Inelastic seismic response of single-story structure in hilly areas owing to ground excitation: Mitigating by vibration control device TLD

Krishnendu Chowdhury[1], Utsha Chowdhury[2], Goutam Bairagi[3]

[1,2]Assistant Professor, Civil Engineering Department, K K College of Engineering & Management, Jharkhand, India
[3]Professor & Head, Civil Engineering Department, Jalpaiguri Govt. Engineering College, West Bengal, India

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Abstract – *This study examines the inelastic seismic response of an idealized single-story RC structural system in hilly region under sloppy ground subjected to bi-directional ground motion excitation. In this exertion, models have various degree of inelasticity, are subjected to a set of near-fault ground motion with different characteristics for both symmetric and asymmetric structural systems. The columns are varying height owing to sloping ground conducted different angle of slopes like 15°, 25°, 35° and 45° on symmetric and asymmetric system for evaluating the overall response of load resisting elements and their mitigation techniques due to uncontrolled vibration and heavy weight land slide using beam-column joint and also modern technique of tuned liquid damper (TLD). The broad conclusions present in this study helps the fine tune of the provisions in the seismic code.*

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

1. INTRODUCTION

The deficiency of RC building in hilly areas can be observed a major serious challenging issue through out the globe. The seismic performance of buildings depends on shapes and plan of structural elements. In that case, at hilly area structures are constructed based on ground orientation make the structures 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 fabricates an irregular weak supporting frame work that induce a torsional effect in an inelastic region of load resisting structural elements owing to ground motion. Also, soil of the hills and mountains are those to be found in areas with altitude minimum above 300m sea level and slope 15% and above. This serious condition makes unease for developing the foundation strong for ages. Need some new observations will be made on keeping in mind that overall particular matter so the 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 used and the proper designing program of structural construction with respect to the plan orientation in hilly region. Some exemplar shows in Fig. 1-3 that makes a serious matter in human life. The limited work done has been conducted on this particular aspect for single-story model structure. Researchers have been proposed that the effect due to bi-directional excitation in hilly region buildings, clearly conclude that the primary failure mode is created by shear failure of short columns as a result lower seismic capacity of structural system in sloppy ground [1]. Furthermore, another serious observation on RC frame buildings in hilly slopes clearly shows that the slope angle increasing, building is becoming stiffer for short columns where shear force is increasing [2]. Recently, researchers have been assessed the seismic response for different stories on sloping ground clearly conclude that the overall response of flat ground structures are much more suitable than sloping ground in hilly areas [3]. Generally, in hilly areas, column and slab thickness are varied in 0.127m to 0.178m and 0.038m to 0.0762m respectively for only causes due to light weight construction. That specific issues create the major aspect for vulnerability of elemental deformation show in Fig. 3. On the other hand, brick masonry walls are commonly damage due to ground motion show in Fig. 2 and sometimes by heavy land slide show in Fig. 4. for low flexible properties of brick material also a challenging aspect for controlling the damage from pre- and post-earthquake situation may built a justified guideline. 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 for symmetric and asymmetric systems in a critical seismic zone IV in India. Moreover, different parameters are considered and lies in a feasible

Fig. 1. Damage and collapse of buildings due to earthquake in hilly areas.

Fig. 2. 28 April 2021 Sonitpur (Assam) Earthquake (Magnitude 6.4*)*, diagonal shear cracking and subsequent collapse of masonry infill wall and out-of-plane collapse of masonry parapet walls.

Fig. 3. Sikkim-Nepal Border Earthquake of September 18, 2011 (Magnitude 6.9), (a) Damaged masonry building wall of the police check post at Lachung. (b) Damage to storage facility building wall in Chungthang.

Fig. 4. Collapse of buildings due to land slide.

