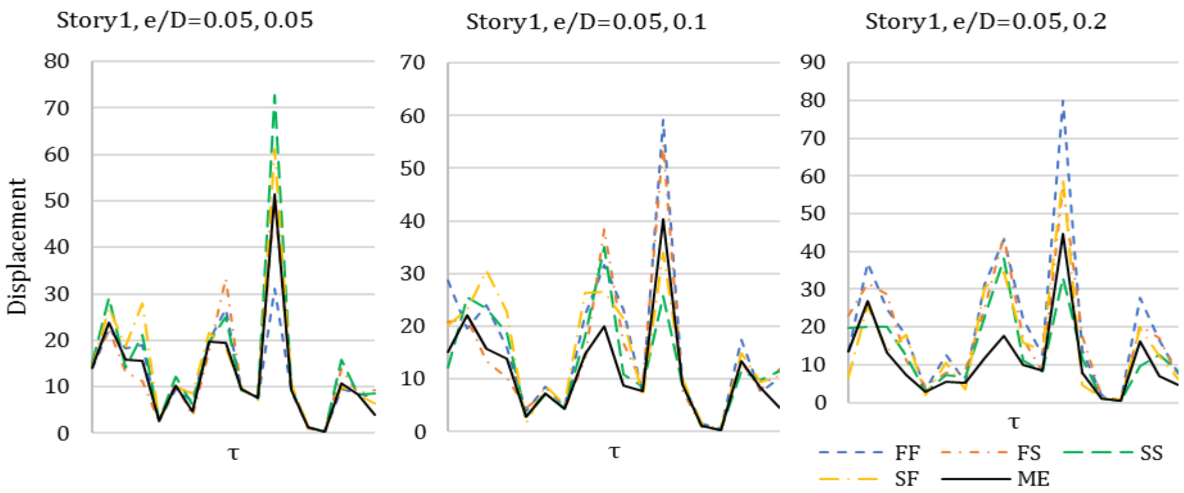

Fig. 10. Maximum displacement response of MDOF asymmetric system for T=1sec at 15° (Rμ=6).

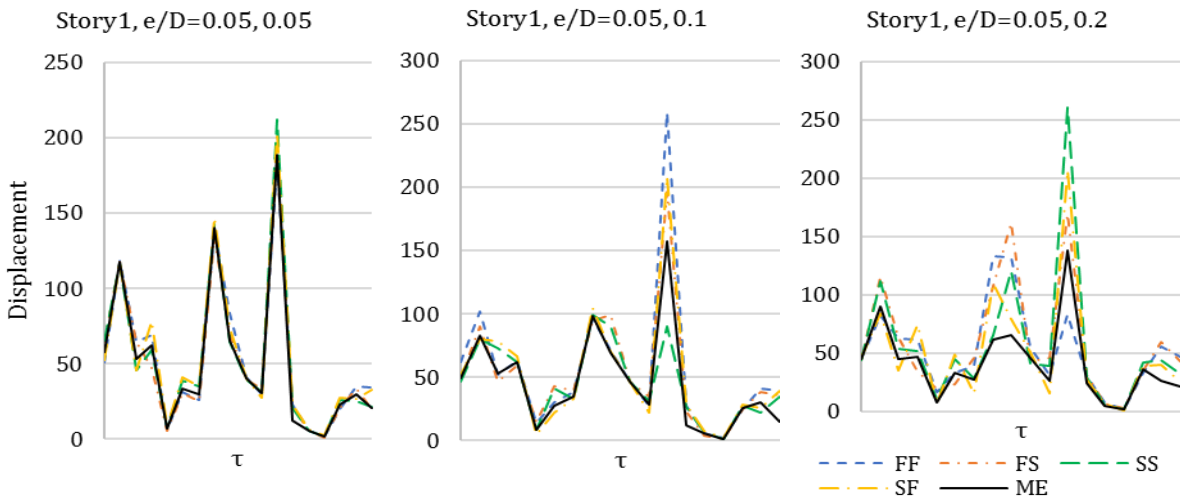

Fig. 11. Maximum displacement response of MDOF asymmetric system for T=2sec at 15° (Rμ=6).

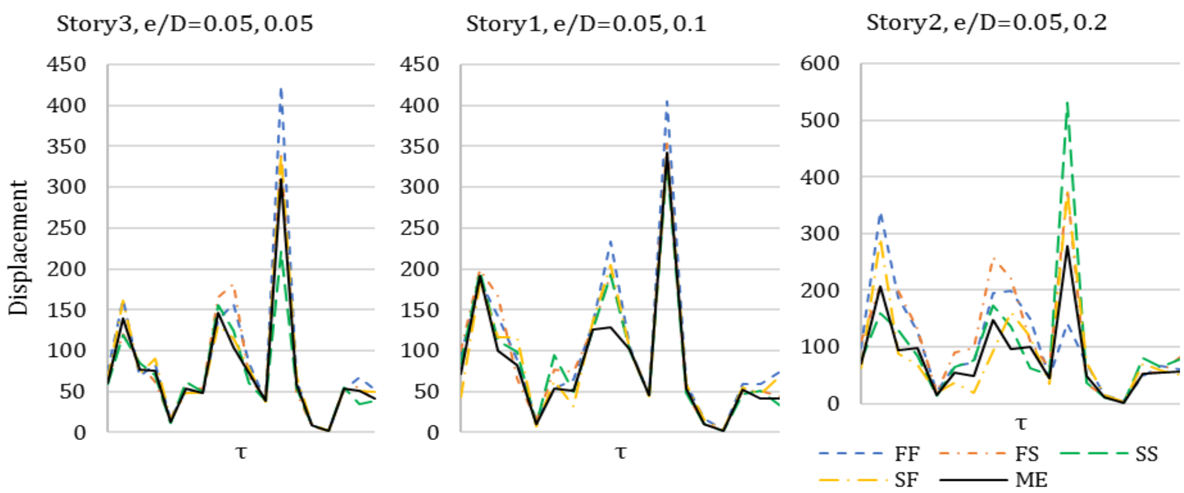

Fig. 12. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° (Rμ=6).

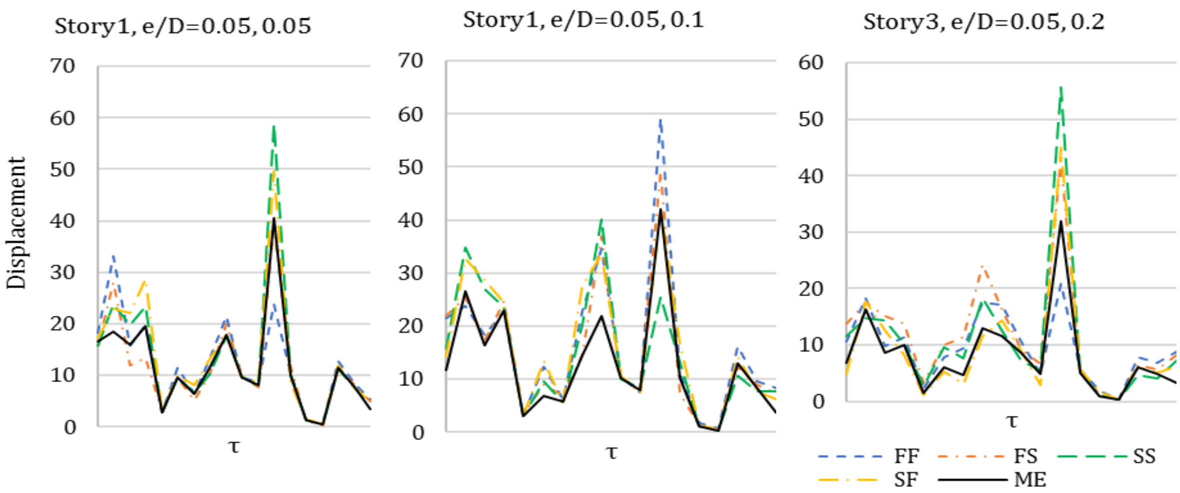

Fig. 13. Maximum displacement response of MDOF asymmetric system for T=1sec at 25° (Rμ=6).

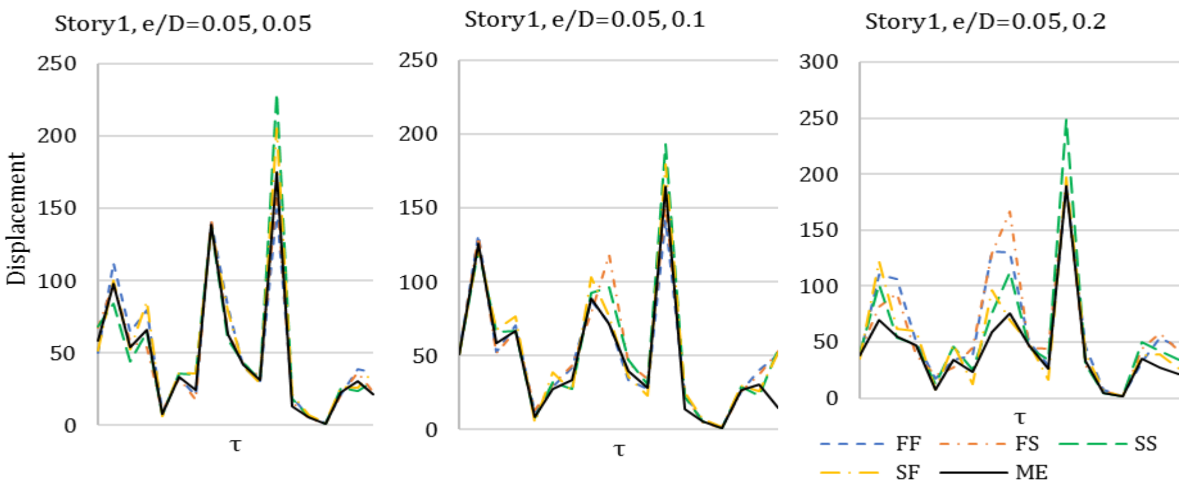

Fig. 14. Maximum displacement response of MDOF asymmetric system for T=2sec at 25° (Rμ=6).

