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Seismic Response of Multi-Story Structural System in North-East India Due to Bi-directional Ground Motions

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Abstract: This study examines the inelastic seismic response of low-rise multi-story asymmetric structural system with varying general class of story eccentricities due to bi-directional ground excitation in north-east India. The present study comprehensively analyzes the deportment of stiffness and mass eccentric systems together to perceive the seismic demands in higher modes is found to be potentially high and reflects the real scenario more closely. Study also indicates the degrading attributes of load resisting elements for six-story system may cause increase in inelastic demands owing to ground excitation. This bi-directional component of ground motions is designated for observing the seismic demand of mainly such areas that characterized depends on such layered soil conditions. Inelastic seismic demand may prove convenient in the nomination of the relevant response reduction factor in practical design. This study may help to flourish more insight into the collective behavior of multi-story asymmetric systems, leading to fine tune the provisions in the seismic code.

Keywords: **Seismic response, Inelastic, Asymmetry, Multi-story, Torsional effect, Eccentricity, Bi-directional.**

I. INTRODUCTION

In the recent past, researchers have been proposed the severe damage of low to high rise RCC buildings as well masonry structures in north-east regions. These regions are mainly identified as a high seismic zone belonging in India. Damage survey and to manifest major causes has been clarified in several case studies [1-4]. This case studies have established only the damage identification criteria as a result seismic vulnerability assessment is parallelly influential issues for dominating the crucial deformation of load resisting elements for multi-story structural systems. Although, the seismic vulnerability assessment of that regions [Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Nepal, Bhutan, Sikkim, Darjeeling, Siliguri, Jalpaiguri, Coochbehar, Alipurduar, Assam, Manipur, Mizoram] are estimated so long for single-story [5] and multi- story [6] structural systems in hilly pocket sloppy ground areas due to ground excitation. Besides of that multi-story structural system also a fundamental aspect for inelastic seismic demand of north-east in India whereas, multi-story systems are more vulnerable owing to strong ground motions of Sikkim [1-3] and Nepal [4] etc. earthquake that already recorded. This high amplitude ground motions are herein essential database for adopting to analysis the behavior of low-rise multi-story buildings with different orientation of work. In that case, study has been proposed not only the assessment of an inelastic seismic response of multi-story structural systems but also the ultimate judgmental declaration of story limitation in those high seismic zones. The purified survey clearly shows some complicacy at internal and external damages of especially multi-story buildings as in collapsed in one side of buildings especially lower stories about 80% whereas, top floors were relatively less affected almost 10% [2]. Multi-story buildings were commonly pounding that collided with the one situated to its right almost 60% [2]. This major amplified ground motions were fabricated the damage percentage of low to high rise buildings i.e. 3-story (75%), 5-story (80%), 8-story (85%) and 10-story (95%) respectively. A rigorous survey has been conducted about the impotency of load resisting elements where RCC beams and columns were damaged 80% [1, 2]. The plastic hinge formation at column capitals in soft ground story or partially soft story were affected just about 70% [2]. The beam-column junctions and shear failure of RC columns were invaded nearly 65% that already captured by researchers. Furthermore, masonry infill walls were developed the shear cracks at opening or at the door-window openings about 85% [1] for single-story and multi-story both cases. Wide cracks at the floor and plinth level (30%), transverse cracks along the shear walls (5%) and some minor damage of stair cases (7%) were apparent due to heavy ground excitation of north-east regions. In this contemplate, researchers have been responsible for observing the ultimate diffusion of multi-story systems under seismic excitation in north-east India. Researchers have been worked since the late nineties of the previous decade in the field of seismic response in multi-story structures. Generally, plan asymmetric system occurs due to the variation of center of mass (CM) and center of stiffness (CS) represent the torsional unbalanced system. For multi-story system having the CM and CS of each story level on same vertical line is rare in practice. Furthermore, 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. Efforts have been conducted to locate the ultimate position of CS of each story level [7]. Some other put forward a methodology without determining the CS of each story for assessing of multi-story asymmetric system [8]. Studied on asymmetric multi-story systems, that is CM and CS lie on two different vertical lines at a fixed distance over height, that is unappropriated for such MDOF systems [9]. After that, the seismic code analysis for multi-story structure in general asymmetricity has been estimated [10]. This complaint is even uncertain in most of the code provisions about the multi-story asymmetric buildings, perhaps owing to the convolution involved in the definition of center of mass and center of stiffness. Researchers have been developed to understand the behavior of low-rise multi-story system where CS varies in different stories with general uni-directional and bi-directional eccentric conditions and CM lies in the same vertical line [11]. Few studies have been conducted about this crucial matter of multi-story structural system whereas researchers failed to identify the clarity of the perfect position of CS and CM [12-21]. Recently, seismic analysis has been assessed for multi-story building with general mass irregularity by time history method conclude that the response to be less affected by the floor to floor variation for mass irregularities [22]. Last but not the least, the comparison between CM and CS has been clarified for low-rise MDOF system in bi-directional both stiffness and mass eccentric conditions under bi-directional ground motions very recently [23] where the position of CS lies in the same vertical lines for assessing the behavior of mass eccentric condition, vice versa. The survey showed that up to ten 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. The significant less amount of work has been done in this case, but the aperture indicates the judgmental response of plan area structures due to seismic synthetic bi-directional ground motions of asymmetric multi-story systems in a critical seismic zone north-east in India. In this backdrop, this case study reckons to estimate the inelastic seismic response of low-rise multi-story asymmetric structural system owing to bi-directional ground motions. 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. 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.

II. IDEALIZED MODEL STRUCTURE

In this study, two typical idealized multi-story structures are developed show in Fig. 1. The simplified model even can used to at least to grossly understand the seismic performance in inelastic region. In this study, idealized six 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. 1. The same six-element system was also developed by some researchers in earlier studies [6]. 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. 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. 2 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 on a two different vertical axis at each story connection and by the by connected on a single common axis create each bi-directional eccentric condition depends to each other. 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. 2(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. 2(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 [6]. The stiffness eccentric system is chosen as few literatures in this particular field has only considered asymmetric system for mass eccentricity [6]. Such this study gives an idea about the nature of eccentricity makes any difference or not in the behavior.

III. 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 $\beta = 0.25$

[24-28]. 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 [24, 25]. 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 [24]. 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 [6].

$$m\{\ddot{u}\}+c\{\dot{u}\}+k\{u\}=-m\{\ddot{u}_g\} \quad \text{...... Eq. 1}$$

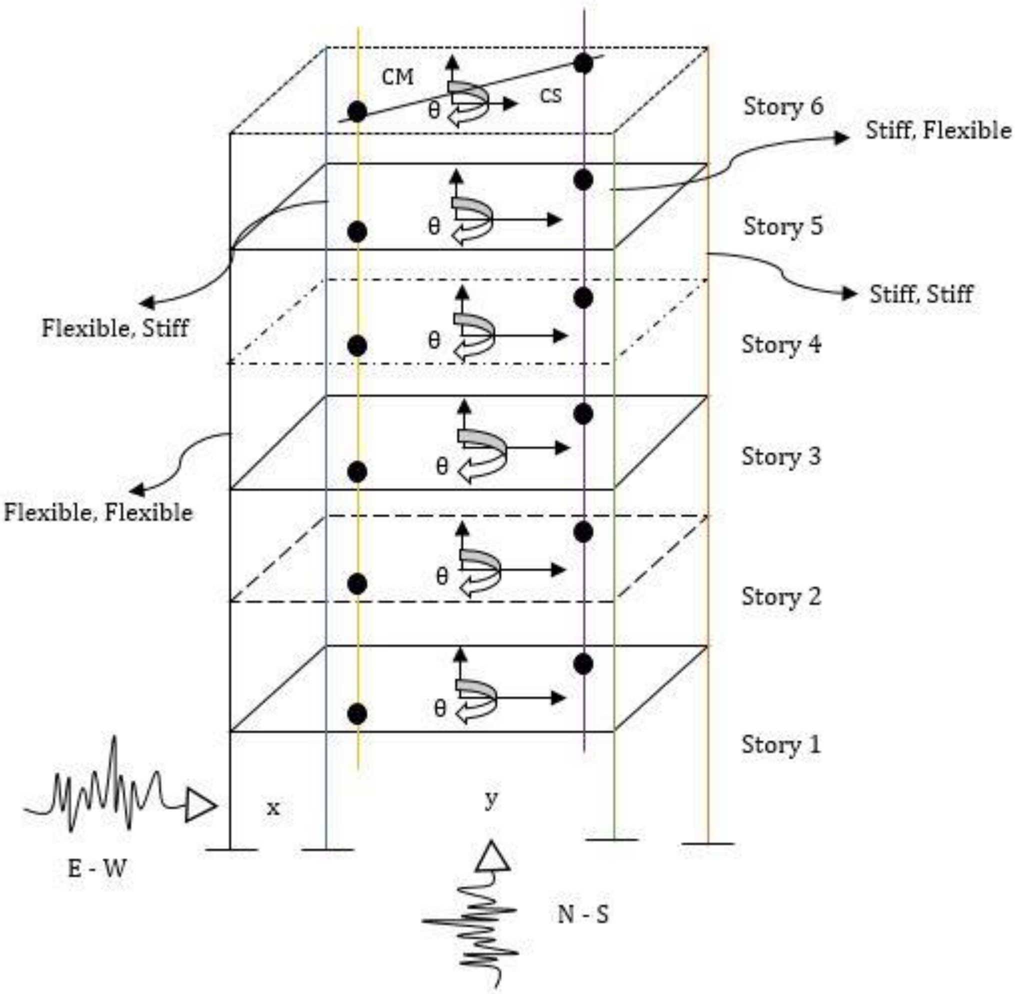


Fig. 1. Idealized multi-story asymmetric model structure.

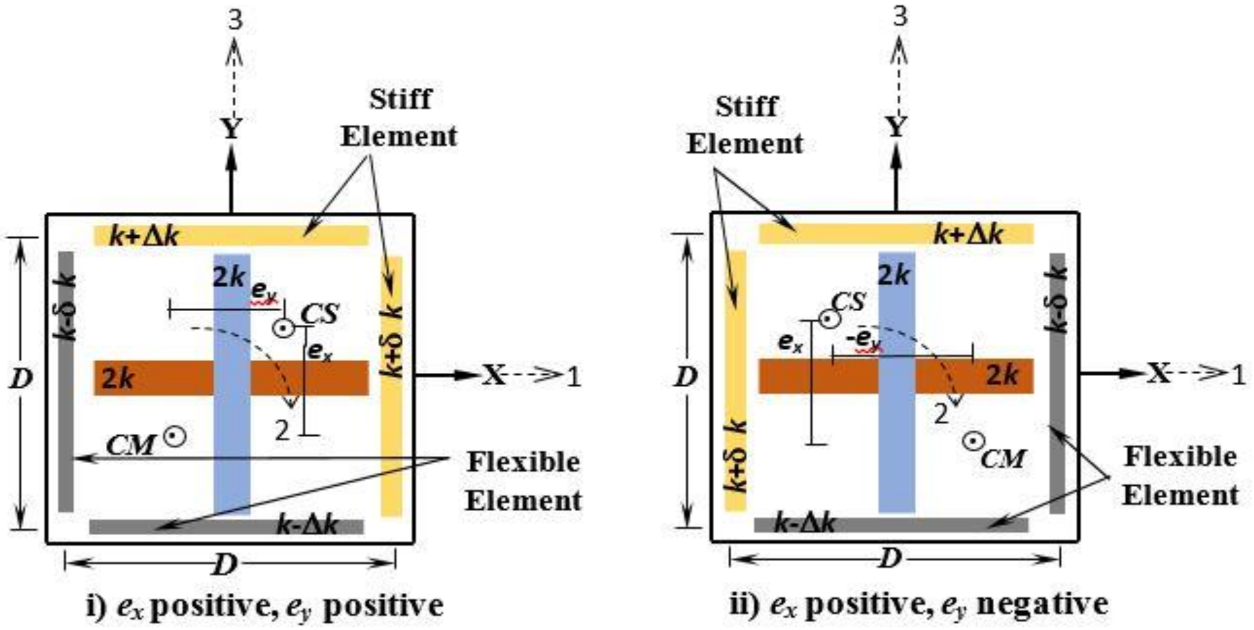


Fig. 2. Bi-directionally asymmetric system.

IV. GROUND MOTIONS

For the multi-story structural model an enhanced non-linear dynamic analysis has been used which is capable to capture progressive seismic damage of structures under inelastic range. As scaled near-fault (NF) ground motions are considered from CESMD for the performance analysis [4]. The ground motions are 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 NF synthetic ground motion history under north-east India. The case studies in this paper are investigated for a set of ten bi-directional synthetic ground motions to resist any variability arising subjected to the particular characteristic of any specific ground motion. Details of the ground motions are shown in Table 1. Selected ground motions in terms of geophysical parameters, viz., magnitude-distance-soil conditions triads in north-east zone. 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 recoded in different stations of north-east India. These ground motions are considered to verify the performance if multi-story structures in north-east India due to the PGA values of such ground motions are dependent on the soil condition. Through this kind of work will be possible to assess the vulnerability of buildings everywhere. All recoded parameters are considered in a justified range.

Table 1. Details of ground motions used.

Sl No.	Event (Year)	Station	Record ID	Magnitude (M_W)	PGA (g)
1.	Nepal, 2015	Municipality Office, Kirtipur	KTP	7.8	0.260
2.	Nepal, 2015	Dept. Geology, Tribhuvan Univ, Kirtipur	TVU	7.8	0.234
3.	Nepal, 2015	Kanti Path, Kathmandu, Nepal	KATNP	7.8	0.163
4.	Nepal, 2015	Pulchowk Campus, Tribhuvan Univ, Patan	PTN	7.8	0.154
5.	Nepal, 2015	Univ Grants Comm., Sanothimi Bhaktapur	THM	7.8	0.154
6.	Sikkim, 2011	Gangtok	GTK	6.9	0.151
7.	Imphal, 2016	Mawlaik	MWK	6.9	0.146
8.	Imphal, 2016	Silchar	SLC	6.7	0.154
9.	Guwahati, 2021	Dhekiajuli, Assam	DKJ	6.0	0.182
10.	Pokhara,	Kathmandu,	KTNP2	5.8	0.146

2021	Nepal

V. 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 MDOF asymmetric system 0.25sec, 0.5sec and 1.0sec 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 [5, 24]. 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. 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 [6, 25]. The combination of eccentric conditions in Table 2. have been considered at each level (up to six stories) due to which the critical response overwhelmed by each level has been highlighted in this paper. Hence, standard six 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}) = 0.5e is considered in this study for observing the effect of asymmetry that also influenced the inelastic torsional behavior of structures [6]. Generally, common buildings like residential buildings, hotels, offices 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 standard values of ductility reduction factor (R_μ) = 4, 6 and 8 is chosen for this system only. These values are highly recommended by the different codes, such as ASCE 7-05 [29] and NEHRP [30].