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. Besides of elemental deformation, the exterior section of building like masonry brick wall, balcony and chajja are more vulnerable for high stiffness and less strength show in Fig. 4. Commonly brick infill wall be a common part of a building whereas, balcony and chajja are not suitable element for constructing in hilly areas buildings clearly show in Fig. 4. Instead of temporary chajja can be used causes due to ground excitation that acting on the exterior section of structures highly as per previous incidence. The dimension for chajja is 0.6×0.6m and 0.4×0.4m for balcony may be considered by field survey. Keep in mind the vulnerability of the structure, the mitigation technique being shown in this study, beam-column joint can be considered as a significant technique by observe field survey which is shown in Fig. 1. The tuned liquid damper (TLD) can be used along with beam-column joint 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 [12] 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 accompanying with masonry brick infill wall. 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, three typical idealized single-story structures are developed under the sloping ground terrain in different slope angle show in Fig. 5, where the columns are free from each other situated below the basement slab show in Fig. 5(a). On the other hand, another system is developed with beam-column joint show in Fig. 5(b) with same idealization for assessing the overall response for both cases and their serviceability due to ground excitation. Fig. 5-(i) shows the passive vibration control device consist a rigid square liquid (water) container which is connected to the top-mid of the structure that reduce structural vibration by sloshing of liquid inside the tank construct by brick masonry. All parameters are considered from past issue [12]. The liquid sloshing can move in a coupled horizontal and rotational direction. The length and width of system are considered 3m × 3m, also the depth of liquid 0.5m and sloshing liquid depth 1m at a section in TLD. The rotational motion of liquid is specified by θ_b. Therefore, the governing equations are adopted by previous case study [12] to assess the reducing percentage of vibration. On the other hand, the masonry wall can withstand considerable compressive stress but not nearly tensile stress when subjected to seismic loads. In that case, masonry brick infill provides additional stiffness appearing from compressive strut effect, as mentioned in Fig. 20(a). Caused by the lateral deformation of the simple rectangular panel by seismic load, the panel assumes the shape of parallelogram, causing one diagonal to expand and the other to shorten. The short diagonals will carry a compressive load and behave like a compressive strut in the same sense. Fig. 20(b) represent the different shape of columns section with specific dimensions. The simplified model even can used to at least to grossly understand the seismic performance in inelastic region. In this study, two different type of idealized structural system are represented namely, (a) completely symmetric system, (b) bi-directionally asymmetric system where the eccentricity is caused by the stiffness and mass eccentricity show in Fig. 6. The same six-element system was also developed by some researchers in earlier studies [4]. 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. The system has three degrees of freedom 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.

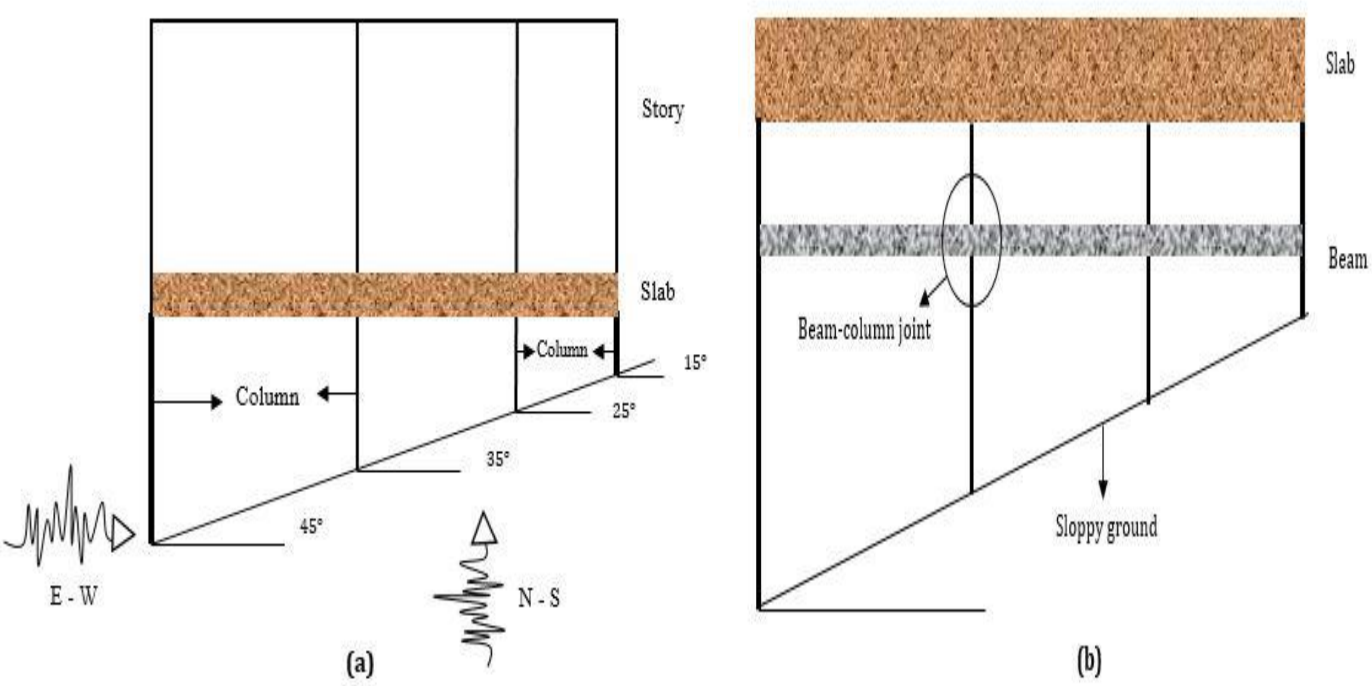


Fig. 5. Idealized single-story model structure.