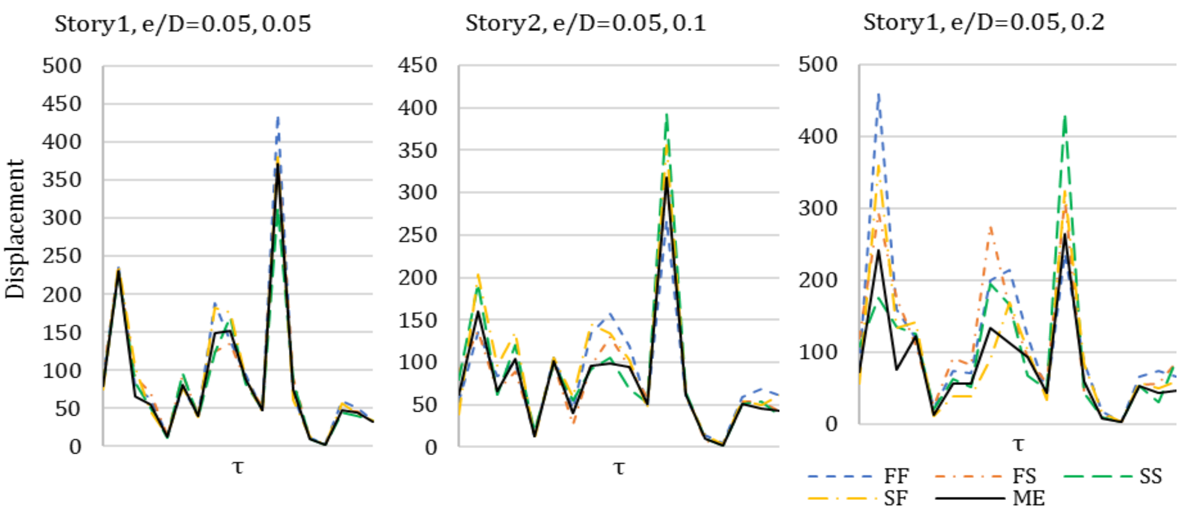

Fig. 15. Maximum displacement response of MDOF asymmetric system for T=3sec at 25° (Rμ=6).

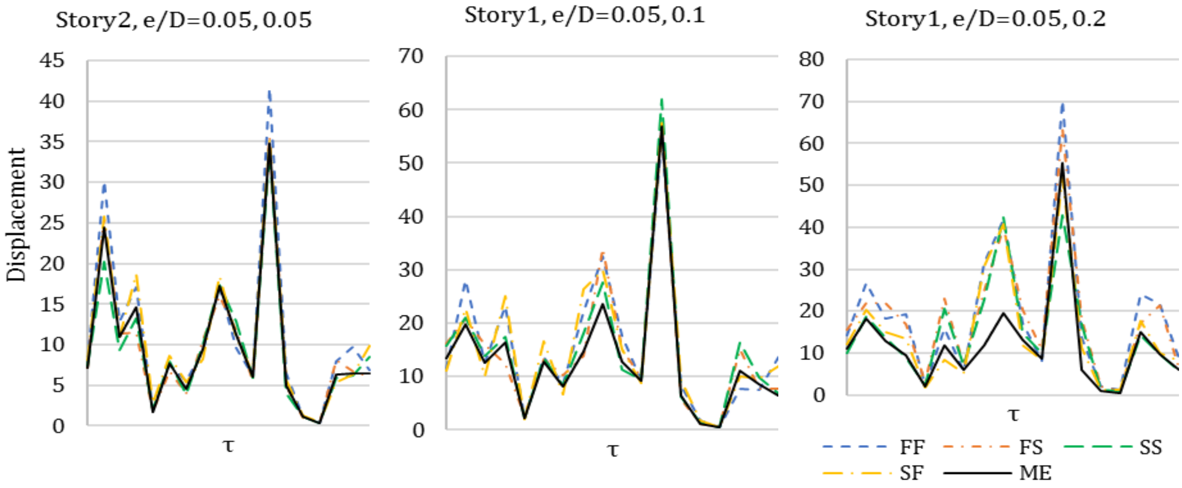

Fig. 16. Maximum displacement response of MDOF asymmetric system for T=1sec at 15° (Rμ=8).

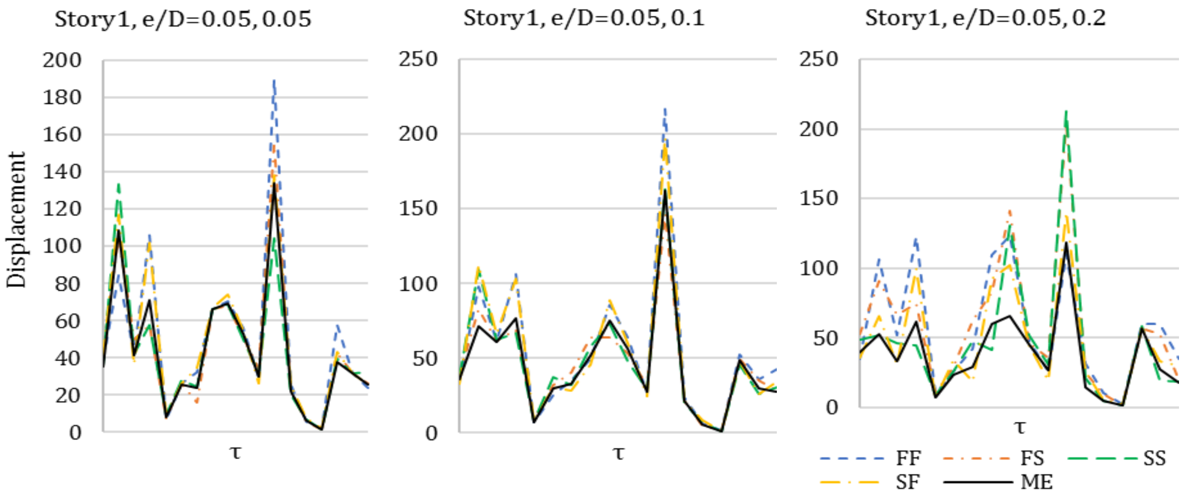

Fig. 17. Maximum displacement response of MDOF asymmetric system for T=2sec at 15° (Rμ=8).

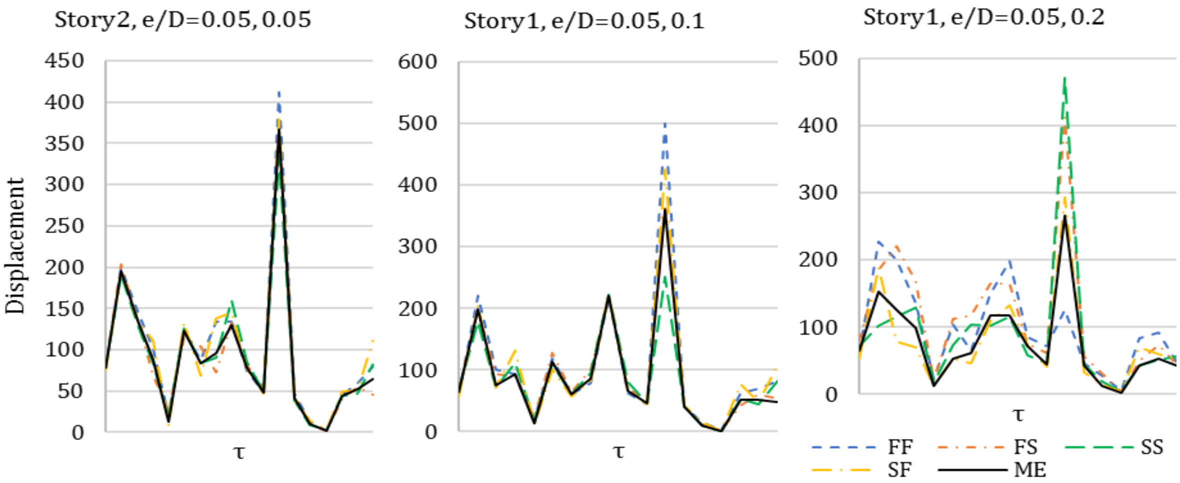

Fig. 18. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° (Rμ=8).

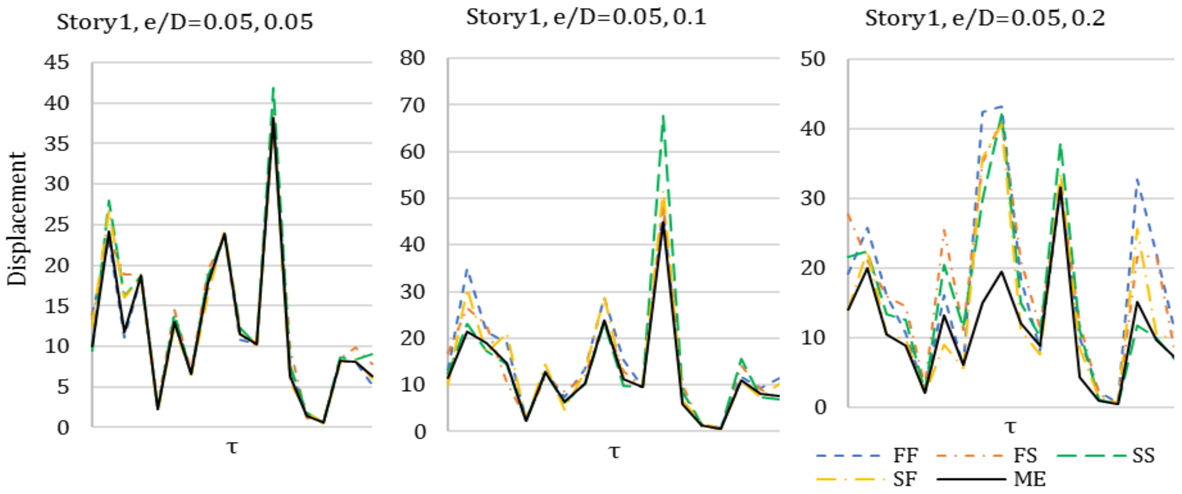

Fig. 19. Maximum displacement response of MDOF asymmetric system for T=1sec at 25° (Rμ=8).