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
4.	0.1	0.05
5.	0.2	0.05
6.	0.1	0.2

VI. RESULTS AND DISCUSSION

The present study contemplates the resultant drift of the load resisting elements as the response quantity of interest as more defenceless against to the coupling of lateral to torsional vibration for asymmetric setback. The resultant drift demand of any directional elements of each floor are interpreted as a maximum elemental displacement criterion of two orthogonal directions along the principal axis. The nonlinear dynamic analysis of multi-story structural system through mean element displacement under critical inelastic sense is presented with plotting as representative of the trend with the time variation lies between small to large lateral periods that is 0.25 sec to 1.0sec for asymmetric MDOF systems. Mean displacement response, as mentioned earlier [6], 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 multi-story asymmetric system has represented with four corner elements for each story (up to six 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 ten number of ground motions are presented in a graphical formation.

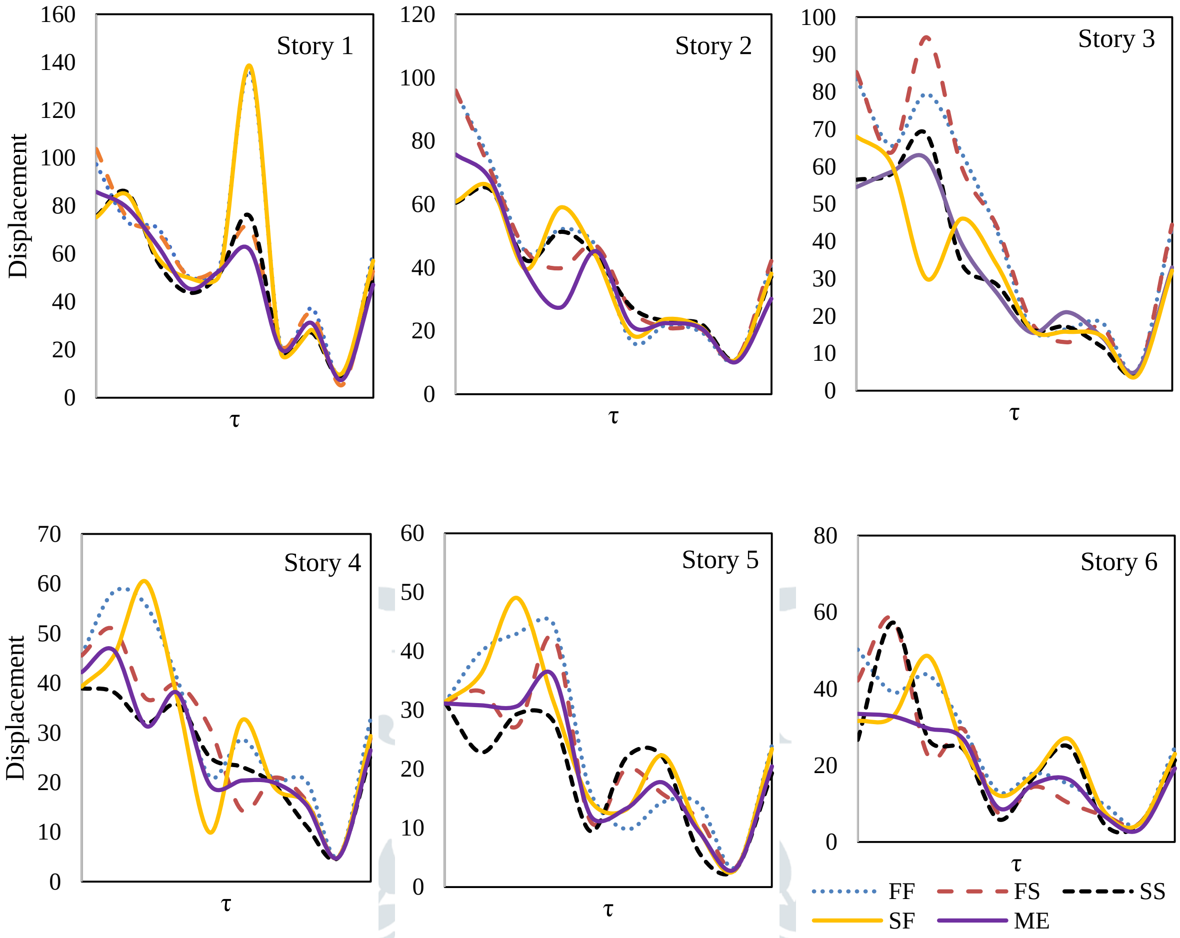
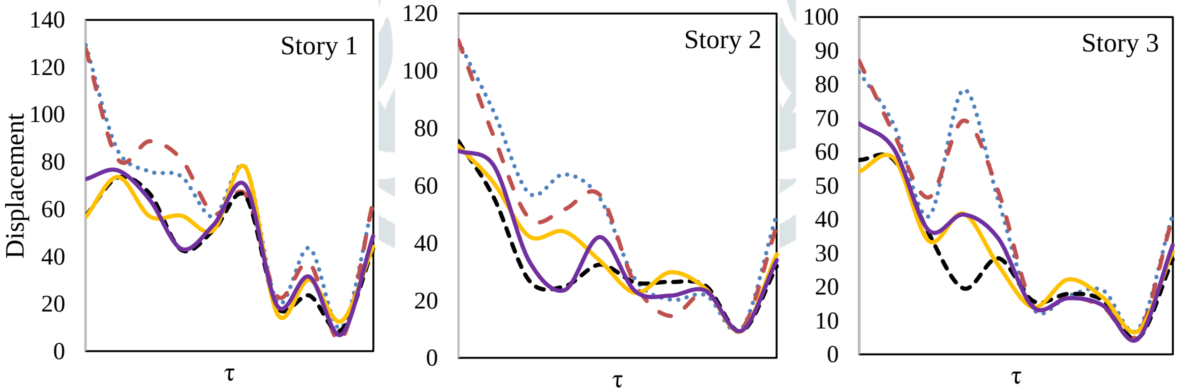


Fig. 3. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.05 at 0.25sec (Rμ=4).



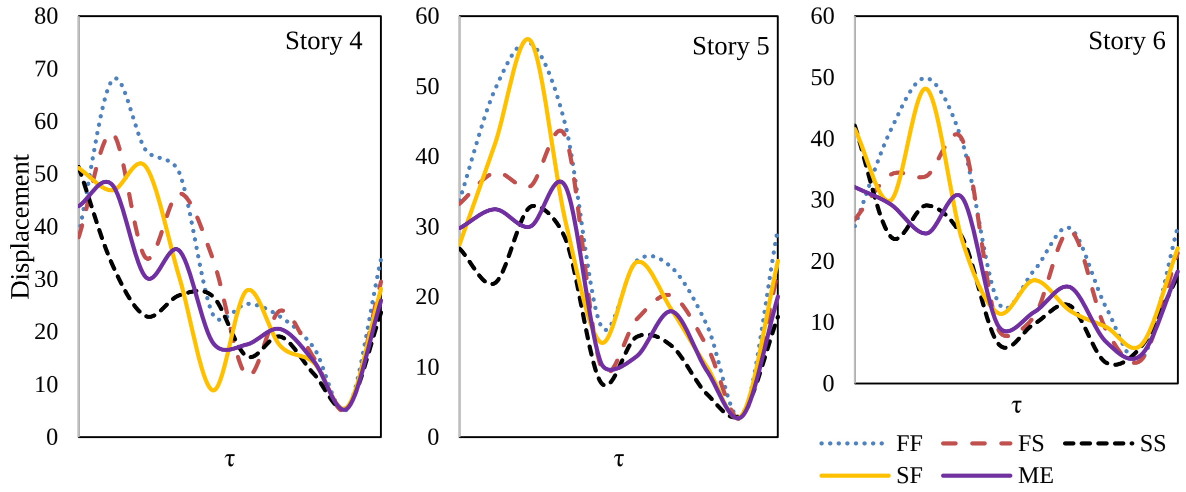


Fig. 4. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.1 at 0.25sec (Rμ=4).

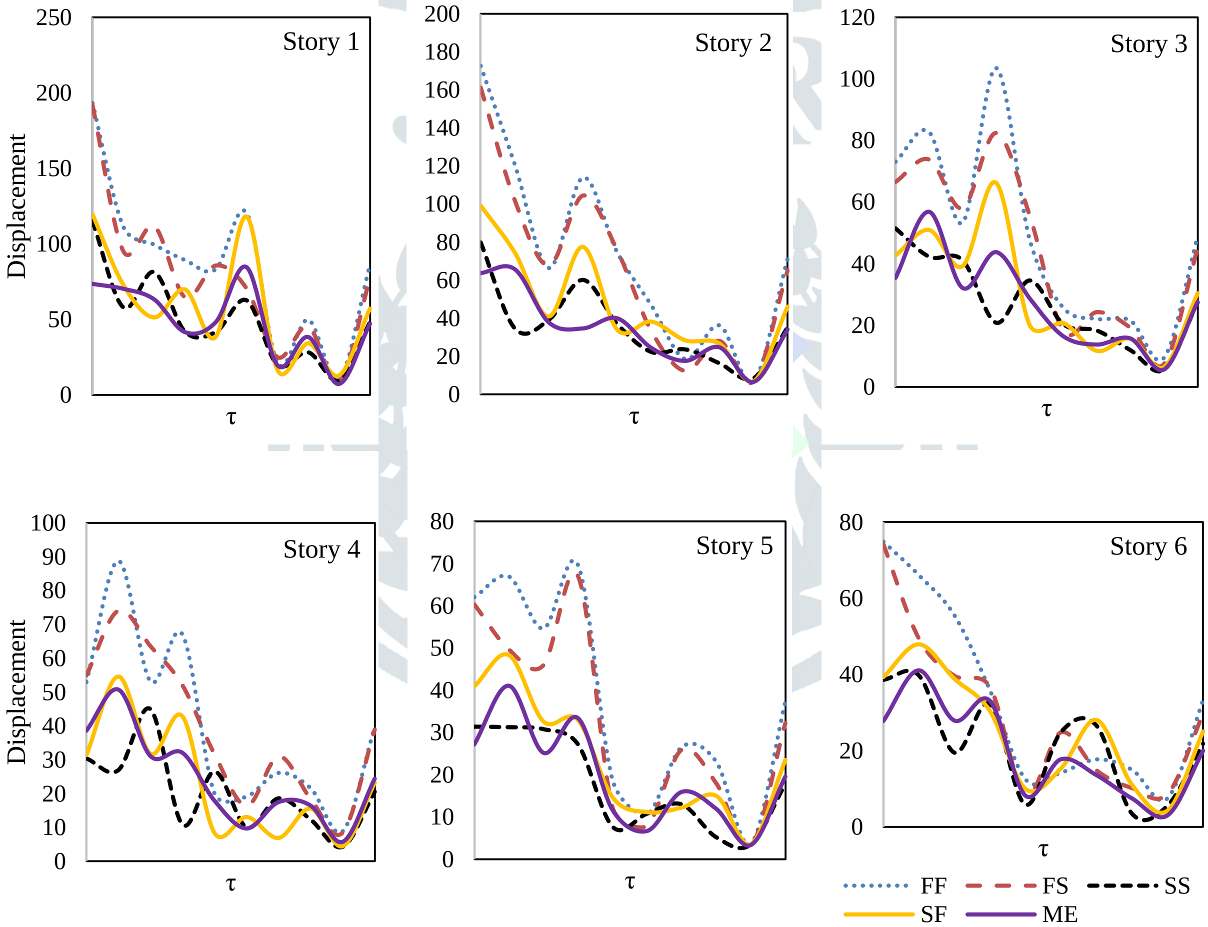


Fig. 5. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.2 at 0.25sec (Rμ=4).

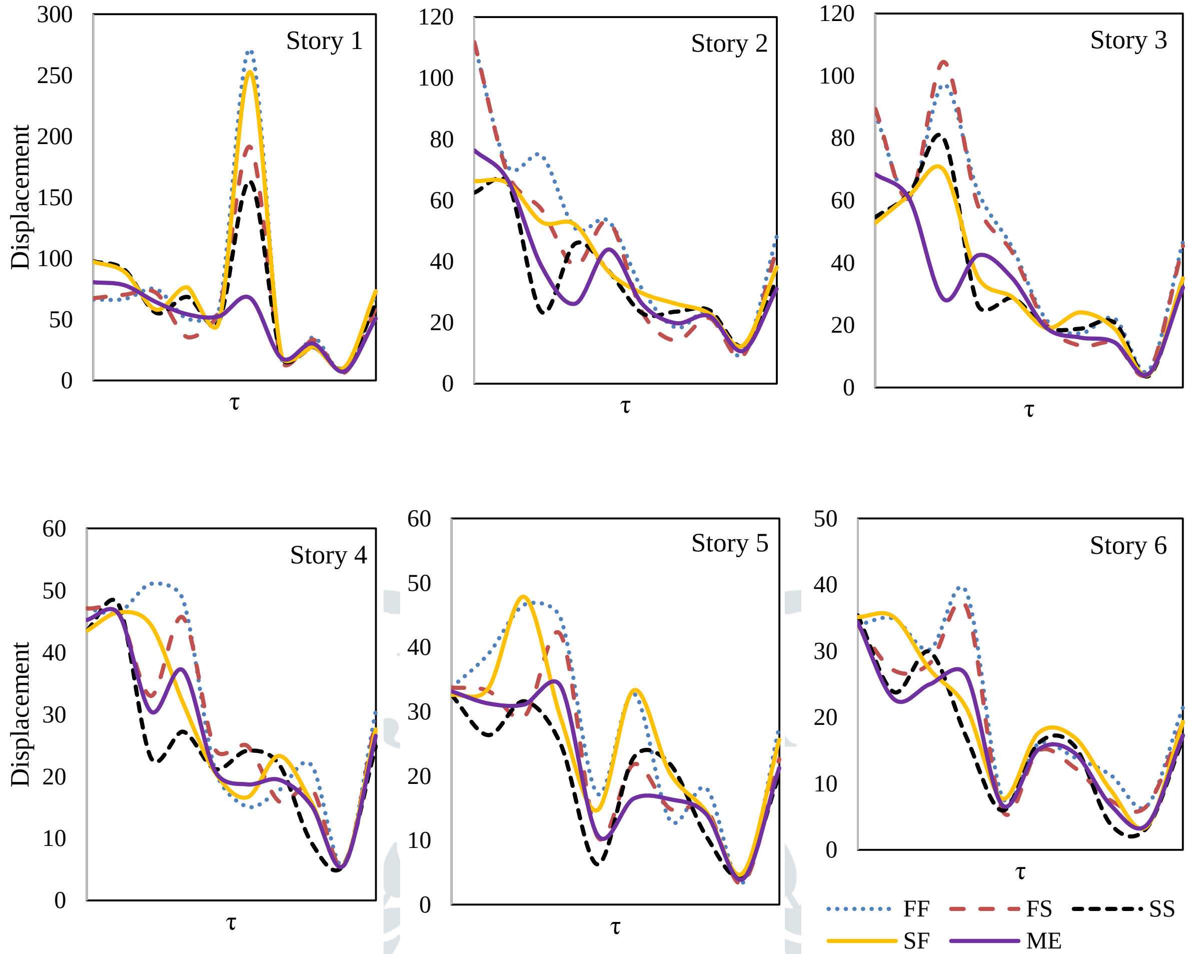


Fig. 6. Maximum displacement response of MDOF asymmetric system for e/D = 0.1, 0.05 at 0.25sec (Rμ=4).