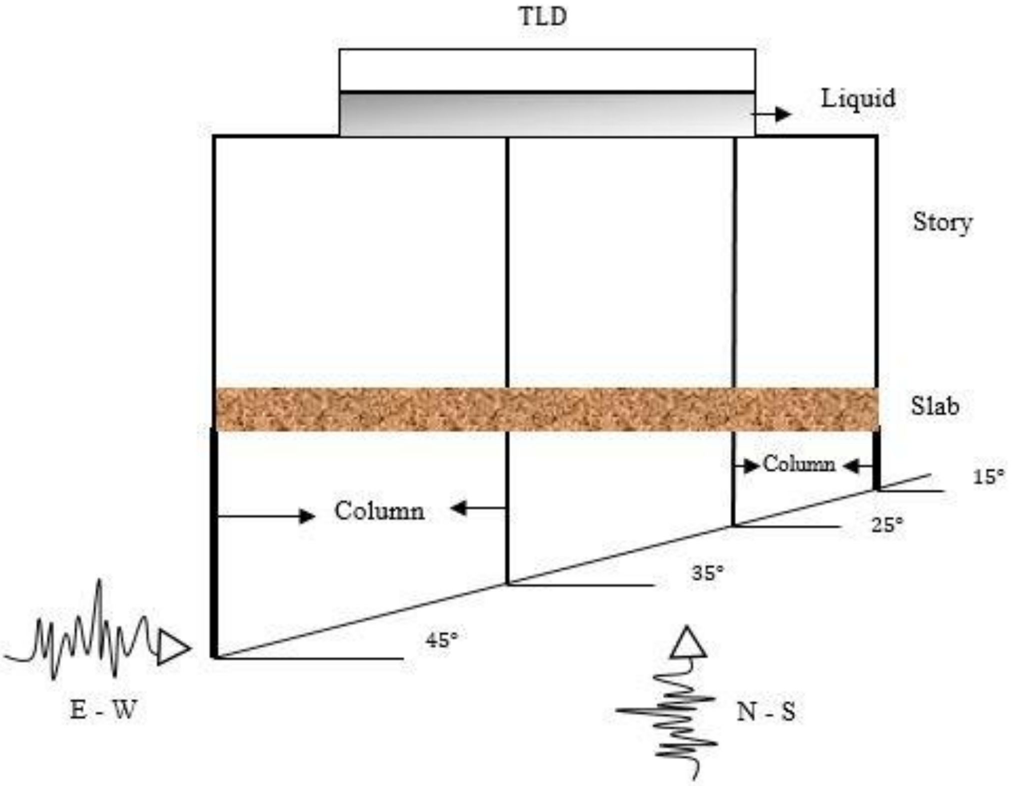
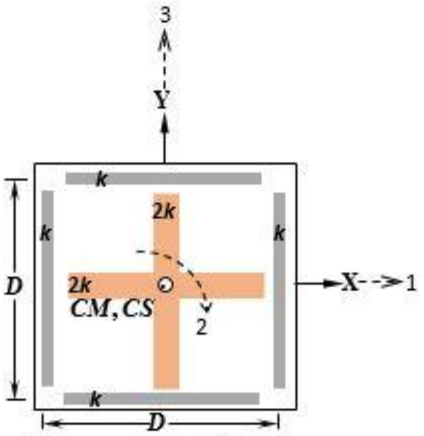
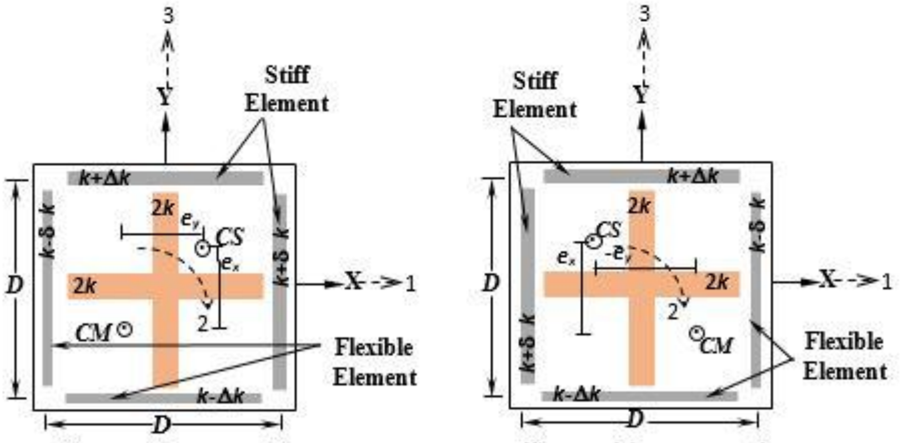


Fig. 5-(i). Idealized single-story model structure with a rectangular TLD.