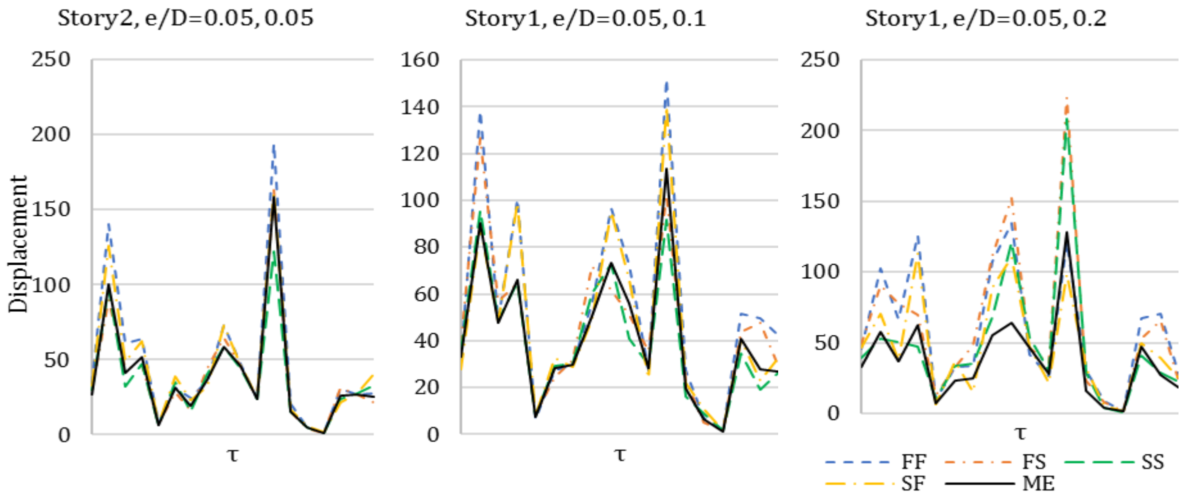

Fig. 20. Maximum displacement response of MDOF asymmetric system for T=2sec at 25° (Rμ=8).

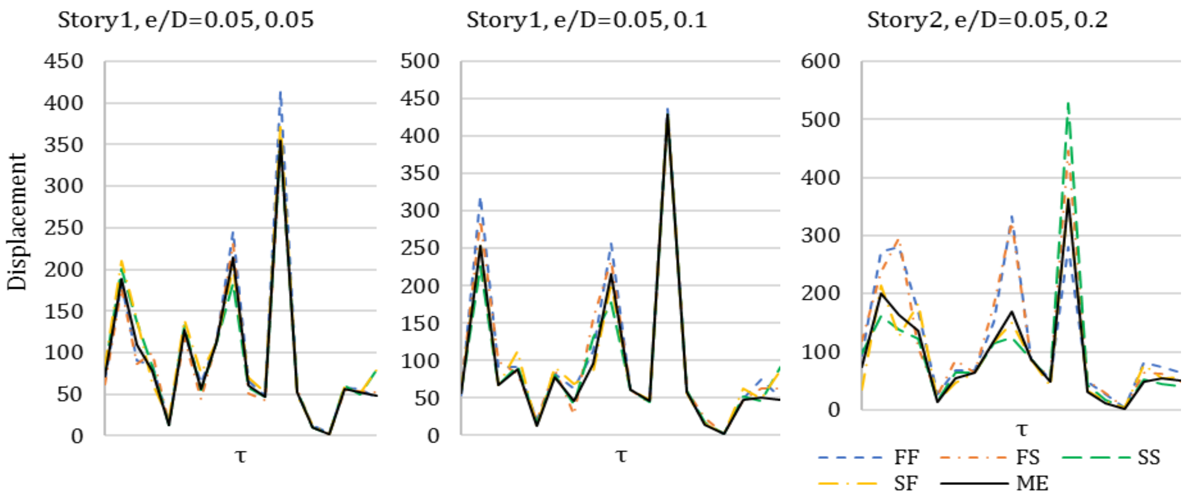

Fig. 21. Maximum displacement response of MDOF asymmetric system for T=3sec at 25° (Rμ=8).

The apparent response from the combination of these three standard eccentric conditions is represented for each story. Among them, the graphs are made by giving priority to the maximum response and considering each story. Since the scope is limited, the maximum response for each eccentricity is visible through that paper which story is more. Fig. (6) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where element 1, element 1 and element 3 may leads to an increase in the dynamic maximum response with the value of τ up to 414.60, 368.81 and 440.53 times in story1, story2 and story2 for Rμ= 4 respectively. Additionally, element 2,4 for small, element 2,4 for medium and element 1,2,4 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Fig. (7) describes the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 25° sloppy ground in 1.0sec where element 1 may leads to an increase in the dynamic maximum response with the value of τ up to 53.81, 46.36 and 66.43 times in story2, story2 and story1 for Rμ= 4 respectively. Additionally, element 2,4 for small, element 2,4 for medium and element 3,4 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Fig. (8) recites the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 25° sloppy ground in 2.0sec where element 3, element 1 and element 2 may leads to an increase in the dynamic maximum response with the value of τ up to 189.98, 199.86 and 177.71 times in story2, story1 and story3 for Rμ= 4 respectively. Additionally, other elements for small, element 2,4 for medium and element 1,2 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Fig. (9) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 25° sloppy ground in 3.0sec where element 1, element 1 and element 3 may leads to an increase in the dynamic maximum response with the value of τ up to 383.81, 389.86 and 455.43 times in story2 for Rμ= 4 respectively. Additionally, element 2,4 for small, element 2,4 for medium and element 1,2 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity.

Fig. (10) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 1.0sec where element 3, element 1 and element 1 may leads to an increase in the dynamic maximum response with the value of τ up to 72.84, 59.15 and 80.04 times in story1 for Rμ= 6 respectively. Additionally, element 2,4 for small, element 2,3 for medium and element 2,4 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Fig. (11) shows the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 2.0sec where element 3, element 1 and element 3 may leads to an increase in the dynamic maximum response with the value of τ up to 212.43, 259.64 and 260.84 times in story1 for Rμ= 6 respectively. Additionally, other elements for small, element 2,4 for medium and element 1,2 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Fig. (12) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where element 1, element 1 and element 3 may leads to an increase in the dynamic maximum response with the value of τ up to 424.39, 404.81 and 530.70 times in story3, story1 and story2 for Rμ= 6 respectively. Additionally, other elements for small, element 2,3,4 for medium and element 1,2 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Fig. (13) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 25° sloppy ground in 1.0sec where element 3, element 1 and element 3 may leads to an increase in the dynamic maximum response with the value of τ up to 58.74, 59.21 and 55.71 times in story1, story1 and story3 for Rμ= 6 respectively. Additionally, element 2,4 for small, element 2,3 for medium and element 1,2 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Also, Fig. (14) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 25° sloppy ground in 2.0sec where element 3 may leads to an increase in the dynamic maximum response with the value of τ up to 229.26, 192.98 and 249.17 times in story1 for Rμ= 6 respectively. Additionally, other elements for small, medium and element 2,4 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Fig. (15) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 25° sloppy ground in 3.0sec where element 1, element 3 and element 1 may leads to an increase in the dynamic maximum response with the value of τ up to 436.20, 393.22 and 459.31 times in story1, story2 and story1 for Rμ= 6 respectively. Additionally, other elements for small, element 2,4 for medium and element 2,3,4 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Further, Fig. (16) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 1.0sec where element 1, element 3 and element 1 may leads to an increase in the dynamic

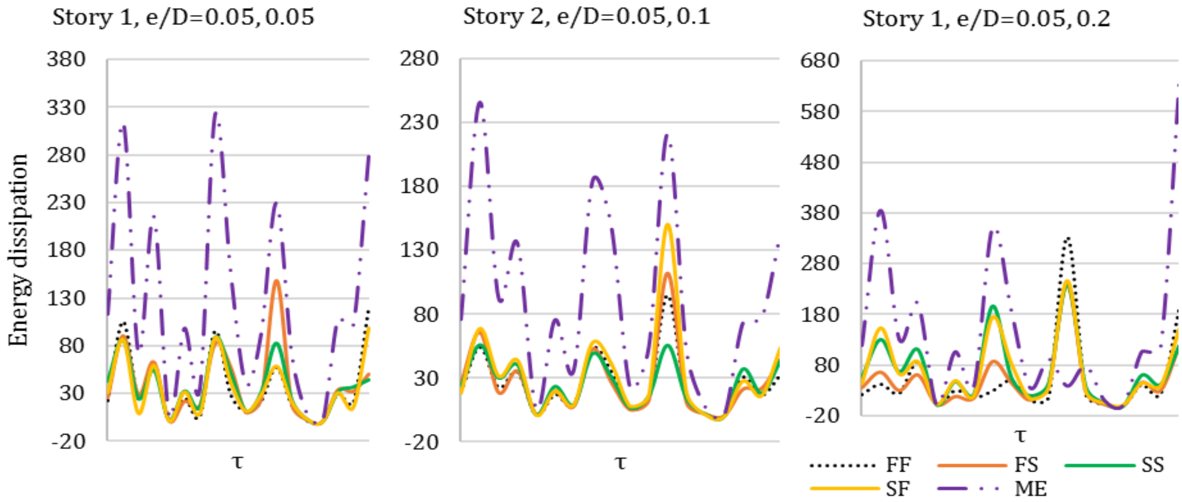

Fig. 22. Maximum energy dissipation response of MDOF asymmetric system for T=1sec at 15° (Rμ=4).

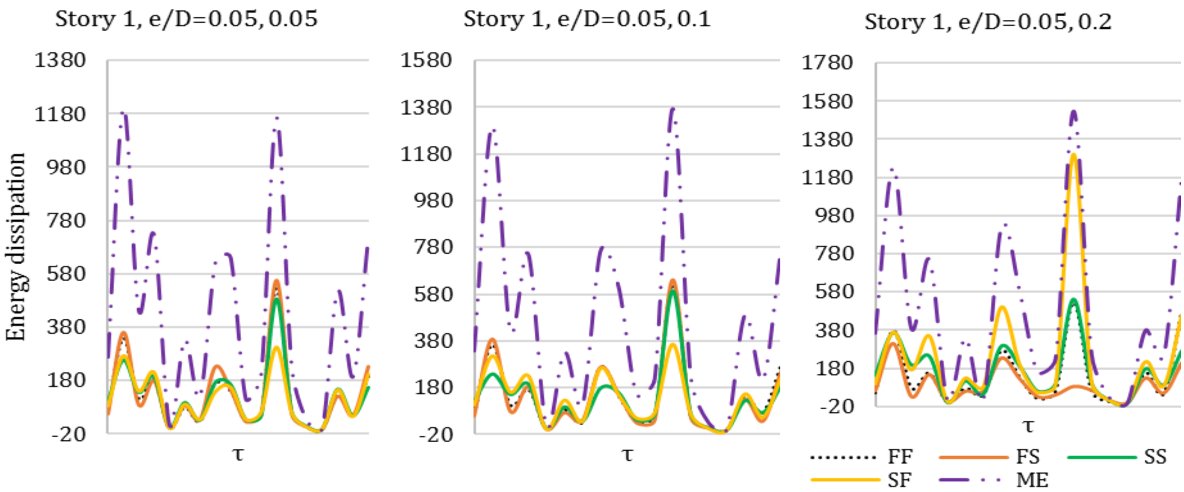

Fig. 23. Maximum energy dissipation response of MDOF asymmetric system for T=2sec at 25° (Rμ=6).