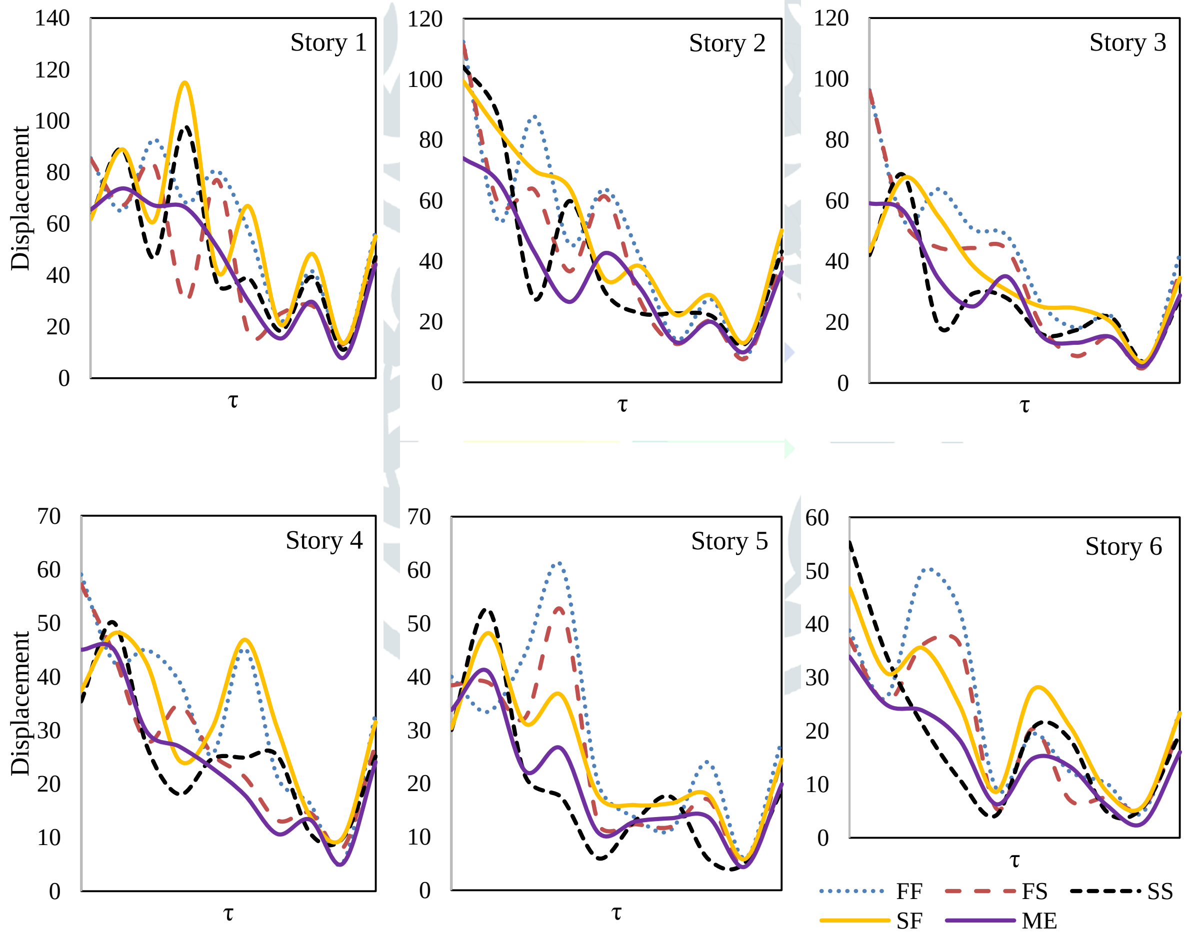


Fig. 7. Maximum displacement response of MDOF asymmetric system for e/D = 0.2, 0.05 at 0.25sec (Rμ=4).

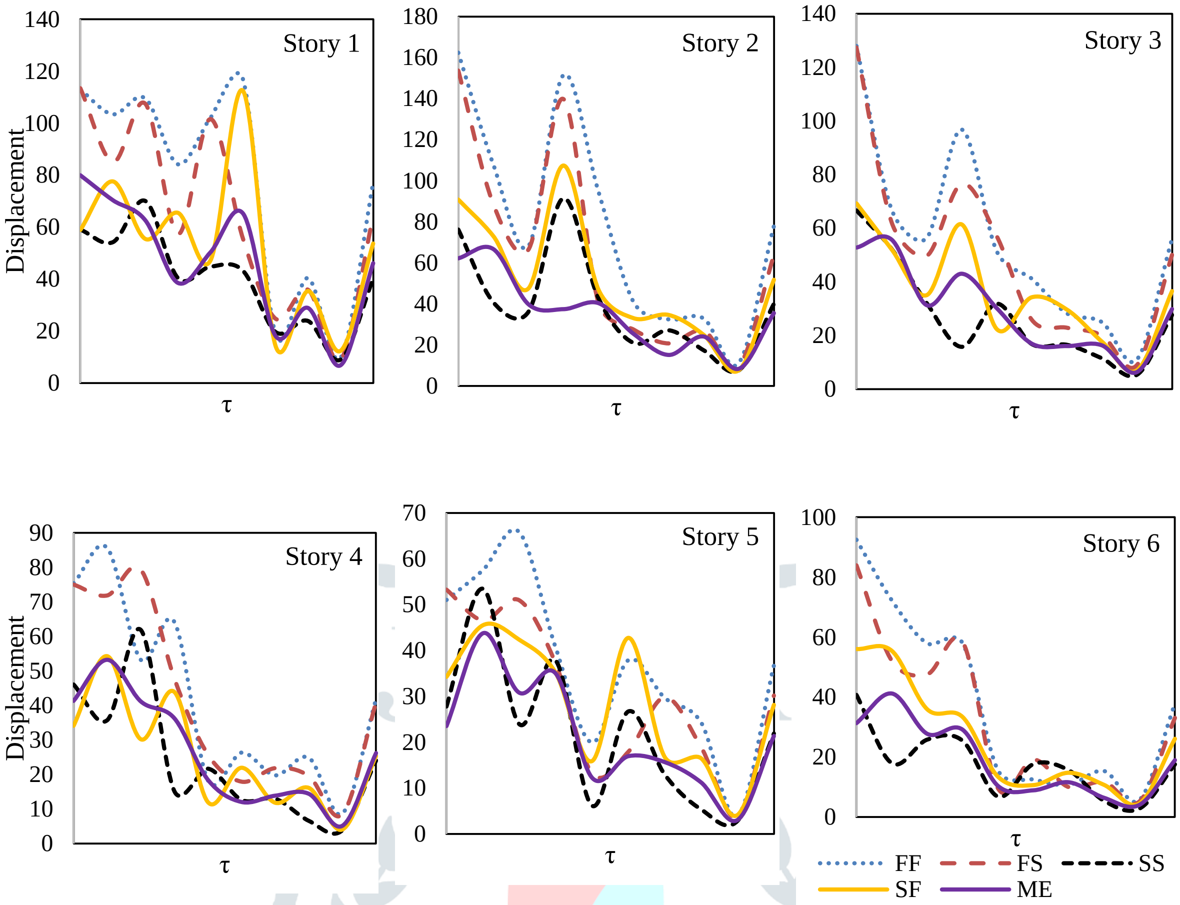


Fig. 8. Maximum displacement response of MDOF asymmetric system for e/D = 0.1, 0.2 at 0.25sec (Rμ=4).

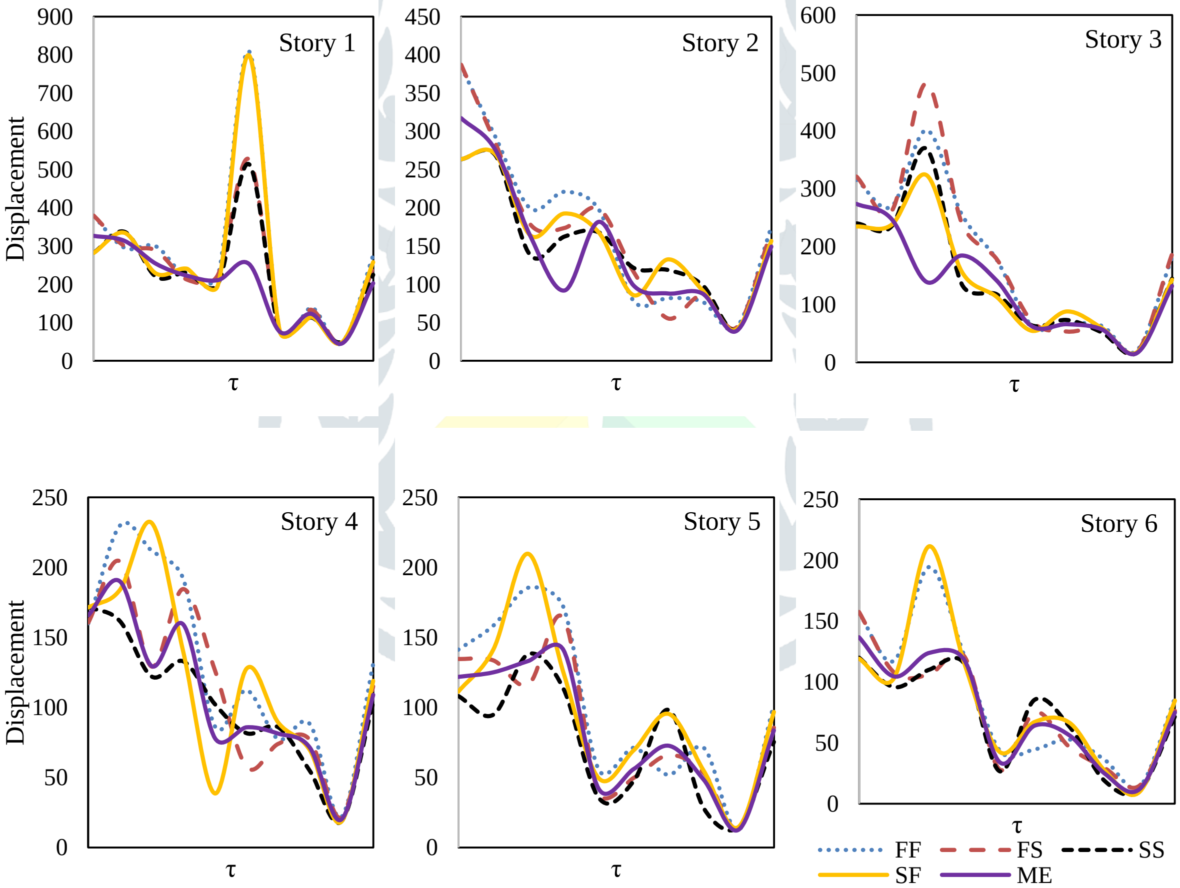


Fig. 9. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.05 at 0.5sec (Rμ=4).