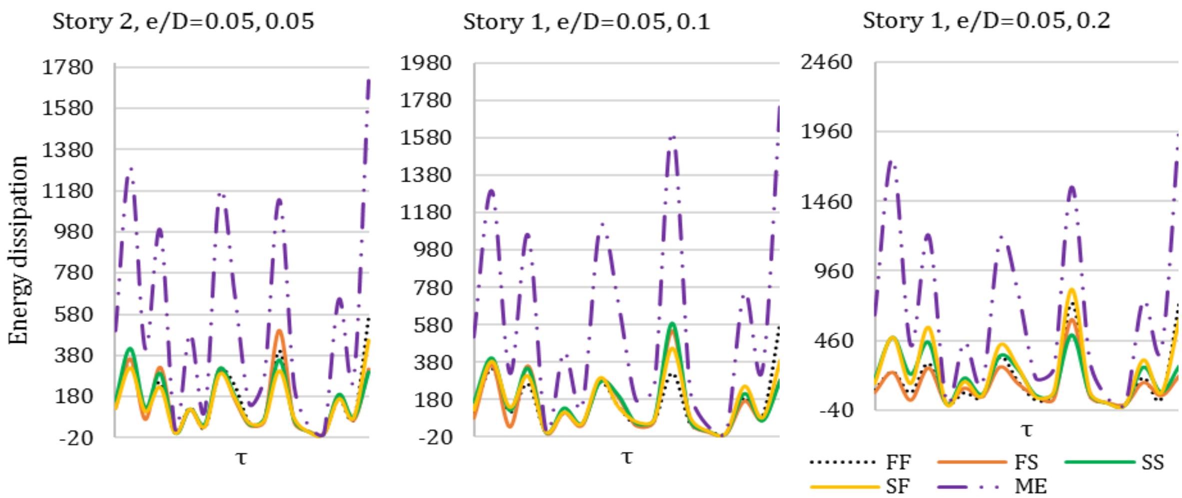

Fig. 24. Maximum energy dissipation response of MDOF asymmetric system for T=3sec at 15° (Rμ=8).

Maximum response with the value of τ up to 41.62, 61.96 and 70.15 times in story2, story1 and story1 for Rμ= 8 respectively. Additionally, other elements for small, element 2,4 for medium and element 1,2,4 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Fig. (17) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 2.0sec where element 1, element 1 and element 3 may leads to an increase in the dynamic maximum response with the value of τ up to 189.71, 216.82 and 212.50 times in story1 for Rμ=8 respectively. Additionally, other elements for small, element 2,4 for medium and element 1,2,4 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Also, Fig. (18) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where element 1, element 1 and element 3 may leads to an increase in the dynamic maximum response with the value of τ up to 412.13, 500.87 and 470.96 times in story2, story1 and story1 for Rμ=8 respectively. Additionally, other elements for small, element 2,4,5 for medium and element 1,2 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Furthermore, Fig. (19) display the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 25° sloppy ground in 1.0sec where element 3, element 3 and element 1 may leads to an increase in the dynamic maximum response with the value of τ up to 41.84, 67.67 and 43.24 times in story1 for Rμ=8 respectively. Additionally, element 2,3,4 for small, element 1,4 for medium and element 2,3,4 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Fig. (20) shows the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 25° sloppy ground in 2.0sec where element 1, element 1 and element 2 may leads to an increase in the dynamic maximum response with the value of τ up to 194.39, 151.71 and 223.38 times in story2, story1 and story1 for Rμ=8 respectively. Additionally, element 2,4 for small, element 2,4 for medium and element 1,2,3 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity. Finally, Fig. (21) represents the response for different bi-directional eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 25° sloppy ground in 3.0sec where element 1, element 1 and element 3 may leads to an increase in the dynamic maximum response with the value of τ up to 414.04, 436.80 and 528.76 times in story1, story1 and story2 for Rμ=8 respectively. Additionally, other elements for small, element 2,4,5 for medium and element 1,2 for large eccentricities shows a similar trend of response may be due to similar combination of stiffness eccentricity.

Inelastic response is also assessed through maximum hysteretic energy ductility demand (MHEDD) for various lateral times, angle of slopes and the ductility reduction factor. This estimation is plotted depends on traditional bi-directional eccentric systems with three sets of graphs conduct with torsional effect. From Fig. (22) to Fig. (24) represents the maximum hysteretic energy ductility demand for each story level and also shows the maximum responses by graphical representation. Fig. (22) shows the maximum response for eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 1.0sec where element 5 may leads to an increase in the dissipated maximum response up to 322.6, 245.84, 635.15 in story1, story2 and story1 for Rμ=4. Further, other four elements show a similar trend of response accept element 2, element 4, element 1 respectively. Fig. (23) shows the maximum response for eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 25° sloppy ground in 2.0sec where element 5 may leads to an increase in the dissipated maximum response up to 635.15, 1200.81, 1375.28 in story1 for Rμ=6. Further, other four elements show a similar trend of response accept element 4 respectively. Fig. (24) shows the maximum response for eccentric combination of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where element 5 may leads to an increase in the dissipated maximum response up to 1715.05, 1783.18, 1995.45 in story2, story1 and story1 for Rμ=8. Further, other four elements show a similar trend of response accept element 2 and element 1 respectively.

It is so much essential criteria to control the major vibration for highly lateral timing accepting to observe the seismic performance due to bi-directional interaction. Keep in mind, a modern medium has been adopted to control the critical response of low-rise multi-story structure, which is situated in two different story level like story 2 and story 3. The visible thing is how much percentage of elemental deformation response is decreasing through this TLD. It is shown from Fig. (25) to Fig. (30) with respect to third story. On the other hand, from Fig. (31) to Fig. (36) shows the response where TLD consider at second story level. Fig. (25) shows the reduction response for standard three bi-directional eccentric conditions of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where elements may lead to reduce the percentage up to 42.63, 45.81 and 43.12 for Rμ=4 respectively. Further, at 25° sloppy ground elements may leads to reduce less percentage up to 37.61, 36.27 and 34.53 show in Fig. (26).

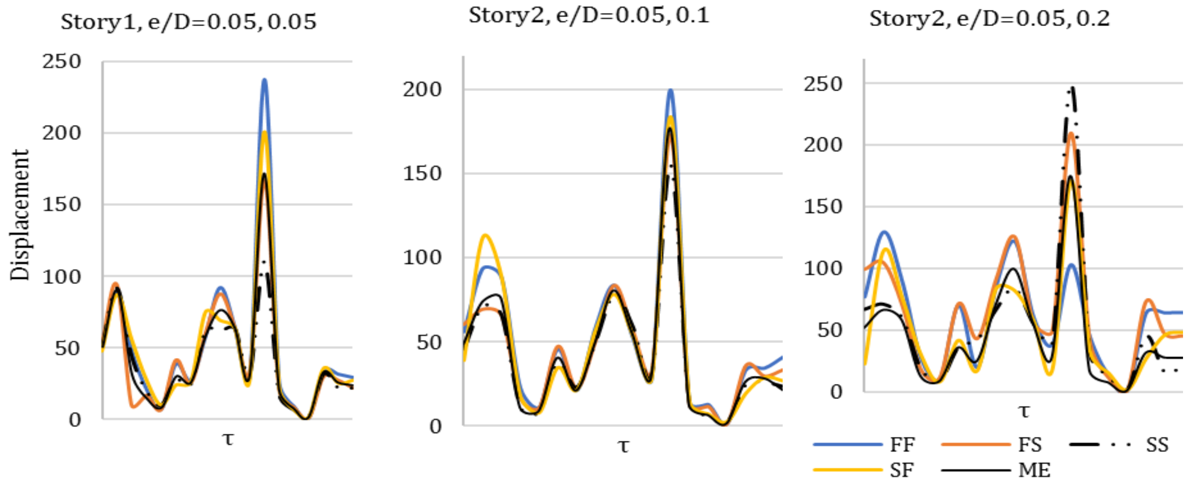

Fig. 25. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° using TLD in story3, Rμ=4.

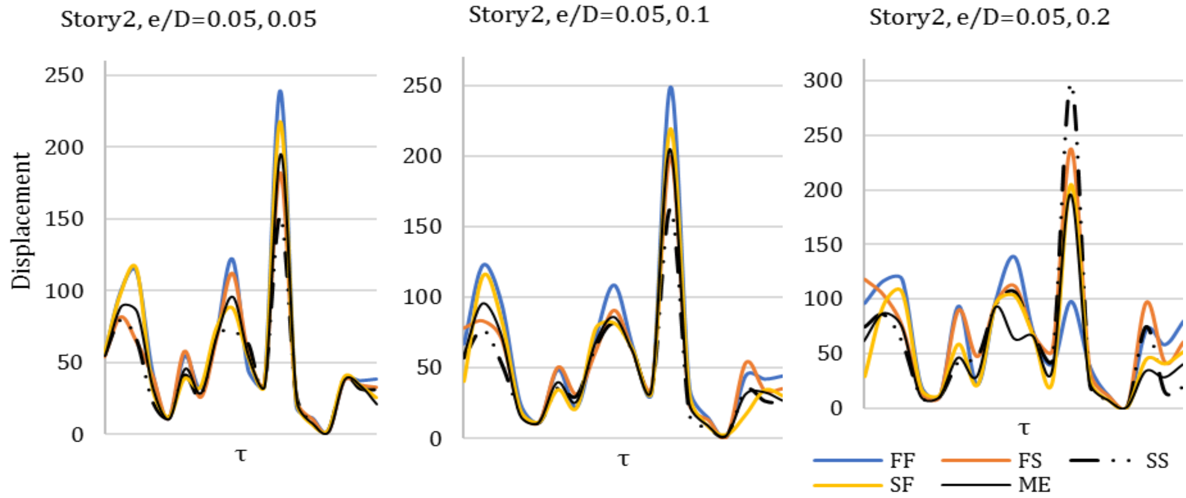

Fig. 26. Maximum displacement response of MDOF asymmetric system for T=3sec at 25° using TLD in story3, Rμ=4.