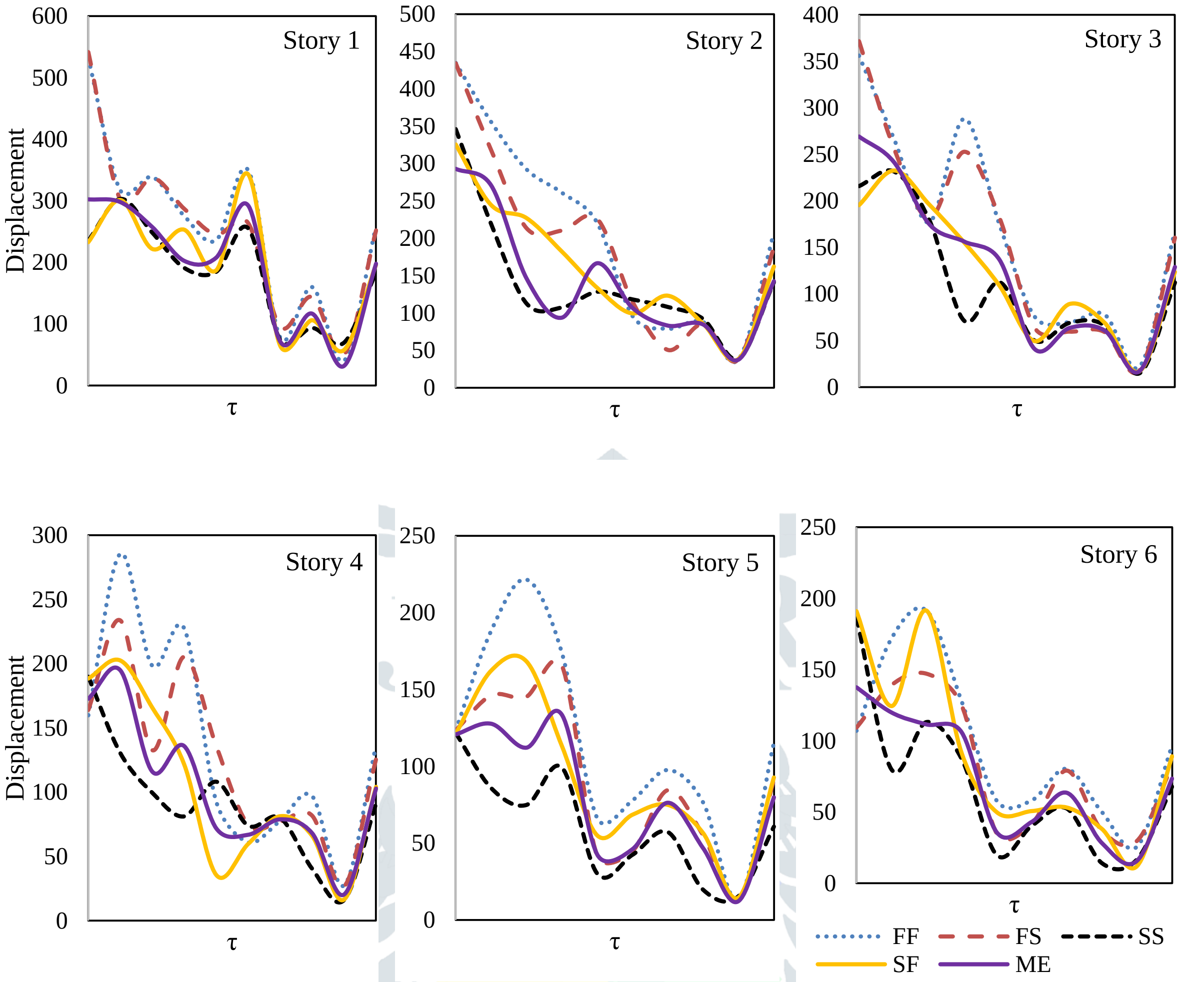
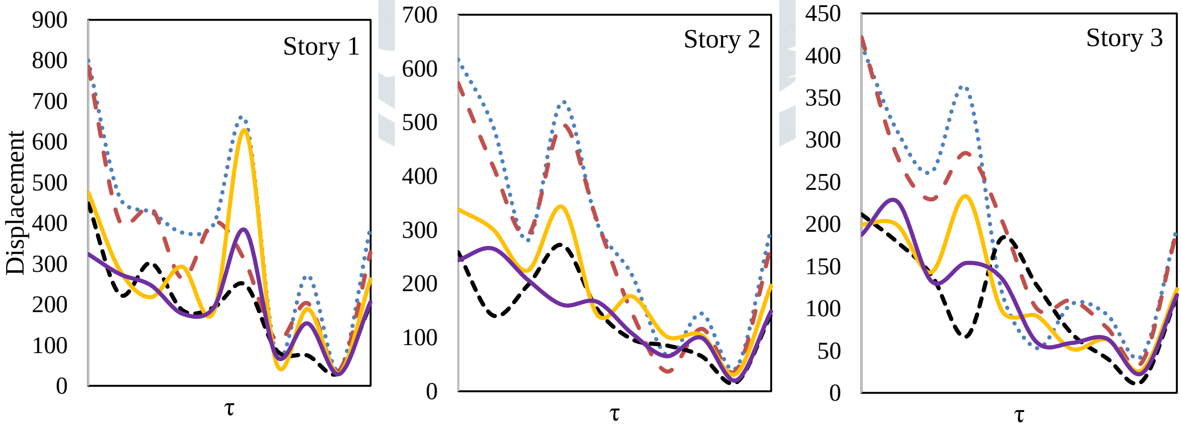


Fig. 10. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.1 at 0.5sec (Rμ=4).



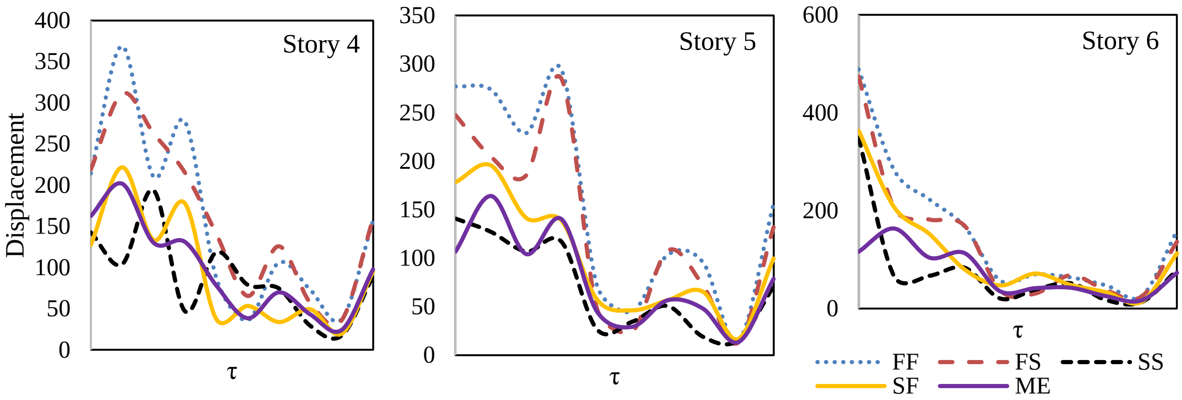


Fig. 11. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.2 at 0.5sec (Rμ=4).

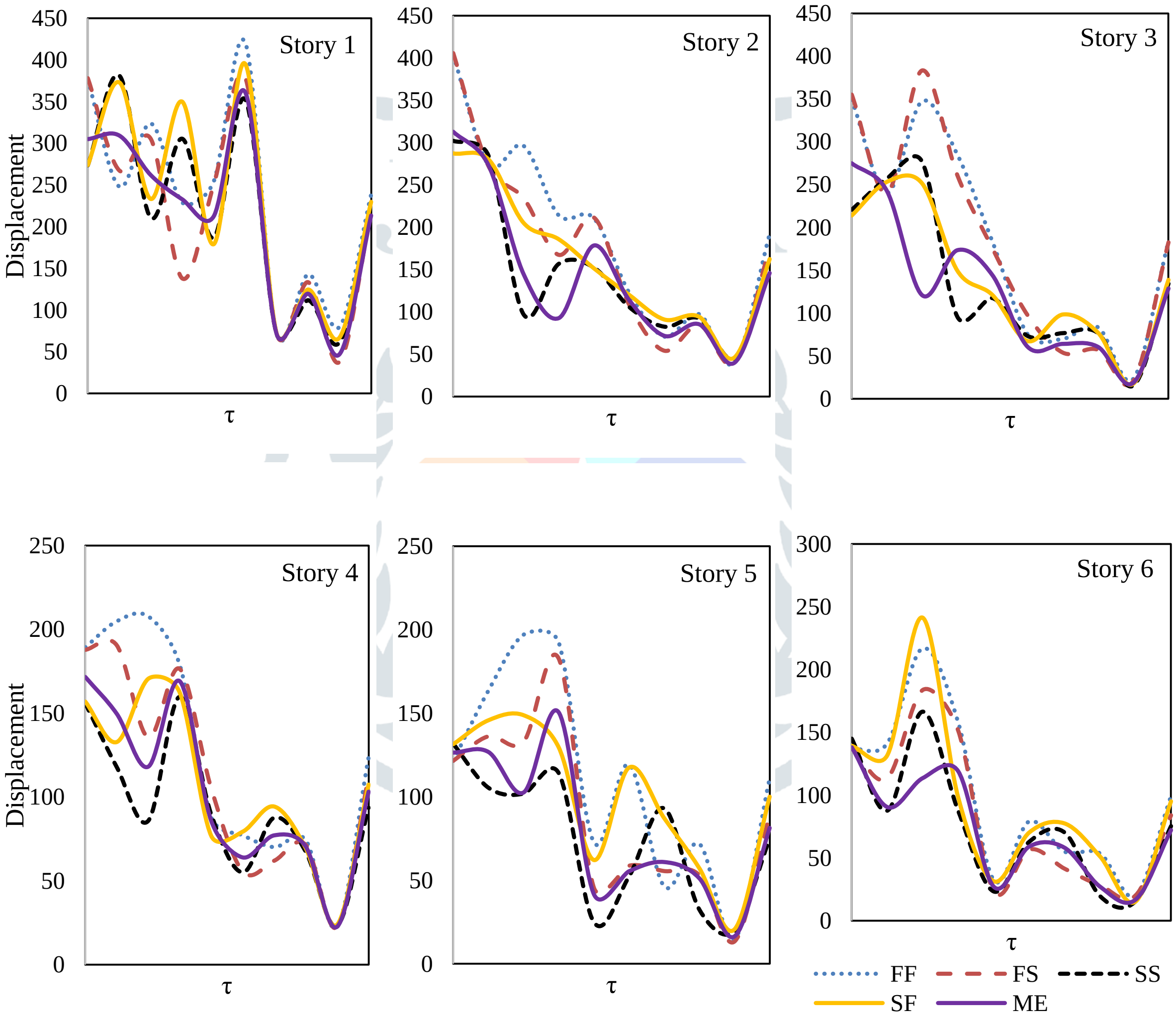


Fig. 12. Maximum displacement response of MDOF asymmetric system for e/D = 0.1, 0.05 at 0.5sec (Rμ=4).

In the graphs, the mean maximum displacement response is plotted at ordinate and torsional to lateral period ratio (τ) at abscissa. Fig. (3) to Fig. (20) shows the ultimate scenario with six sets of graphs (ground to top story) for the standard reduction factor and the different lateral times. Further, each graph exhibits the response with different combination of bi-directionally eccentric system and for standard strength eccentricity. Fig. (3) to Fig. (20) shows the ultimate scenario with six sets of graphs (ground to top story) for the standard reduction factor (R_μ) = 4 and the different lateral times. Further, each graph exhibits the response with different combination of bi-directionally eccentric system and for standard strength eccentricity. Fig. 3 represents the maximum elemental deformation in story 1 for 0.25sec at e/D = 0.05, 0.05. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in mid-rise story levels whereas story 1, 4 and 5 shows the maximum deformation response for element 1 and element 4. Other stories may lead to an increase in the dynamic response near about same for differential elemental approach. Fig. 4 represents the maximum elemental deformation in story 1 for 0.25sec at e/D = 0.05, 0.1. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in up-rise story levels whereas story 1, 2 and 3 shows the maximum deformation response for element 1 and element 2. Other two stories, story 5 and 6 may lead to an increase in the dynamic response near about same for element 1 and element 4. However, Fig. 5 represents the maximum elemental deformation in story 1 for 0.25sec at e/D = 0.05, 0.2. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in low-rise story levels whereas each story shows the maximum deformation response for element 1 and element 2. Fig. 6 represents the maximum elemental deformation in story 1 for 0.25sec at e/D = 0.1, 0.05. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in mid-rise story levels whereas story 2, 3 and 6 shows the maximum deformation response for element 1 and element 2. Other stories story 1 and story 5 may lead to an increase in the dynamic response near about same for differential elemental approach for element 1 and element 4. In contrast, Fig. 7 represents the maximum elemental deformation in story 1 for 0.25sec at e/D = 0.2, 0.05. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in low-rise story levels whereas story 2, 3 and 4 shows the maximum deformation response for element 1 and element 2. Story 5 and story 6 may lead to an increase in the dynamic response near about same for differential elemental approach for element 1 and element 3. Fig. 8 represents the maximum elemental deformation in story 2 for 0.25sec at e/D = 0.1, 0.2. Effect has been developed to the other stories that influence by story 2. The scattering of elemental displacement has been clearly observed in story 1, 4 and 5 whereas each story shows the maximum deformation response for element 1 and element 2. On the other hand, story 6 may lead to an increase in more dynamic response than story 4 and story 5. Similarly, elemental response for story 3 is more than story 1. However, Fig. 9 appear for the maximum elemental deformation in story 1 for 0.5sec at e/D = 0.05, 0.05. Effect has been developed to the other

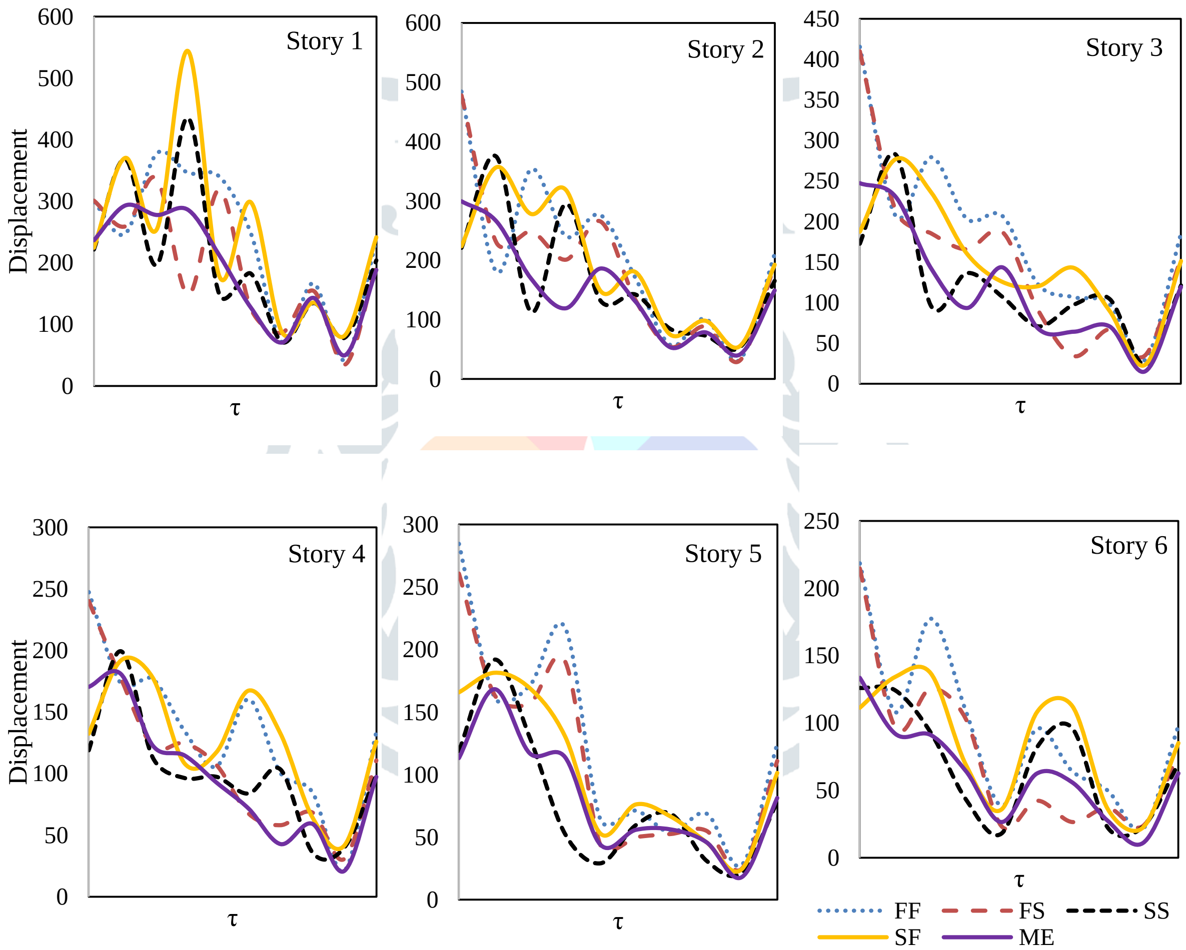


Fig. 13. Maximum displacement response of MDOF asymmetric system for e/D = 0.2, 0.05 at 0.5sec (Rμ=4).

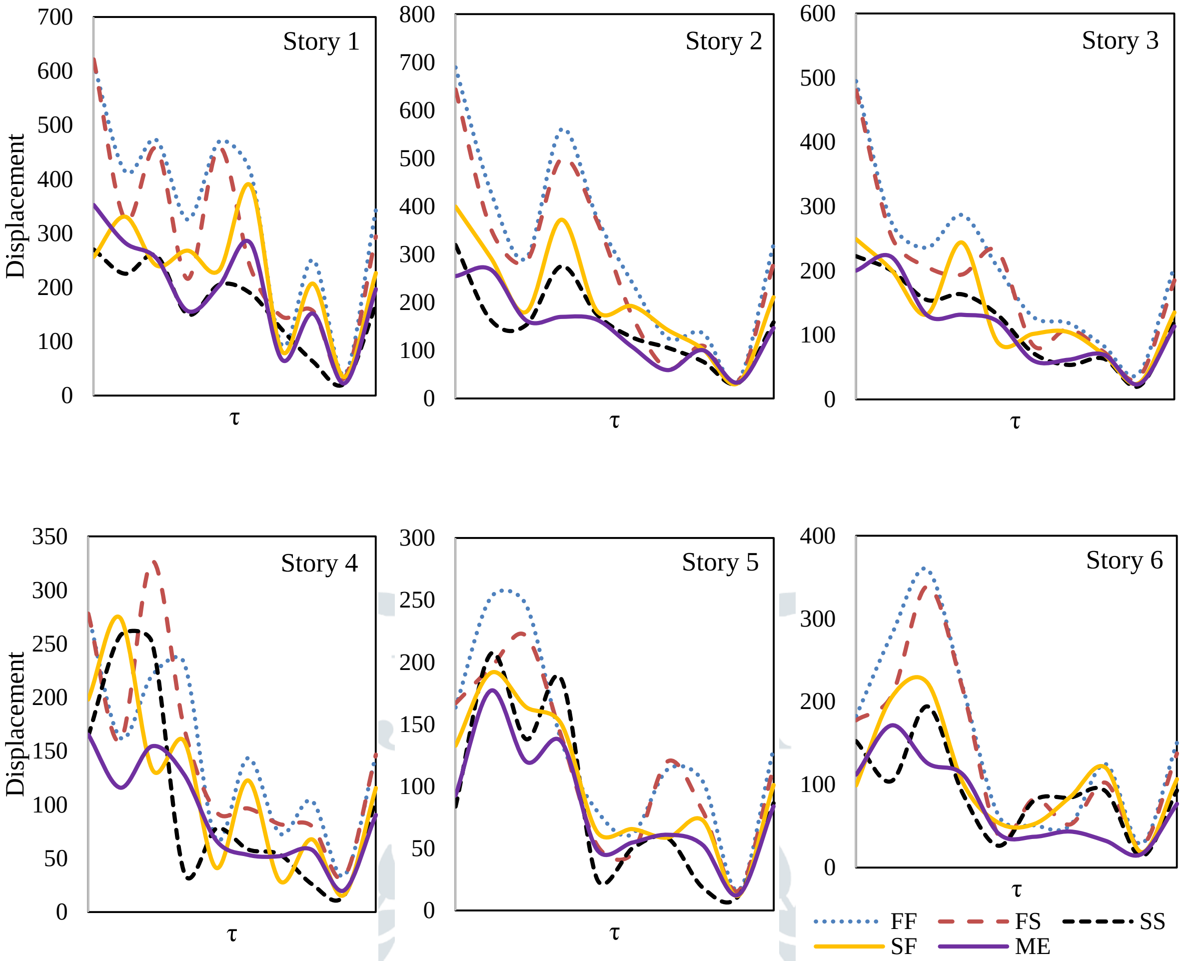


Fig. 14. Maximum displacement response of MDOF asymmetric system for e/D = 0.1, 0.2 at 0.5sec (Rμ=4).

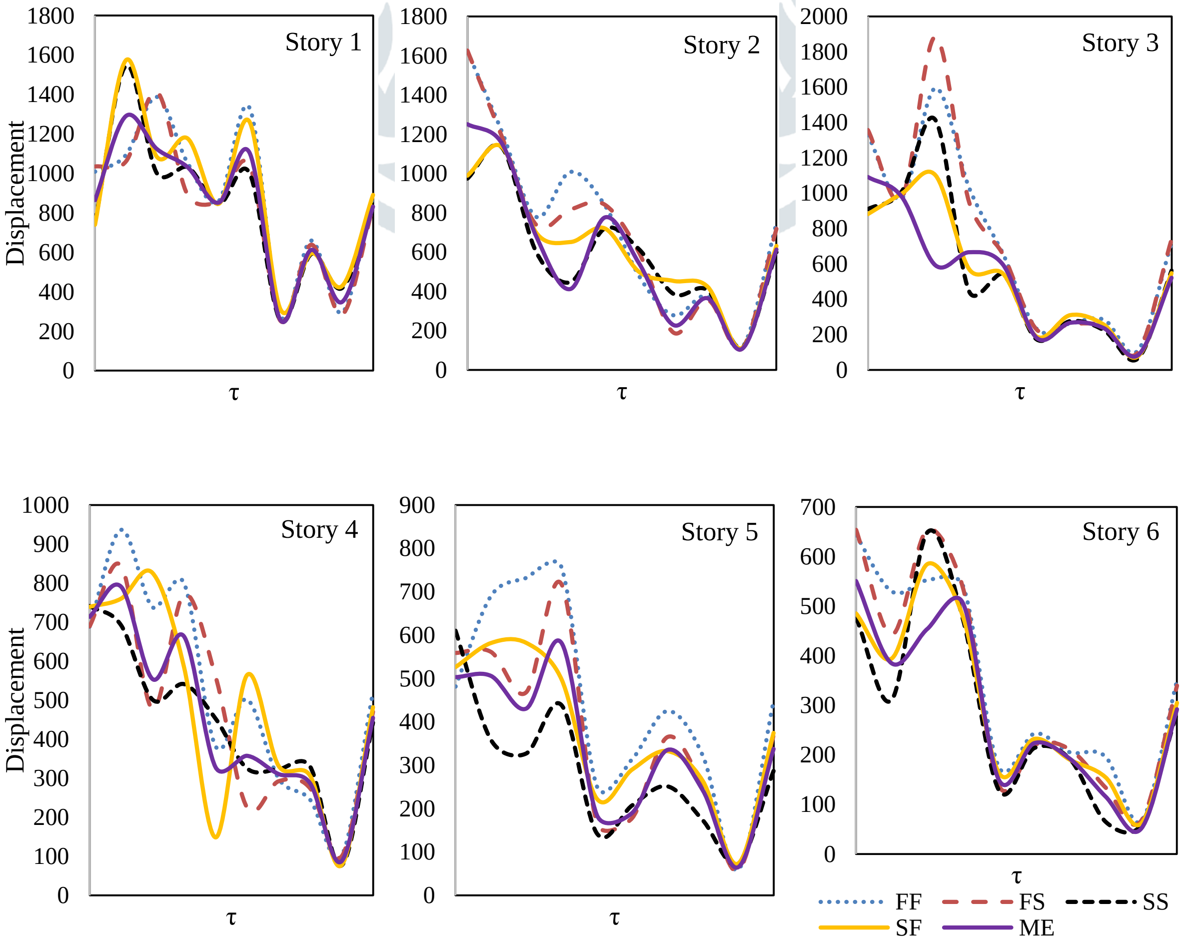


Fig. 15. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.05 at 1.0sec (Rμ=4).

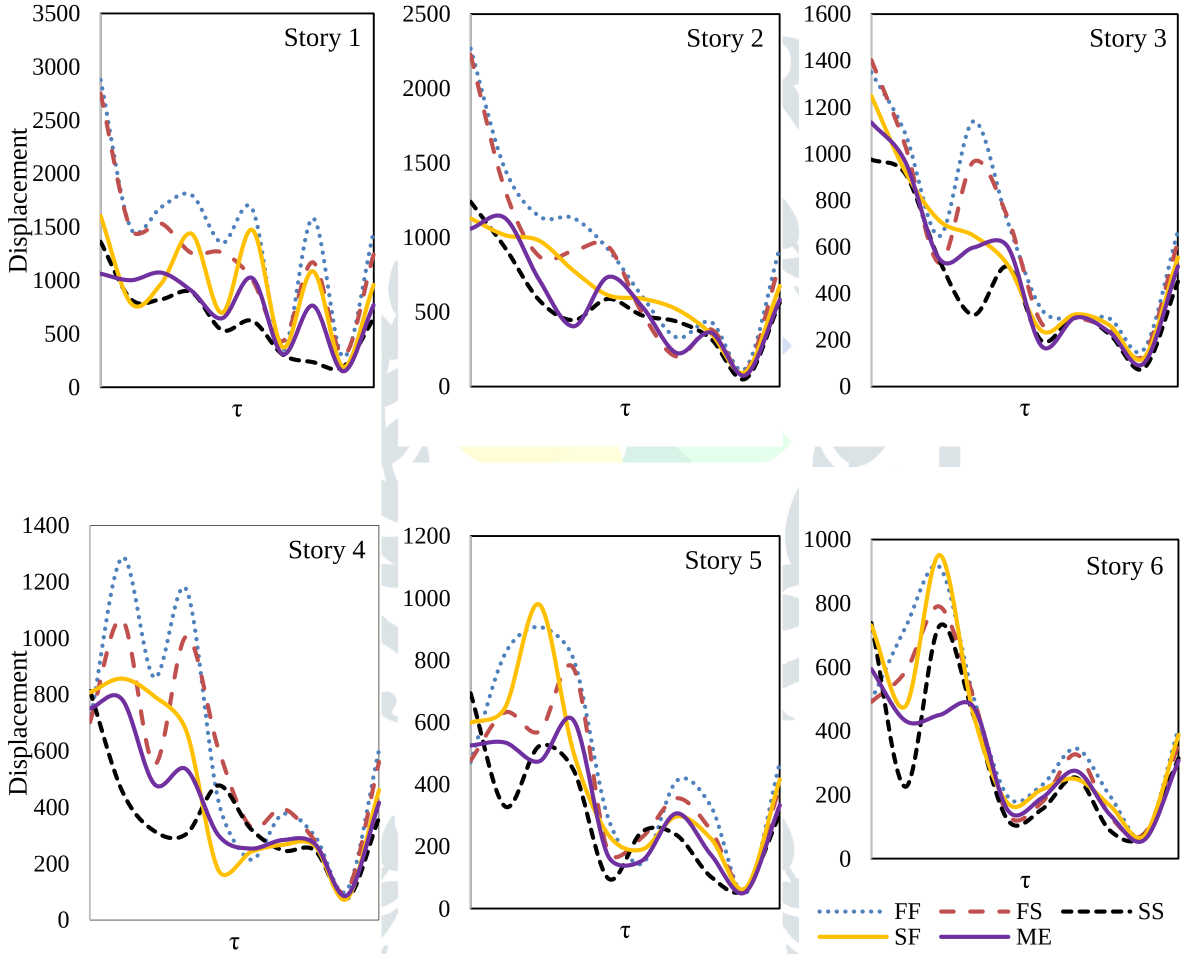
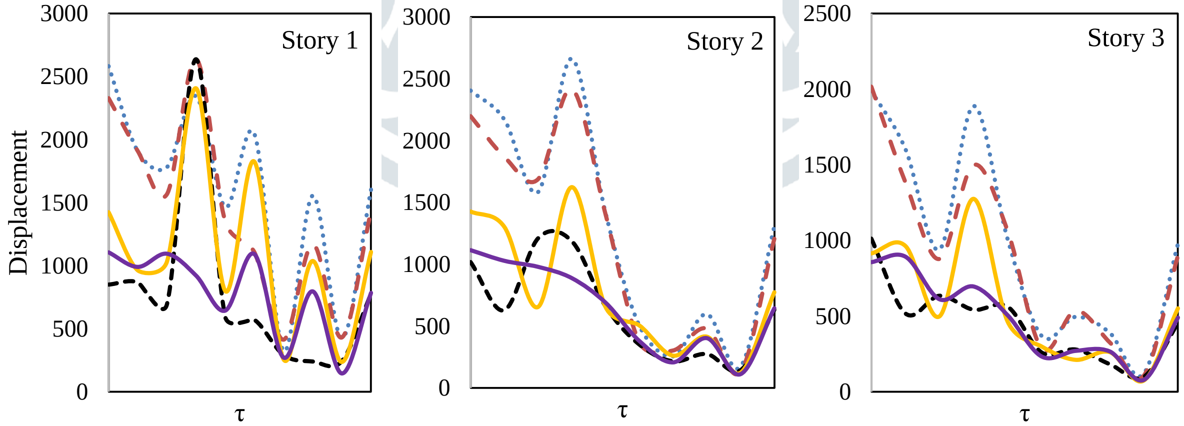


Fig. 16. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.1 at 1.0sec (Rμ=4).



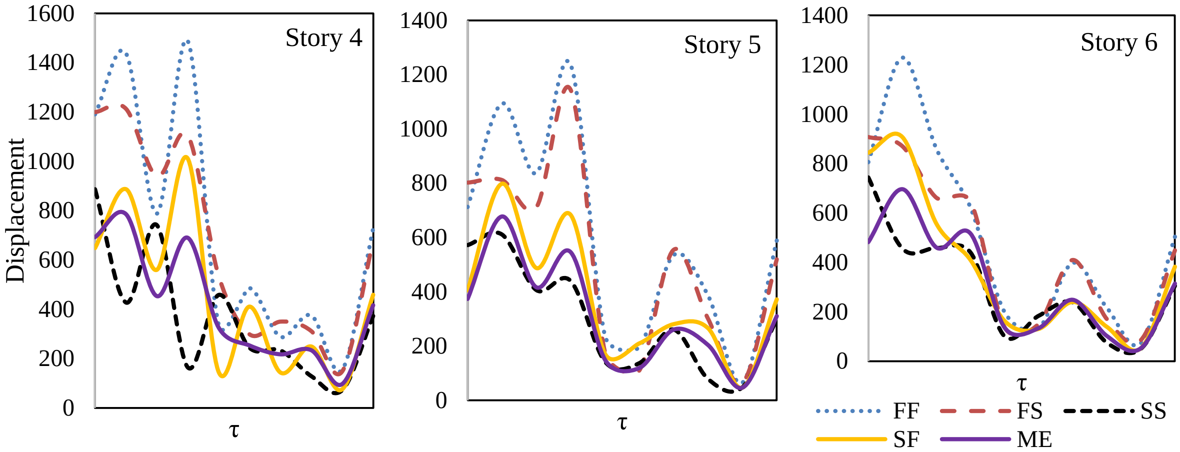


Fig. 17. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.2 at 1.0sec (Rμ=4).