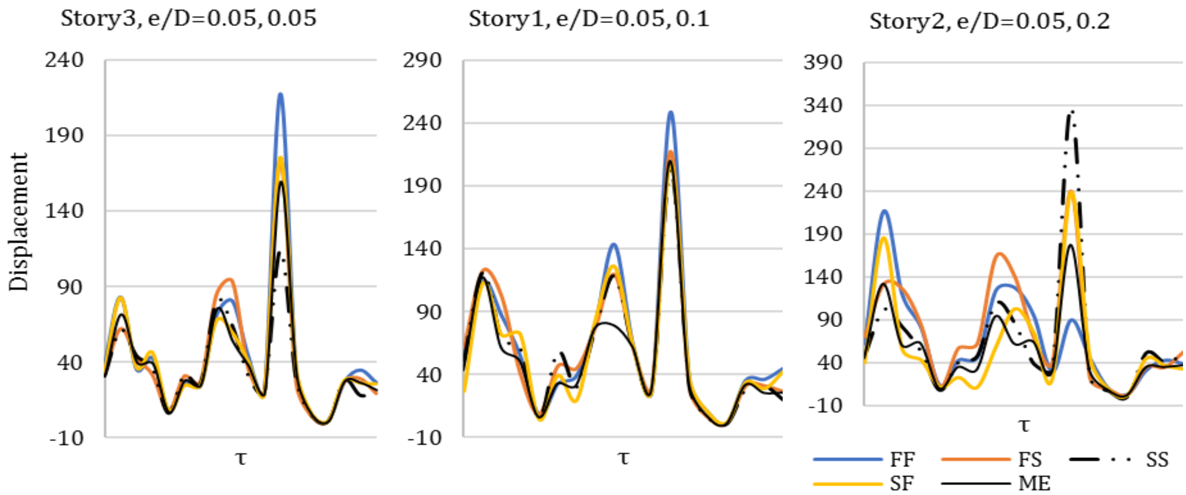

Fig. 27. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° using TLD in story3, Rμ=6.

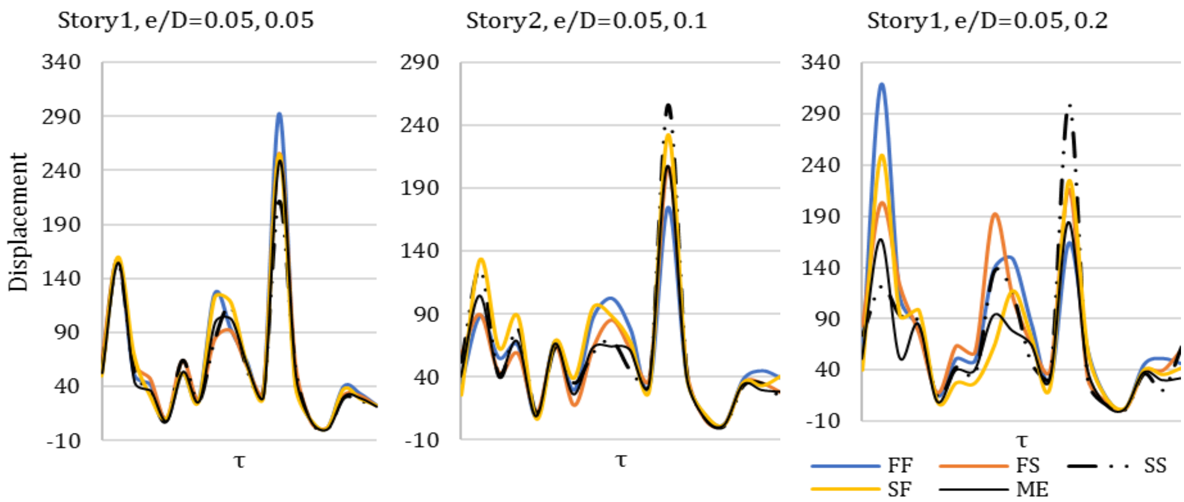

Fig. 28. Maximum displacement response of MDOF asymmetric system for T=3sec at 25° using TLD in story3, Rμ=6.

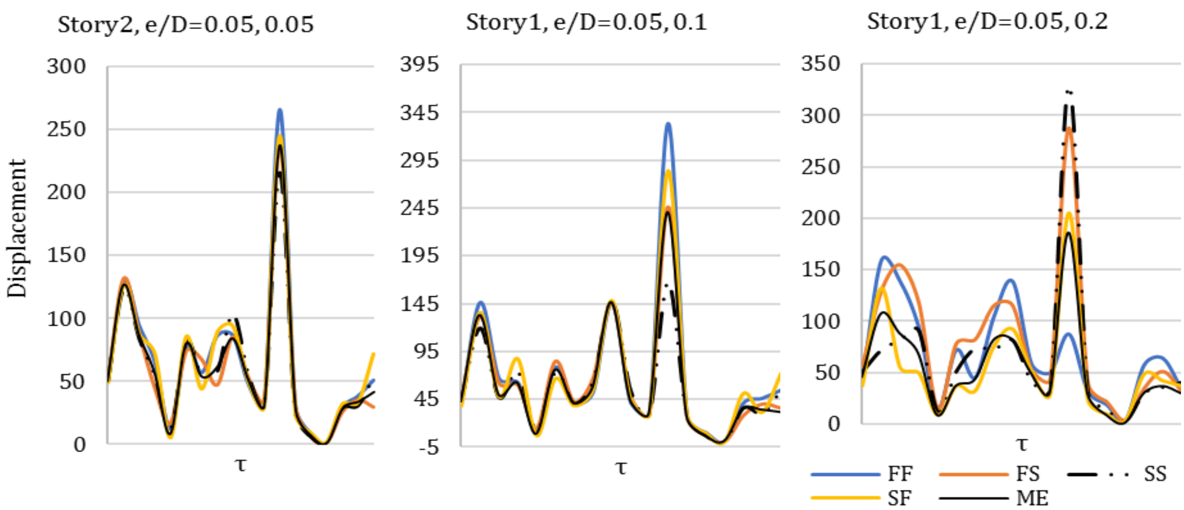

Fig. 29. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° using TLD in story3, Rμ=8.

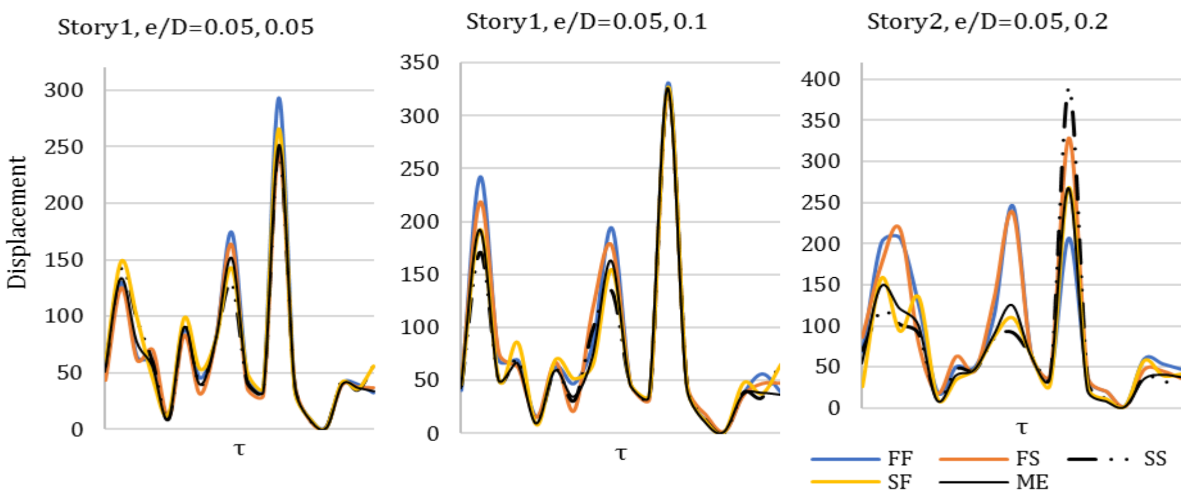

Fig. 30. Maximum displacement response of MDOF asymmetric system for T=3sec at 25° using TLD in story3, Rμ=8.

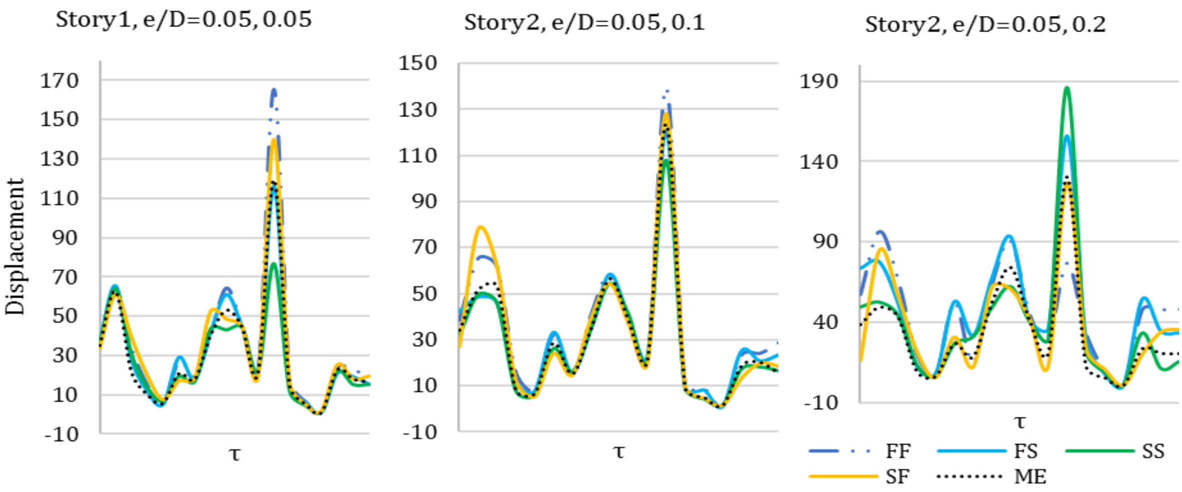

Fig. 31. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° using TLD in story2, Rμ=4.

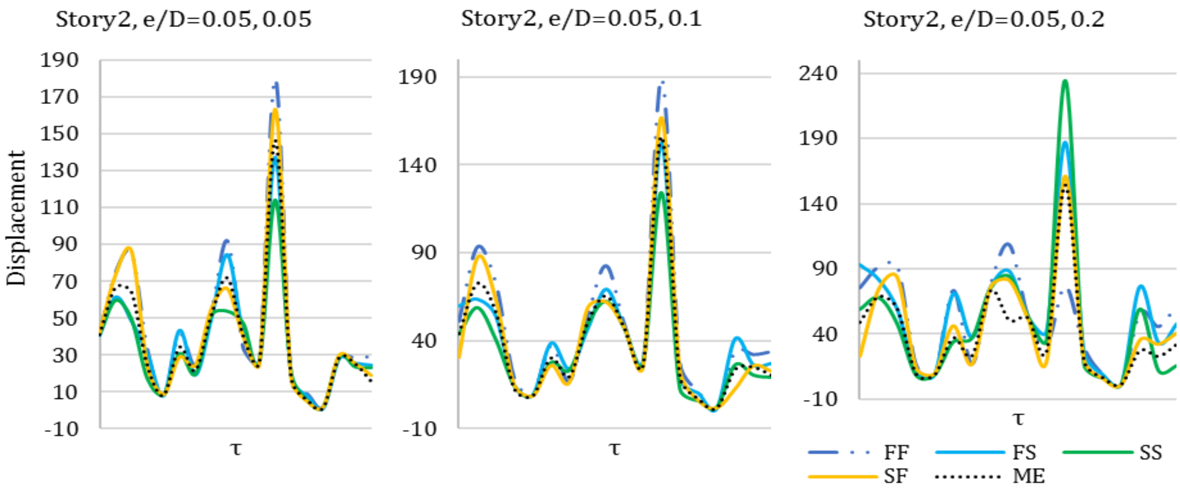

Fig. 32. Maximum displacement response of MDOF asymmetric system for T=3sec at 25° using TLD in story2, Rμ=4.

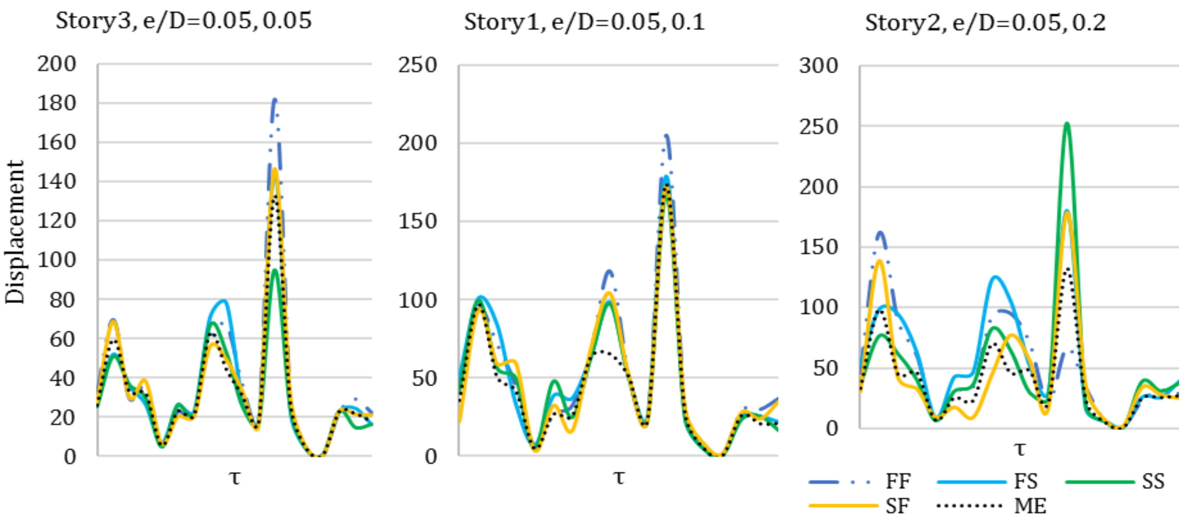

Fig. 33. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° using TLD in story2, Rμ=6.

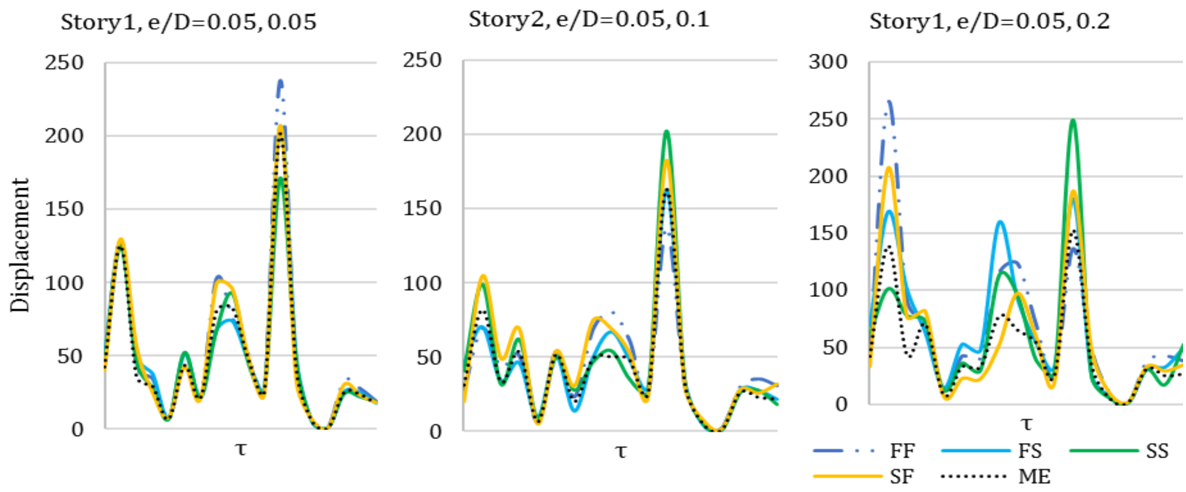

Fig. 34. Maximum displacement response of MDOF asymmetric system for T=3sec at 25° using TLD in story2, Rμ=6.

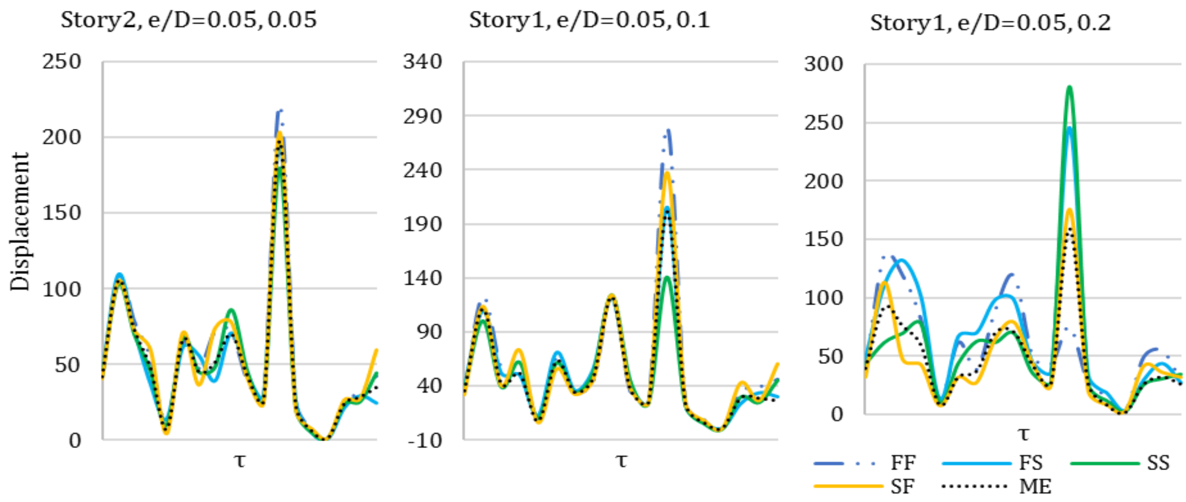

Fig. 35. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° using TLD in story2, Rμ=8.

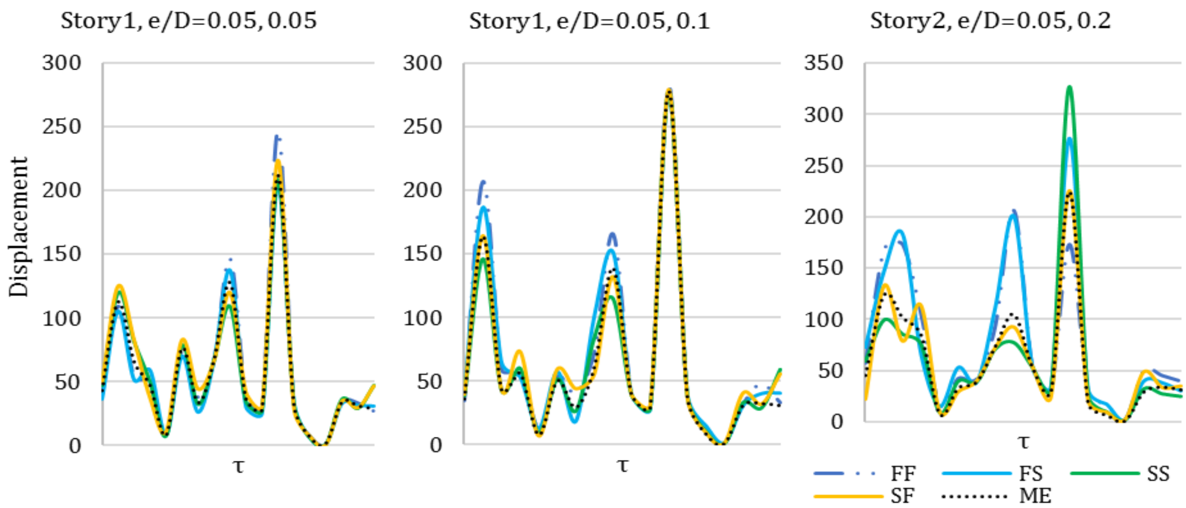

Fig. 36. Maximum displacement response of MDOF asymmetric system for T=3sec at 25° using TLD in story2, Rμ=8.