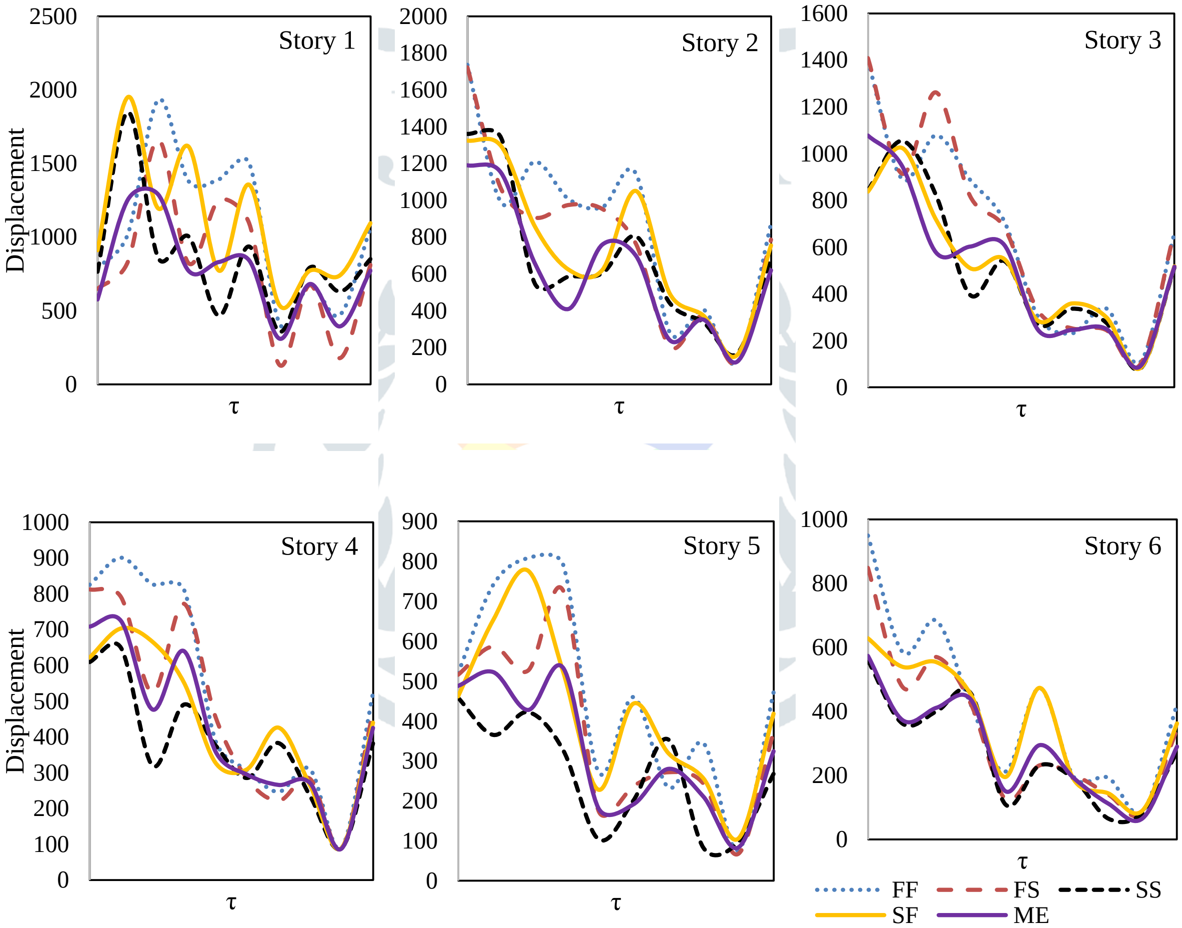


Fig. 18. Maximum displacement response of MDOF asymmetric system for e/D = 0.1, 0.05 at 1.0sec (Rμ=4).

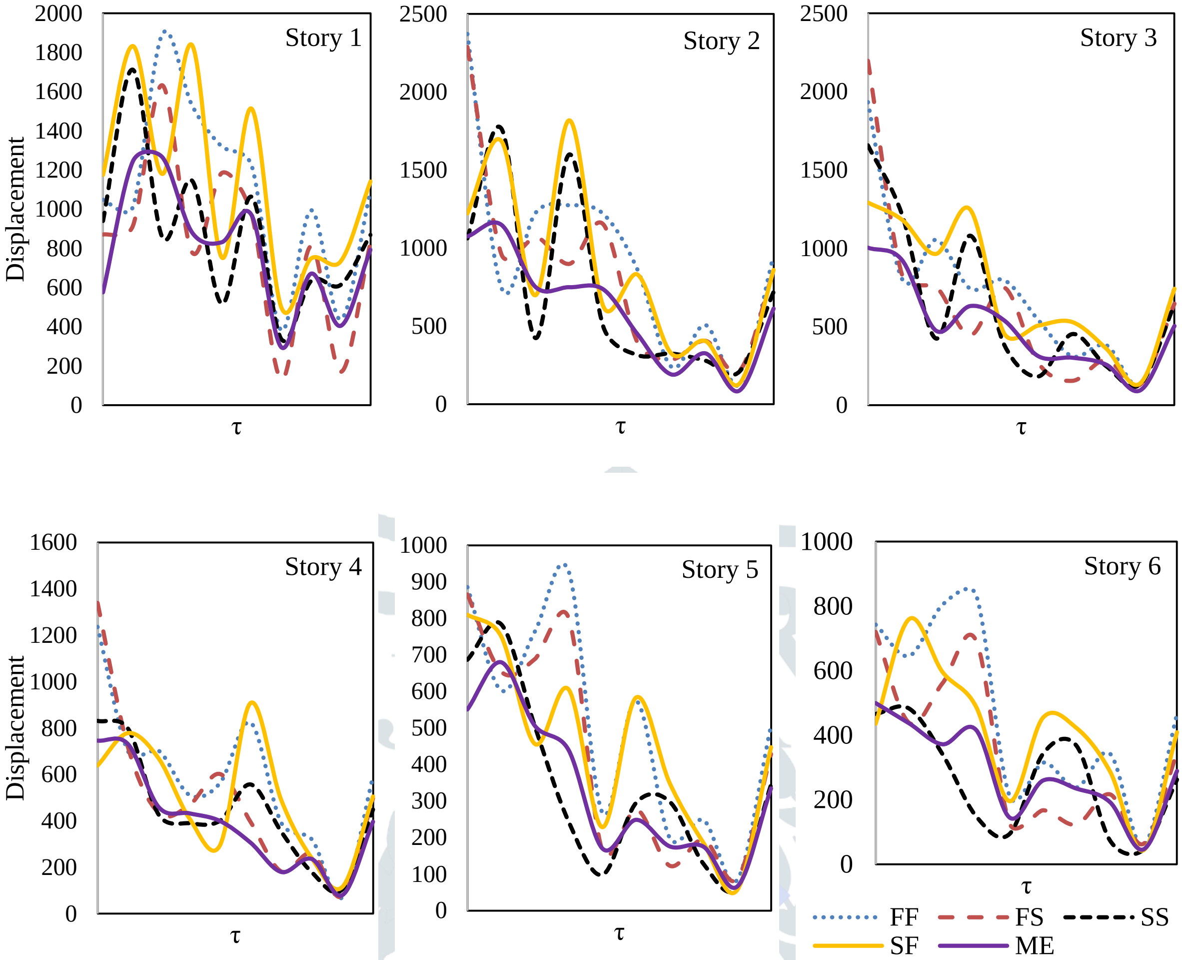


Fig. 19. Maximum displacement response of MDOF asymmetric system for e/D = 0.2, 0.05 at 1.0sec (Rμ=4).

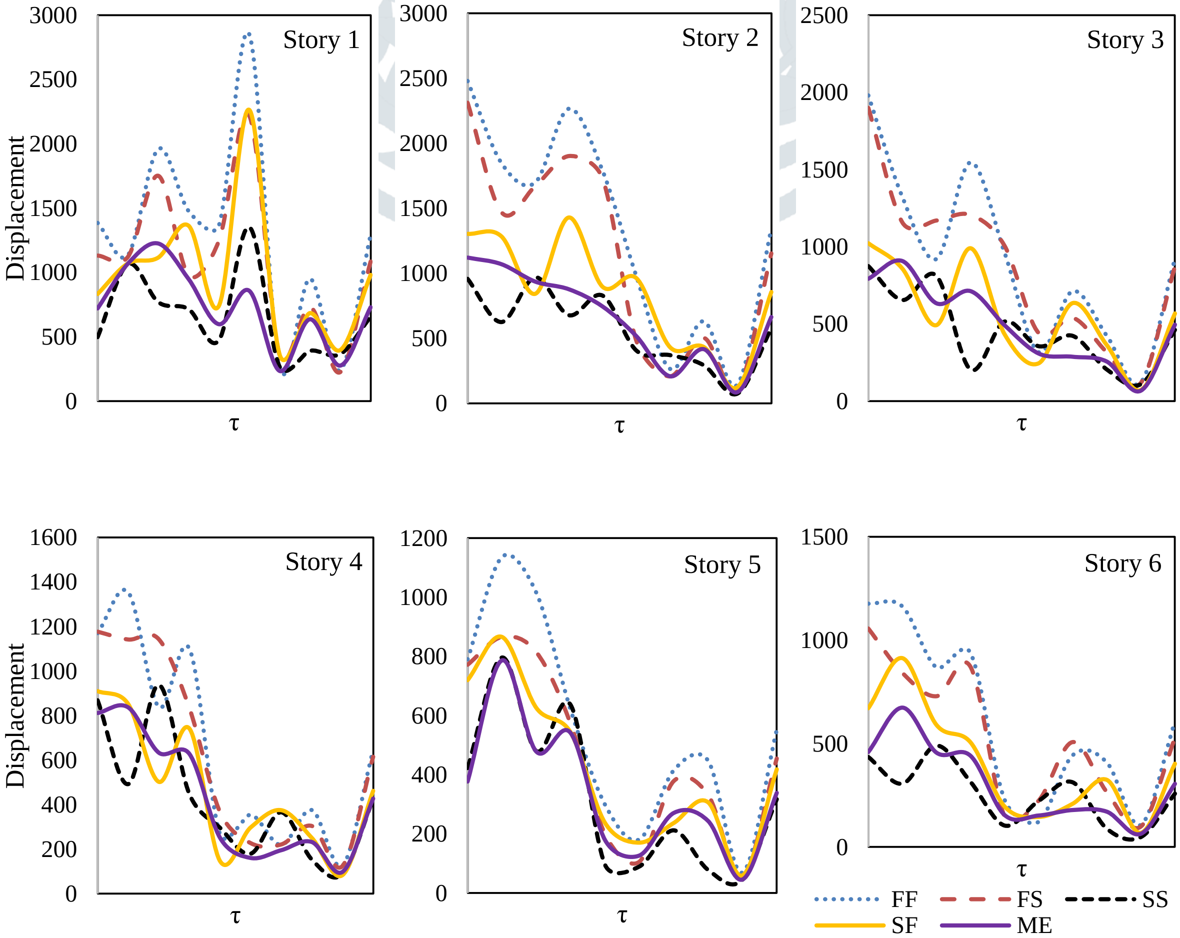


Fig. 20. Maximum displacement response of MDOF asymmetric system for e/D = 0.1, 0.2 at 1.0sec (Rμ=4).

stories that influence by story 1. The scattering of elemental displacement has been observed in story 4 whereas story 1, 4, 5 and 6 shows the maximum deformation response for element 1 and element 4. Other stories 2 and 3 may lead to an increase in the dynamic response almost same for differential elemental approach for element 1 and element 2. Some observation clearly shows that the response of story 3 and 6 is more than story 2 and 5 respectively.

On the other hand, Fig. 10 appear for the maximum elemental deformation in story 1 for 0.5sec at e/D = 0.05, 0.1. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in up-rise story levels whereas story 1 to story 4 shows the maximum deformation response for element 1 and element 2. Other stories may lead to an increase in the feasible dynamic response near about same. Fig. 11 appear for the maximum elemental deformation in story 1 for 0.5sec at e/D = 0.05, 0.2. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in low-rise story levels whereas each story shows the maximum deformation response for element 1 and element 2. Response of story 6 is more than story 3, 4 and 5. Moreover, Fig. 12 appear for the maximum elemental deformation in story 1 for 0.5sec at e/D = 0.1, 0.05. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in story 1 whereas story 2, 3 and 4 shows the maximum deformation response for element 1 and element 2. Other stories story 1 and story 6 may lead to an increase in the dynamic response near about same for differential elemental approach for element 1 and element 4. Response of story 6 is more than story 4 and 5. Furthermore, Fig. 13 speak for the maximum elemental deformation in story 1 for 0.5sec at e/D = 0.2, 0.05. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in low-rise story levels whereas story 2 to story 6 shows the maximum deformation response for element 1 and element 2. Story 1 may lead to an increase in the dynamic response near about same for differential elemental approach for element 3 and element 4. Response of story 5 is more than story 4. However, Fig. 14 play for the maximum elemental deformation in story 2 for 0.5sec at e/D = 0.1, 0.2. Effect has been developed to the other stories that influence by story 2. The scattering of elemental displacement has been clearly observed in each story levels whereas story 1, 2, 3, and 6 shows the maximum deformation response for element 1 and element 2. Other stories may lead to an increase in average dynamic response. Response of story 6 is more than story 4 and 5.

Besides of that, Fig. 15 appear for the maximum elemental deformation in story 3 for 1.0sec at e/D = 0.05, 0.05. Effect has been developed to the other stories that influence by story 3. The scattering of elemental displacement has been clearly observed in mid-stories whereas story 2, 3, 4 and 5 shows the maximum deformation response for element 1 and element 2. Other stories may lead to an increase in the dynamic response almost same for differential elemental approach for element 3 mostly. Fig. 16 appear for the maximum elemental deformation in story 1 for 1.0sec at e/D = 0.05, 0.1. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in lower stories whereas story 1 to story 4 shows the maximum deformation response for element 1 and element 2. Other stories may lead to an increase in the feasible dynamic response near about same for element 1 and element 4. Additionally, Fig. 17 appear for the maximum elemental deformation in story 2 for 1.0sec at e/D = 0.05, 0.2. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in story 1 and 4 whereas story 2 to story 5 shows the maximum deformation response for element 1 and element 2. Fig. 18 appear for the maximum elemental deformation in story 1 for 1.0sec at e/D = 0.1, 0.05. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in story 1 and story 5 whereas story 2, 3, 4 and 6 shows the maximum deformation response for element 1 and element 2 similarly. Other stories story 1 and story 5 may lead the response near about same for differential elemental approach for element 1 and element 4. The response of story 6 is more than story 4 and 5.

In addition, Fig. 19 speak for the maximum elemental deformation in story 2 for 1.0sec at e/D = 0.2, 0.05. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in each story levels whereas story 2 to story 5 shows the maximum deformation response for element 1 and element 2. Story 1 and story 6 may lead to an increase in the dynamic response near about same for differential elemental approach for element 1 and element 4. Moreover, Fig. 20 play for the maximum elemental deformation in story 1 for 1.0sec at e/D = 0.1, 0.2. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in each story levels whereas story 2, 3, 4 and 6 shows the maximum deformation response for element 1 and element 2. Other stories may lead to an increase in average dynamic response. The response of story 6 is more than story 5.

Table 3. Maximum and minimum response of each story for different eccentric condition at 0.25sec (Rμ=4).

No. of story	Maximum e/D	Minimum e/D
1	0.1, 0.05	0.2, 0.05
2	0.05, 0.2	0.05, 0.05
3	0.1, 0.2	0.05, 0.1
4	0.05, 0.2	0.1, 0.05
5	0.05, 0.2	0.1, 0.05
6	0.1, 0.2	0.1, 0.05

Table 4. Maximum and minimum response of each story for different eccentric condition at 0.5sec (Rμ=4).

No. of story	Maximum e/D	Minimum e/D
1	0.05, 0.05	0.1, 0.05
2	0.1, 0.2	0.05, 0.05
3	0.1, 0.2	0.05, 0.1
4	0.05, 0.2	0.1, 0.05
5	0.05, 0.2	0.05, 0.05
6	0.05, 0.2	0.05, 0.1

Table 5. Maximum and minimum response of each story for different eccentric condition at 1.0sec (Rμ=4).

No. of story	Maximum e/D	Minimum e/D
1	0.05, 0.1	0.05, 0.05
2	0.05, 0.2	0.05, 0.05
3	0.2, 0.05	0.05, 0.1
4	0.05, 0.2	0.1, 0.05
5	0.05, 0.2	0.05, 0.05
6	0.05, 0.2	0.05, 0.05

On the other hand, Table 3 to Table 5 represents the ultimate scenario of the variation of different eccentric conditions at each story with respect to the torsional effect for Rμ=4. Tables have been arranged with the response of maximum and minimum eccentric conditions that has been clarified the judgmental suitable eccentric conditions in north-east zones due to bi-directional excitation. The brief conclusions have been decontaminated the results with justified manner. Fig. 21 to Fig. 23 and Fig. 24 to Fig. 26 represents the elemental response for Rμ=6 and Rμ=8 at 1.0sec for the maximum discrete of ductility reduction factors respectively due to 1st five (Show in Table 1) bi-directional excitation. Also, Table 6 and Table 7 represents the ultimate scenario of the variation of different eccentric conditions at each story with respect to the torsional effect for Rμ=6 and 8 respectively.

Fig. 21 and Fig. 22 speaks for the maximum elemental deformation in story 1 for 1.0sec at e/D = 0.05, 0.05; 0.05, 0.1. Effect has been developed to the other stories that influence by story 1. The scattering of elemental displacement has been clearly observed in each story levels, whereas story 3 and 4 also story 5 and 6 shows the maximum deformation response for element 1 and element 2 also element 1 and element 4 respectively. On the other hand, story 2, 3, 4 and 6 shows the maximum deformation response for element 1 and for element 2. Moreover, Fig. 23 play for the maximum elemental deformation in story 2 for 1.0sec at e/D = 0.05, 0.2. Effect has been developed to the other stories that influence by story 2. The scattering of elemental displacement has been clearly observed in each story levels whereas each story shows the maximum deformation response for element 1 and element 2. Other stories may lead to an increase in average dynamic response.

Furthermore, Fig. 24 to Fig. 26 represents for the maximum elemental deformation in story 2 for 1.0sec at e/D = 0.05, 0.05; 0.05, 0.1; 0.05, 0.2. Effect has been developed to the other stories that influence by story 2. The scattering of elemental displacement has been clearly observed in each story levels whereas stories shows the maximum deformation response for element 1, element 2 and element 4 that may lead to an increase in average dynamic response. Table 8 represents the variation of ductility reduction factor (Rμ) for different story levels with the contrast of eccentric conditions. This observation emphasizes the proper guideline in design section.

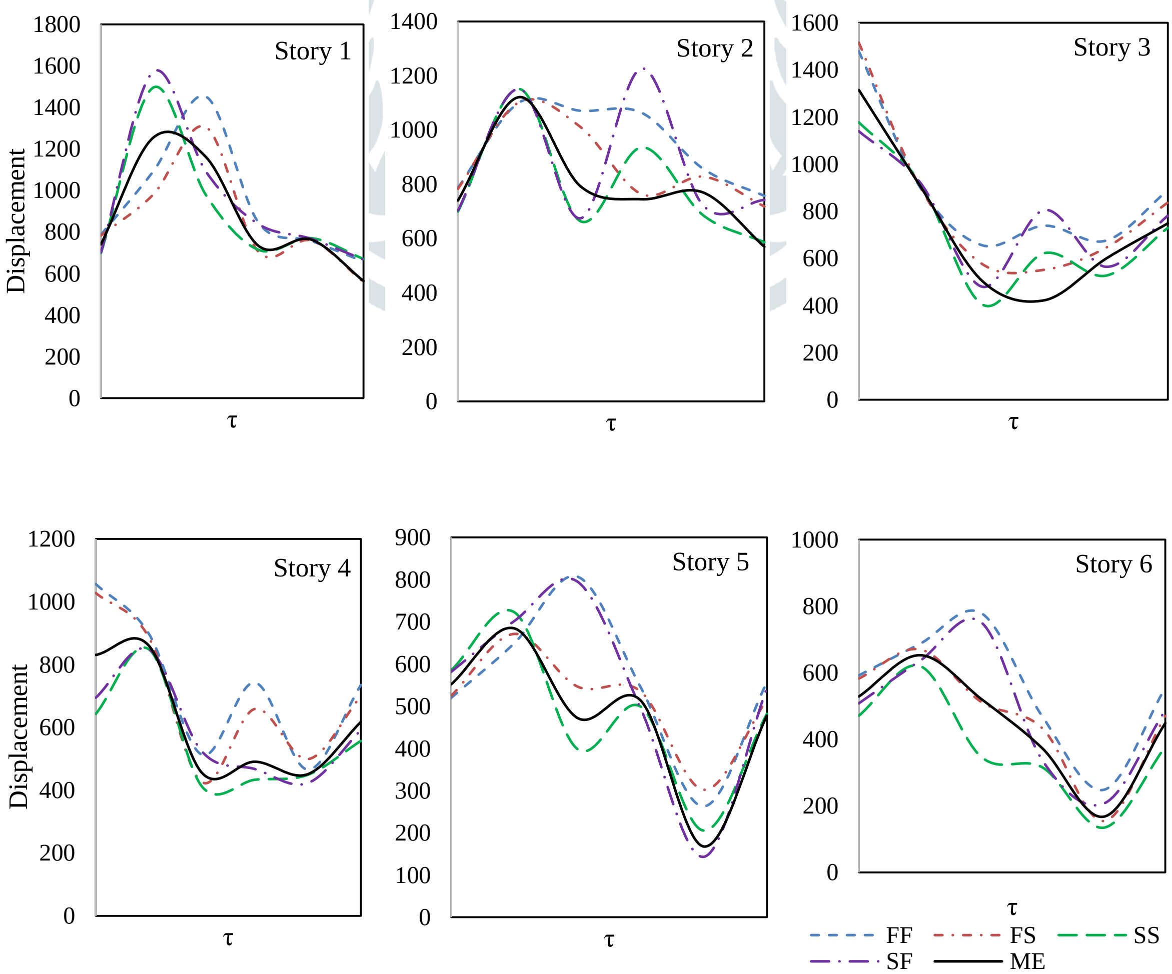


Fig. 21. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.05 at 1.0sec (Rμ=6).

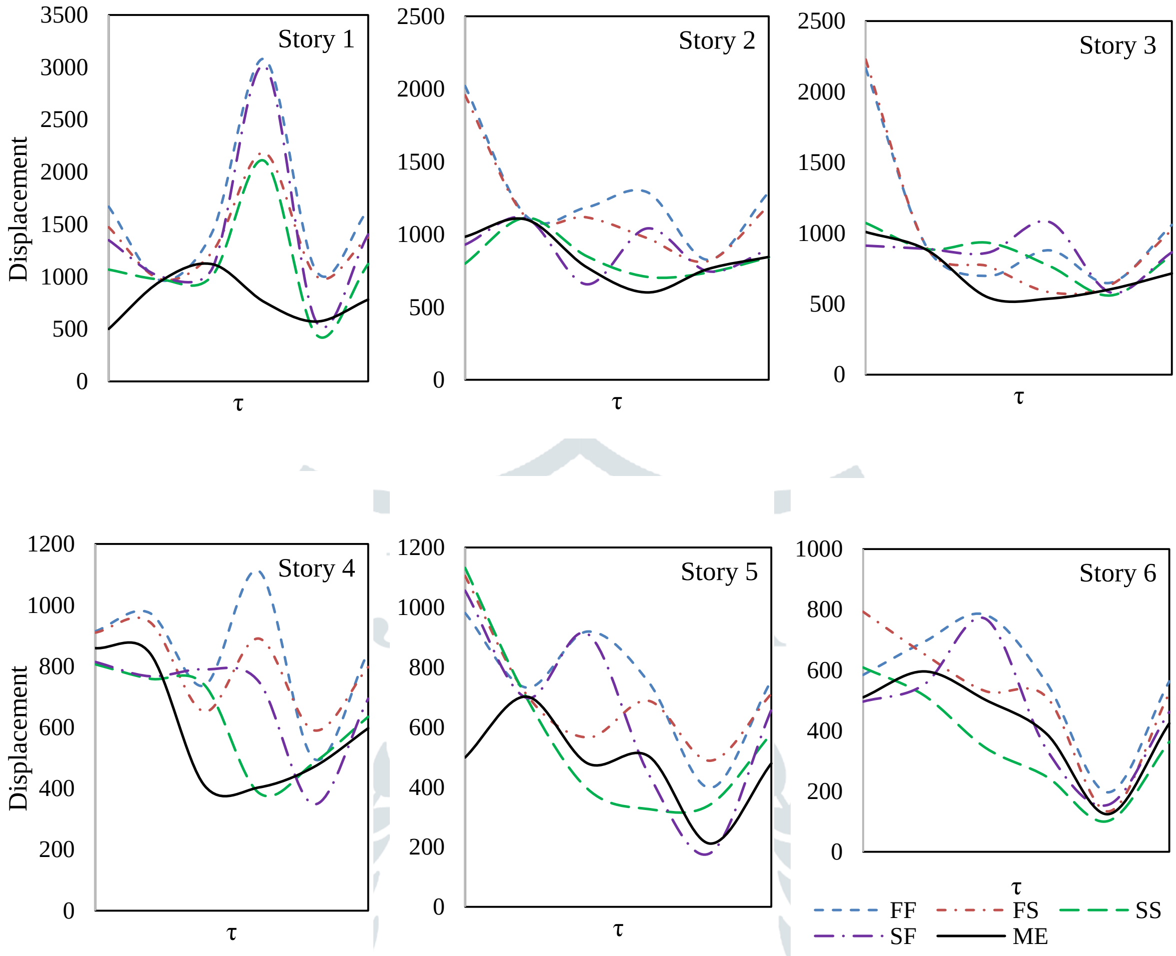
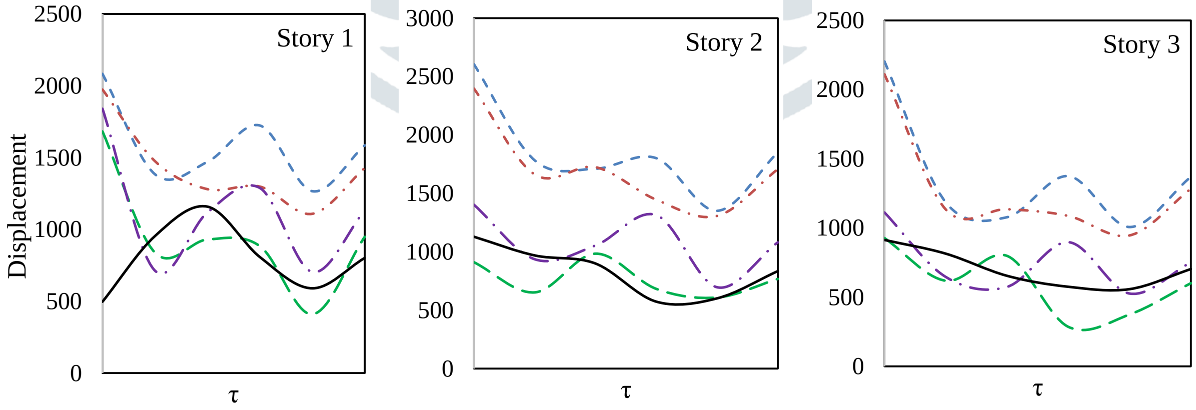


Fig. 22. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.1 at 1.0sec (Rμ=6).



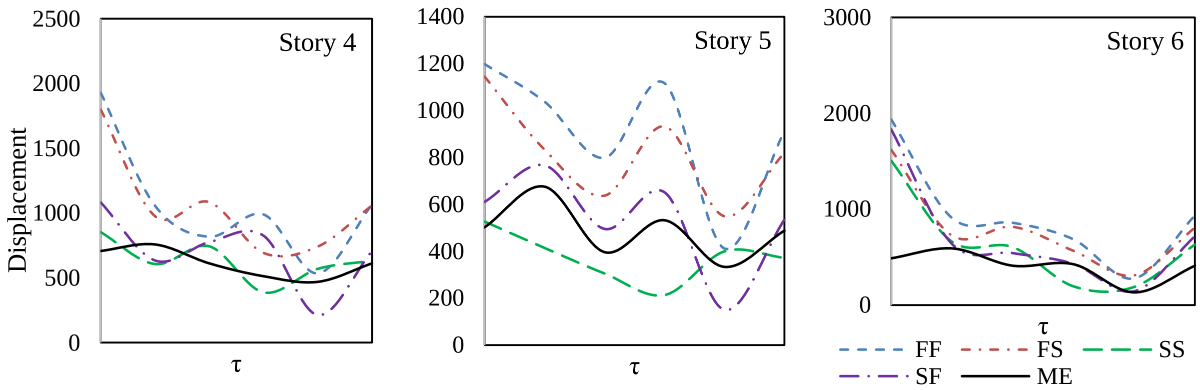


Fig. 23. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.2 at 1.0sec (Rμ=6).