Fig. (27) shows the reduction response for standard three bi-directional eccentric conditions of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where elements may lead to reduce the percentage up to 48.62, 38.41 and 36.32 for Rμ=6 respectively. Further, at 25° sloppy ground elements may leads to reduce less percentage up to 32.81, 34.75 and 30.63 show in Fig. (28). Also, Fig. (29) represents the reduction response for standard three bi-directional eccentric conditions of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where elements may lead to reduce the percentage up to 35.41, 33.30 and 30.26 for Rμ=8 respectively. Further, at 25° sloppy ground elements may leads to reduce less percentage up to 29.26, 24.10 and 26.31 show in Fig. (30). On the other hand, Fig. (31) shows the reduction response for standard three bi-directional eccentric conditions of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where elements may lead to reduce the percentage up to 60.14, 62.20 and 57.84 for Rμ=4 respectively. Further, at 25° sloppy ground elements may leads to reduce less percentage up to 53.02, 51.42 and 48.53 show in Fig. (32). Furthermore, Fig. (33) shows the reduction response for standard three bi-directional eccentric conditions of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where elements may lead to reduce the percentage up to 57.16, 49.27 and 52.42 for Rμ=6 respectively. Further, at 25° sloppy ground elements may leads to reduce less percentage up to 45.51, 48.62 and 42.36 show in Fig. (34). Finally, Fig. (35) represents the reduction response for standard three bi-directional eccentric conditions of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where elements may lead to reduce the percentage up to 46.33, 44.21 and 40.30 for Rμ=8 respectively. Further, at 25° sloppy ground elements may leads to reduce less percentage up to 40.41, 35.20 and 38.15 show in Fig. (36).

For columns of irregular length, part of the traditional buildings is connecting the columns around a beam of standard dimension which has been claimed for a long time to prevent the buckling of the columns [1]. Therefore, it is possible to highlight the integrated program of TLD and BCJ for vibration control through Fig. (37) to Fig. (39) with a very fine view. Fig. (37) represents the reduction response for standard three bi-directional eccentric conditions of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where elements may lead to reduce the percentage up to 62.21, 65.32 and 59.42 for standard ductility reduction factor Rμ=4 respectively, whereas TLD set on third story level at mid position. Fig. (38) represents the reduction response for standard three bi-directional eccentric conditions of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where elements may lead to reduce the percentage up to 61.24, 55.12 and 53.10 for medium reduction factor Rμ=6 respectively, whereas also TLD set on third story level. Fig. (39) represents the reduction response for standard three bi-directional eccentric conditions of 0.05, 0.05; 0.05, 0.1; 0.05, 0.2 at 15° sloppy ground in 3.0sec where elements may lead to reduce the percentage up to 47.20, 45.81 and 42.53 for higher reduction factor Rμ=8 respectively, whereas also TLD set on third story level. The ultimate position of TLD replacement above the story level with the significant shape and size deserves further detailed investigation for resisting the oscillation under long lateral periods.

Afterwards, although the representation of bi-directional eccentric condition through the principal direction of MDOF system is immerged, the coefficient α is computed for observing the overall DAF scenario. These numerous are presented in Fig. (40) for system with prearranged categories against the corresponding eccentricities 0.05, 0.1 and 0.2respectively. Fig. (40) indicates that the dynamic amplification is as high as 4 for small eccentric condition and above 2 for large eccentric systems. The amplification reduces with increasing the eccentricities and also decrease in number of stories. The coefficient (α) = 1.5 already suggested in code is therefore deficient. From the attitude of mechanics, the magnification in an inelastic range response reassert with increasing the coefficient whereas this substantial performance develops by higher torsional modes.

All these results depend on the traditional bi-directional eccentric conditions that act as a rival to each other influenced by all design parameters. This seismic assessment is not prioritized considering the stiffness and strength of load resisting elements, as well soil conditions are also emphasized as analyzed through bi-directional excitation. Influence of bi-directional interaction of ground motion does not affect the vulnerability of load resisting elements; apart from that, the displacement of soil mass can also be taken up to the maximum limit with respect to the foundation of buildings. In the seismic code provision, it is mentioned that the north-east region is considering fully alluvium soil categories where the bearing capacity and shear strength is low in many parts. Although depends on dry, wet and saturated conditions of soil mass that particularly spread towards the hilly terrains. Furthermore, it has been declared from the field survey and the experimental observations, the shear strength of the alluvium soil of this type of hilly areas can be found in 60-62kPa on average. Similarly, the friction angle reduced to 14.23% and the friction angle equal to 59.62°. On the basis of the design parameters show that the bi-directional FF long period oscillations on the rock and sedimentary sites have enough destructive capacity to strongly damage low-rise buildings with natural periods of 3.0 – 6.0 sec at any angle of slopes.

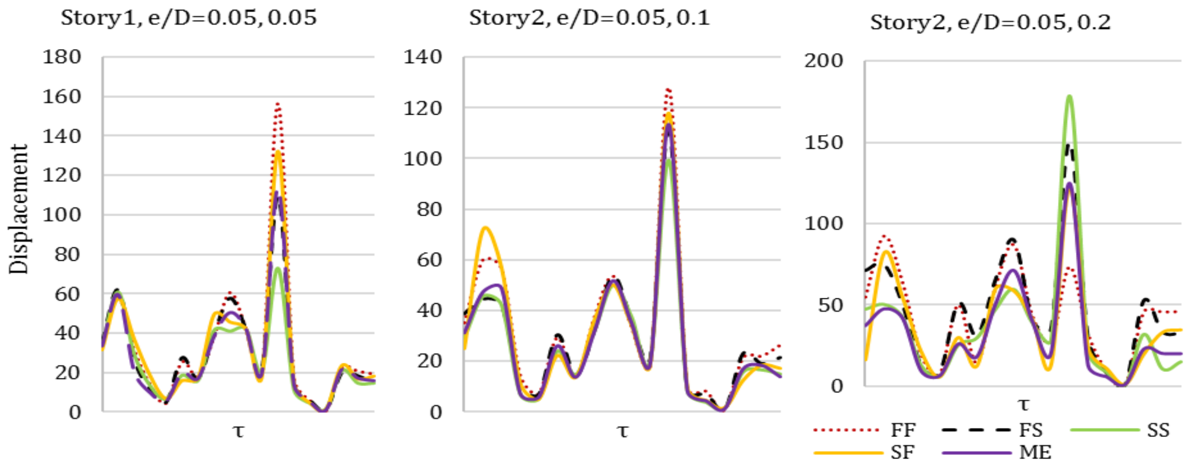

Fig. 37. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° using both BC Joint and TLD, Rμ=4.

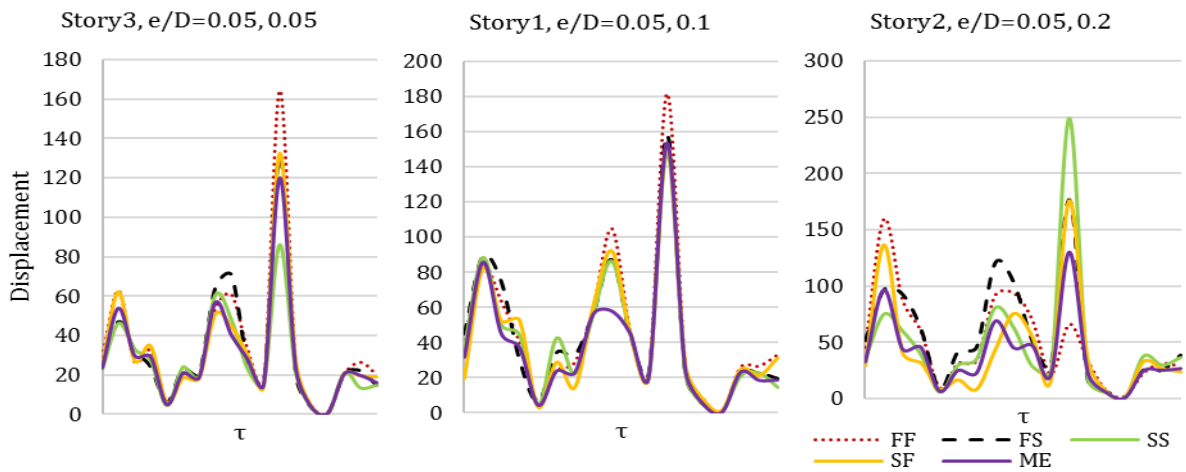

Fig. 38. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° using both BC Joint and TLD, Rμ=6.

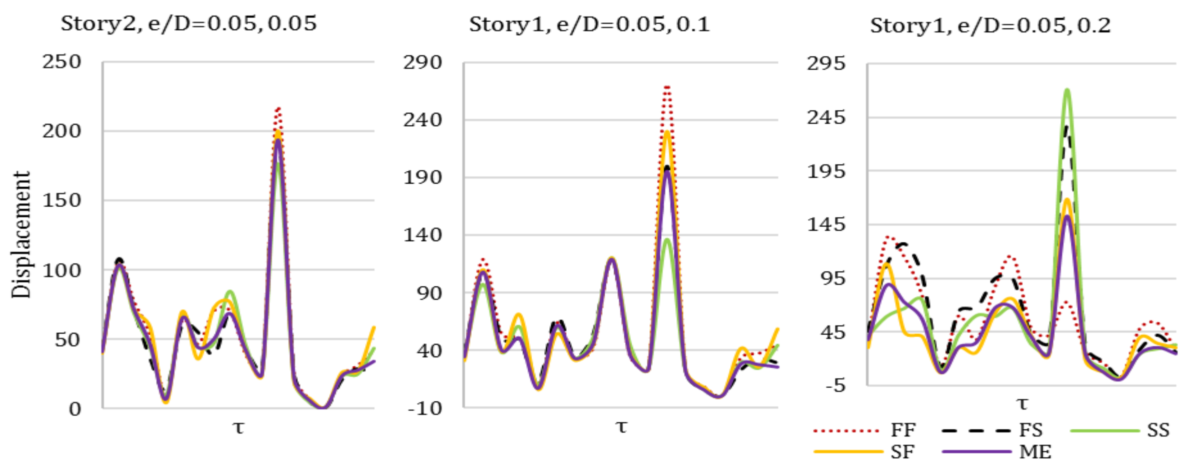

Fig. 39. Maximum displacement response of MDOF asymmetric system for T=3sec at 15° using both BC Joint and TLD, Rμ=8.