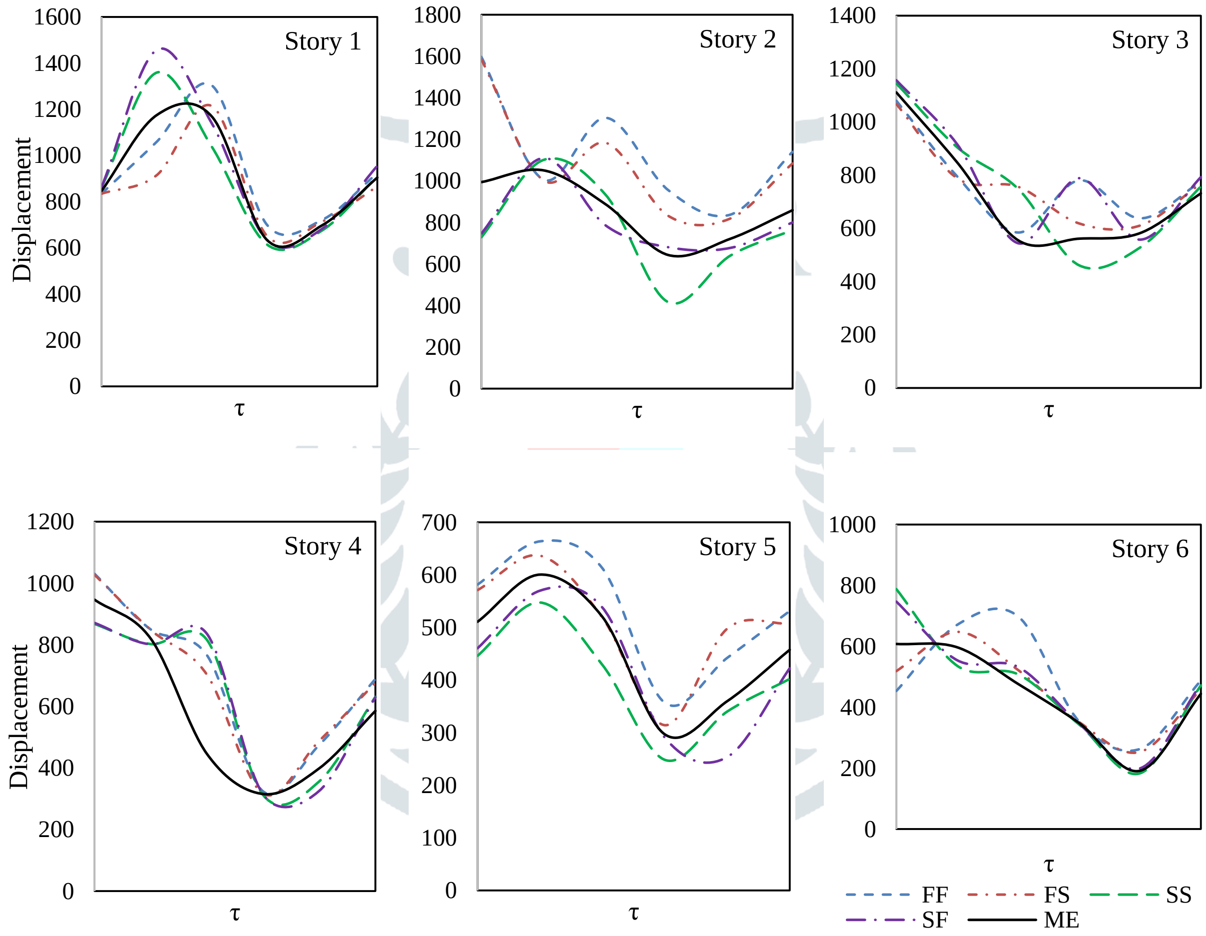
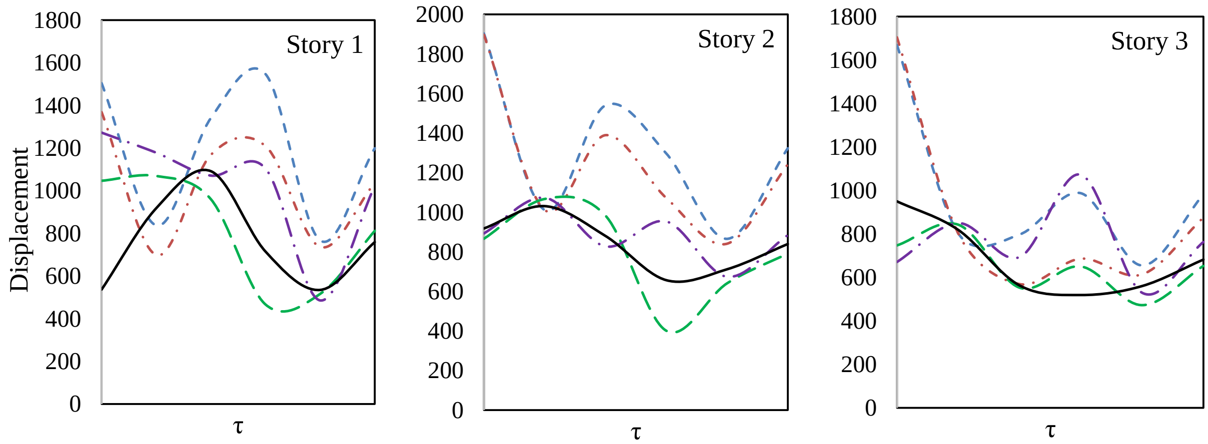


Fig. 24. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.05 at 1.0sec (Rμ=8).



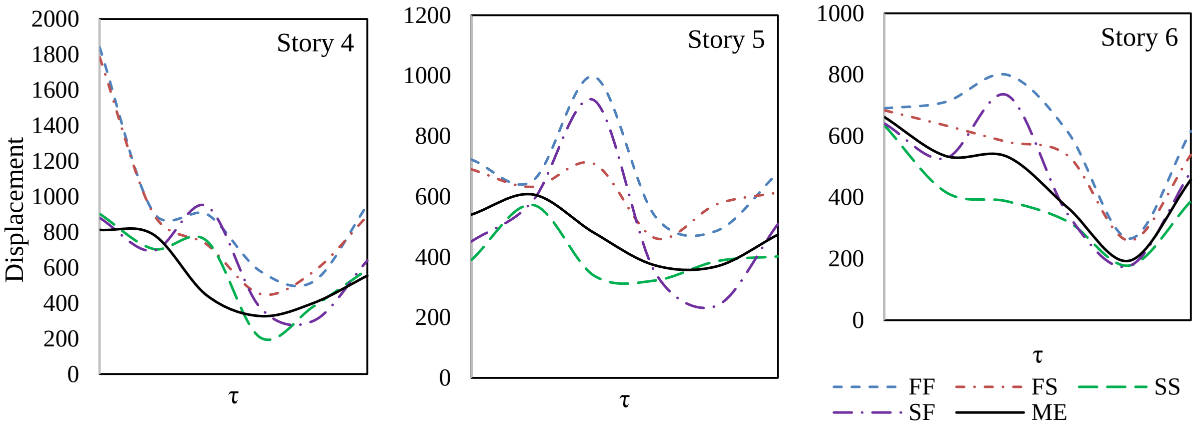


Fig. 25. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.1 at 1.0sec (Rμ=8).

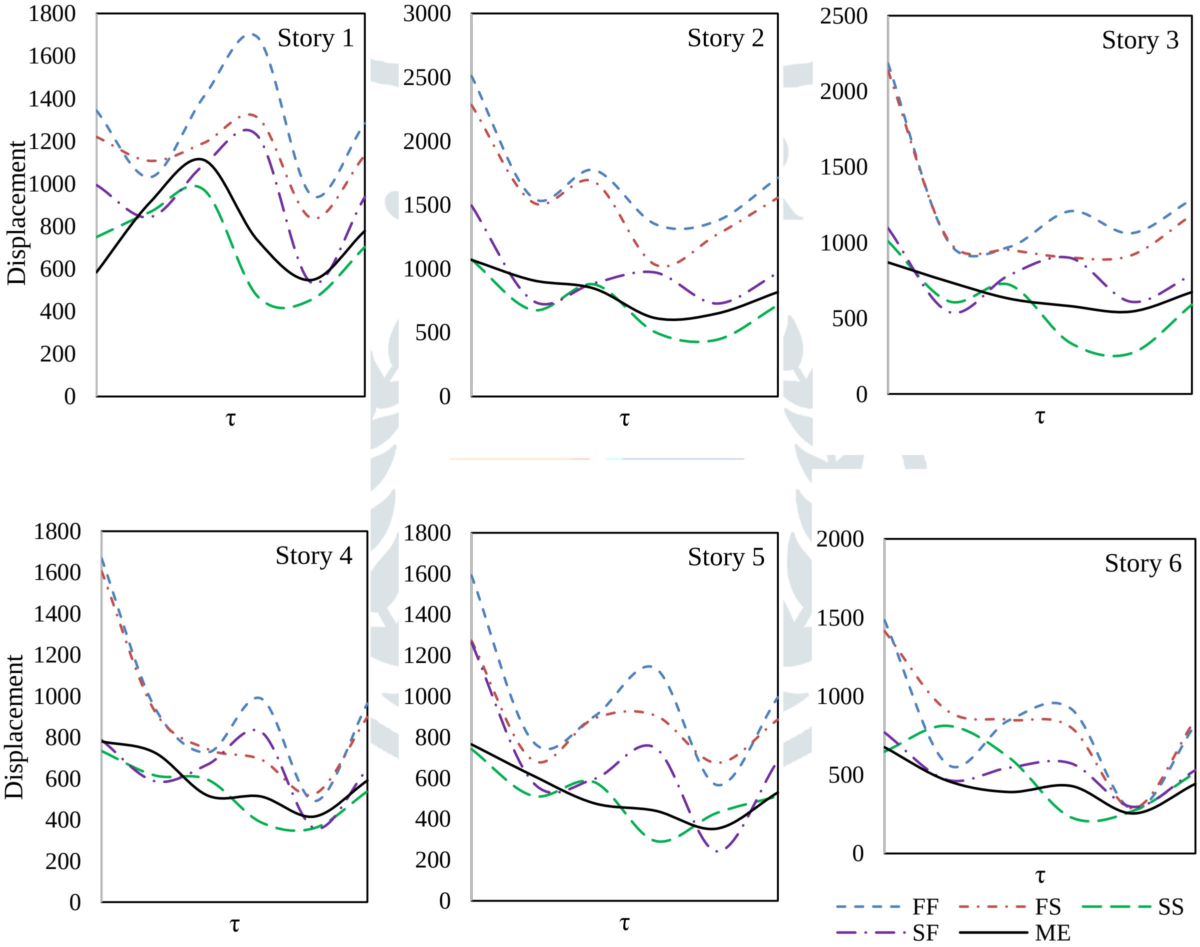


Fig. 26. Maximum displacement response of MDOF asymmetric system for e/D = 0.05, 0.2 at 1.0sec (Rμ=8).

Table 6. Maximum and minimum response of each story for different eccentric condition at 1.0sec (Rμ=6).

No. of story	Maximum e/D	Minimum e/D
1	0.05, 0.1	0.05, 0.05
2	0.05, 0.2	0.05, 0.05
3	0.05, 0.1	0.05, 0.05
4	0.05, 0.2	0.05, 0.05
5	0.05, 0.2	0.05, 0.05
6	0.05, 0.2	0.05, 0.05

Table 7. Maximum and minimum response of each story for different eccentric condition at 1.0sec (Rμ=8).

No. of story	Maximum e/D	Minimum e/D
1	0.05, 0.2	0.05, 0.05
2	0.05, 0.2	0.05, 0.05

3	0.05, 0.2	0.05, 0.05
4	0.05, 0.1	0.05, 0.05
5	0.05, 0.2	0.05, 0.05
6	0.05, 0.2	0.05, 0.05

Table 8. Ductility reduction factor (Rμ) variation for different story levels.

No. of story	Low	Moderate	High
1	8	4	6
2	8	6	4
3	6	8	4
4	4	8	6
5	6	4	8
6	4	8	6

VII. CONCLUSIONS

The present investigation comprehensively studied the inelastic seismic performance of multi-story asymmetric structural system in north-east region under the set of orthogonal pairs of bi-directional ground motions. The results are also indicated the performance evaluation of load resisting elements mainly the column sections for crystalized understanding the serviceability. The following broad conclusions emerge.

1. The response of six-story asymmetric system in inelastic phase is observed critical due to bi-directional excitation and also the variation of story wise eccentric conditions. 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. 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 mass, stiffness and strength eccentric variation. The strong vulnerability is especially apprehended through the common torsional effect of each story which clearly highlights the non-linear dynamic behavior.
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. Buildings with irregular eccentricities at different story levels may experience higher response whereas the minimum stiffness and mass eccentricities resist against the major deformation for e/D=0.05, 0.05. This minimum eccentric condition may be emphasized the serviceability of load resisting elements those less is better. On the other hand, major accidental eccentricity e/D=0.05, 0.2 is performed unsuitably against the various torsional demand modes. Furthermore, the requisite design for stiffness eccentric condition was not comprised in many old buildings in north-east regions which implicit strength eccentricity remains the same as stiffness eccentricity. As a result, the percentage of deformation is high for disparaging. The consequences of decorous and accidental eccentricity may be incorporated separately, as appropriate.
3. Inelastic demand is high inside of flexible elements of this system, particularly for stiff side elements. Buildings may be considered square pattern or low eccentric condition with square column in this particular region owing to high intensity of ground motions. Moreover, it has been clearly judged that for residential buildings the limitation of stories maximum two and for commercial buildings it may be considered maximum three stories that based on soil condition.
4. The variation of response reduction factor (Rμ) is developed to observe the serviceability of old existing buildings to new model structures. The response reduction factors vary story wise with different eccentric conditions. The incremental reduction factors do not clarify the response with increasing the values. These values may be useful for considering specific Rμ for different seismic design of multi-story asymmetric structural systems. These dynamic observations eventuate to be dominant from the viewpoint of mechanics.

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 such plan 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 requirements 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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