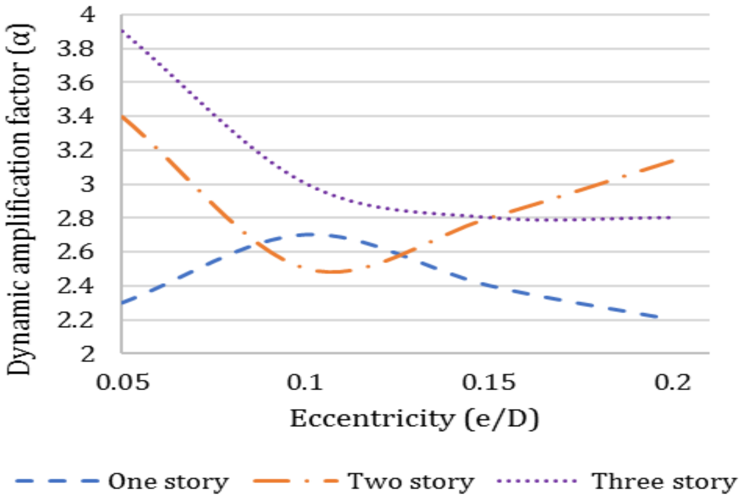

Fig. 40. Dynamic amplification factors related with design eccentricity in MDOF eccentric systems at 15° sloppy ground.

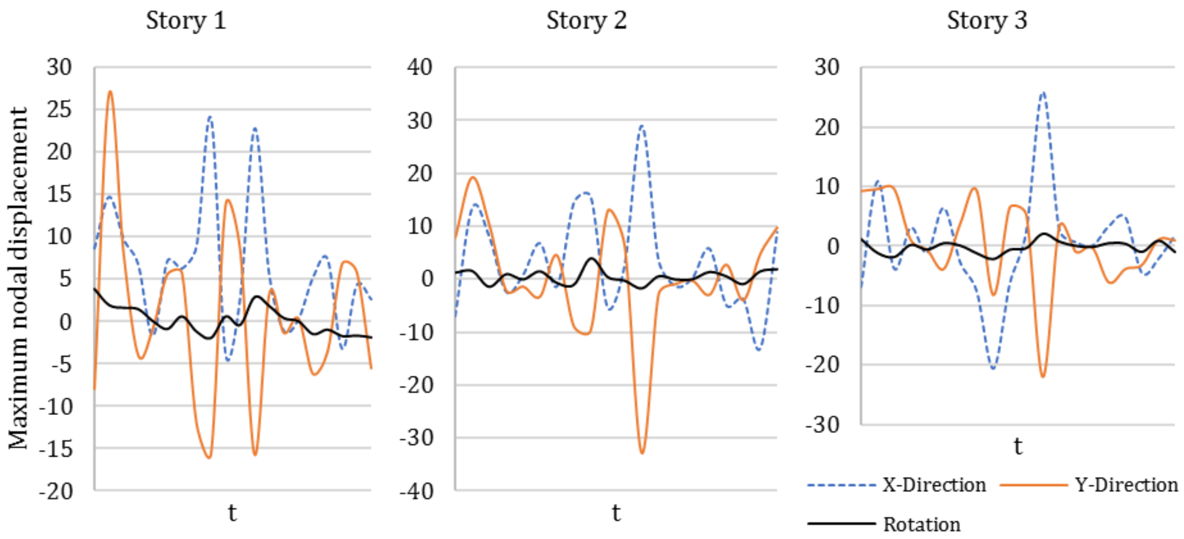

Fig. (A1). Maximum nodal displacement response of MDOF system for T=1.0sec at 15° (e/D=0.05, 0.1; Rμ=4).

Fig. (A1) represents the mean maximum nodal displacement response with respect to time interval (t) of MDOF asymmetric system under different story level (up to three story individually) for T=1.0sec at 15° angle of slope. This nodal response is presented in bi-directional intermediate eccentric standard combination 0.05, 0.1 that shows in three sets of graphical representation. These responses are plotted in three traditional X, Y and rotational directions that clearly shows the elemental deformation response with torsional effect. Fig. (A1) clearly shows that the displacement in X-direction is higher than Y-direction that may be lies 30 times in story2. In that case, the rotational movement is higher with torsional effect. This torsional effect increases as with increasing the response of orthogonal directions. Other two stories story1 and story3 shows the response in a particular manner. Owing to the variation of torsional effect is more in 1st story, the modification of nodal displacement of the structure is increased in both principal directions that has an effect on 2nd story level. This graph is clearly demonstrated that the torsional coupling preforming in higher values that displace the position of story 2 which creates the deformation in lower and upper stories. This nodal effect also the important issue for knowing the performance of column position. Nowadays, engineers should be associated in the design and construction of so-called non-engineered MDOF structural systems without considerable increasing in the cost. This stipulations and regulations are developing the proposal of the level of vulnerability of such buildings for different low to high intensity of ground motions. For convenience engineers can meditate the level of vulnerability that they will recognize by influencing on the importance of the structure and functional demand.

7. CONCLUSIONS

The present investigation analyzes the inelastic seismic performance of low-rise multi-story asymmetric model plan structure with standard two angle of slopes in hilly areas in India owing to bi-directional ground excitation. The results are also indicated the performance evaluation with different size of column sections of asymmetric system for better understanding the serviceability of load resisting elements and additionally modern technique TLD for controlling the major vibration with or without BCJ. The following broad conclusions emerge.

1. Consideration of asymmetric configuration effects owing to simultaneous bi-directional shaking may produces the inelastic demand. The result analysis implies for this case amplifies the response considerably. The response of three story asymmetric MDOF system in inelastic phase is observed critical in hilly terrains due to bi-directional excitation and also the variation of story wise eccentric conditions. Whereas, the variation of lateral periods and ductility reduction factors have been captured very accurately deals the major elemental deformation of lower stories, especially in the lower story due to the major maximum variation of bi-directional eccentric conditions. The strong vulnerability is especially apprehended through the common torsional effect of each story which clearly highlights the non-linear dynamic response.

2. Consideration under inelasticity, the bird's eye observation represents that even though the displacement response of the top story is less as the story height increases, the critical response is created in the first and even the second story due to torsional effect and sloppy ground conditions. The coefficient α exerts herein may be scrutinized for refurbishing the relevant code provisions. The consequences of accidental eccentricity may be incorporated separately, as appropriate. The length of the columns in two orthogonal directions are varied depends on sloppy terrain causes the maximum vulnerability of long side columns are occurred that deform earlier than short columns that response may be easily compared to the previous literature [1].

3. As the ductility reduction factor reduces owing to the inelastic demand being very high, the effect on the first story is greater in intermediate and large eccentric conditions, especially on the flexible side at 15° and 25° sloppy ground at different lateral periods; where the percentage of responsibility at 25° angle of slope is getting more complicated. On the other hand, as ductility reduction factor increases, the effect in the second story is more than the first story owing to the torsional effect in large eccentric condition, especially in stiff and flexible both sides at 15° and 25° sloppy ground in different lateral times. The effect of reduction factor is considered at the medium stage, it has more effect in the first story than in the second and third story for large eccentric conditions, especially on the flexible side at both angles of slopes at different lateral times owing to ground excitation. However, flexible and stiff side elements serve to exhibit a converse trend with decreasing the ductility demand due to bi-directional eccentric condition.

4. Due to the bi-directional small to large stiffness and mass eccentric conditions are considered in each story for torsional effect, highly sporadic deformation of the elements have occurred in the lower to middle story is not possible in the interest of maintaining consistency. Therefore, it can be concluded through specific observation that if the multi-story structure with less than 15° sloppy ground is constructed, may be possible to prevent the major vulnerability of load resisting elements from bi-directional excitation where the strength is considered $e_{st} = 0.5e$.

5. The results are obtained by using TLD in the third story, the results are much better than those used in the second story, By using TLD in top (third story) section of system possible to control the vibration averagely 39% and 31% on 15° and 25° sloppy ground, while in second story using TLD on 15° and 25° angle of slopes possible to control averagely 52% and 45% vibration respectively. Due to the fact, this percentile published in public is very insignificant. It is not feasible to increase the story level in the dominance of TLD under the variation of bi-directional eccentric condition at each story in different angle of slopes, the range of deformation for elemental vibration seems to be higher.

6. The combination of TLD and BCJ control the vibration on abundantly 55% at 15° sloppy ground terrain taken into consideration second mid story. Accordingly, the serviceability of the elements of structure has the possibility to collapse in large seismic pulse. It can be concluded through this careful observation that TLD and even the combined approach of TLD with BCJ is unable to extend the vibration control effect far enough for multi-story structure. This conclusion raises new concerns.

In consequence, the present paper may be helpful in the process of response analysis of the built or to-be-built structures in the event of any anticipated earthquake. Safety level of the structures are undergoing in seismic excitation without collapse, may be assessed to plan for the post-earthquake strategy. Such multi-story structures in hilly areas serve various functional and architectural requirements cause due to plan and interconnection activities lead to the additional vulnerability of system. Furthermore, the sensitivity of the bi-directionally attacking forces execute the seismic deterioration of such systems. This present paper may prove and more overly useful to dispense broad guidelines to address all essential issues and to highlight the needs of investigating the same in further details. These results can therefore help to evaluate the retrofitting assessment due to additional strength demand. These findings point out the limitation of current codes developed primarily on research in this particular aspect that employed a low-rise multi-story asymmetric structural model. Hence, this interesting study may be extended to assess the soil-structure interaction effect obtaining further insight.

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