a) Reference symmetric system



i) $e_x$positive, e_y positive

ii) $e_x$positive, e_y negative

b) Bi-directionally asymmetric system

Fig. 6. Plan elevation of idealized single-story structural 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 symmetric system as shown in Fig. 6 (a), by assigning stiffness is 2k to the middle element 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), Element 2 (Flexible, Stiff), Element 3 (Stiff, Stiff) and Element 4 (Stiff, Flexible). For the reference symmetric system, the location of the center of mass (CM) and the center of stiffness (CS) are initially the same. Contrastingly, for the reference asymmetric system as shown in Fig. 6 (b), the location of the center of mass (CM) and center of stiffness (CS) recline at the different eccentric location towards the principal axis of system. 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 asymmetric systems the stiffness eccentricities are symbolized by e_x and e_y that lies between the distance of center of mass (CM) and center of stiffness (CS) with respect to principal axis of system. Distribution of stiffness and mass eccentric condition is 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. 6 (b-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. 6 (b-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 [4]. 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.

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 $\beta = 0.25$ [4, 5, 6]. 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, we considered time step of $T_x/400$ for appropriate determination of values [4, 5, 6]. 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 by the by added the essential parameters that is moment magnitude, closest site-to-fault-rapture distance, shear wave velocity, mean time period [4]. Using this essential software investigating the ultimate characteristic of ground acceleration motion capacity that has been acted on the structural members. Where, r is the radius of gyration of mass of rigid deck; c is the damping matrix; u_x, u_y, θ are the translations of CM along the x and y axis and rotation of CM is horizontal plane respectively and $\ddot{u}_{gx}$ and $\ddot{u}_{gy}$ are ground accelerations along two perpendicular principal axes respectively. For symmetric system the uncoupled torsional effect is negligible.

$$\begin{bmatrix} m & 0 & 0 \\ 0 & mr^2 & 0 \\ 0 & 0 & m \end{bmatrix} \begin{Bmatrix} \ddot{u}_x \\ \ddot{\theta} \\ \ddot{u}_y \end{Bmatrix} + [C] \begin{Bmatrix} \dot{u}_x \\ \dot{\theta} \\ \dot{u}_y \end{Bmatrix} + \{ f_s \} = - \begin{bmatrix} m & 0 & 0 \\ 0 & mr^2 & 0 \\ 0 & 0 & m \end{bmatrix} \begin{Bmatrix} \ddot{u}_{gx}(t) \\ 0 \\ \ddot{u}_{gy}(t) \end{Bmatrix} \quad ....[1]$$

4. GROUND MOTION

For the single-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 near-fault (NF) 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 SDOF system is estimated subjected to bi-directional NF 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 [4, 6, 8]. 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) [4-6]. 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) considered for symmetric

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

Sl. No.	Event (Year)	Station	Record ID	M_w	r(km)	Vs30(m/s)	PGA (m/s^2)		T_m (s)	
							X - Component	Y - Component	X - Direction	Y- Direction
1.	Corinth_ Greece,1981	Corinth	RSN313	6.6	10.27	361.4	2.32	2.90	0.17	0.14
2.	Landers,1992	Joshua Tree	RSN864	7.3	11.03	379.32	2.68	2.78	0.73	0.78
3.	Landers,1992	Morongo Valley Fire Station	RSN881	7.3	17.36	396.41	2.19	1.61	0.69	0.88
4.	Manjil_Iran,1990	Abbar	RSN1633	7.4	12.55	723.95	5.04	4.87	0.32	0.33
5.	Tottori_Japan,2000	OKY004	RSN3907	6.7	19.72	475.8	8.08	5.28	0.20	0.18
6.	Chuetsu-oki_ Japan,2007	Yoshikawaku Joetsu City	RSN4850	6.8	16.86	561.59	4.44	3.08	0.79	0.83
7.	Iwate_Japan, 2008	MYG005	RSN5664	6.9	13.47	361.24	5.25	4.37	0.78	1.76
8.	Iwate_Japan, 2008	Kurihara City	RSN5818	6.9	12.85	512.26	6.89	4.14	0.39	0.42
9.	Chi-chi_Taiwan03_1999	TCU 129	RSN1023	6.2	10.9	511	9.85	6.12	0.35	0.34
10.	Imperialvalley_1979	El centro Array#4	RSN179	6.5	7.1	209	4.75	3.63	0.68	1.29
11.	Imperialvalley_1979	El centro Array#6	RSN181	6.5	1.4	203	5.19	3.76	0.66	1.22
12.	Imperialvalley_1979	El centro Array#10	RSN173	6.5	8.6	203	5.19	3.76	0.66	1.22
13.	Kocaeli,Turkey_1999	Duzce	RSN1158	7.5	13.5	282	3.06	3.57	0.87	0.50
14.	LomaPrieta_ 1989	Los Gatos - Lexingtond	RSN3548	6.9	5.5	1070	4.34	4.04	0.89	0.98
15.	Denali,Alaska_2002	TAPS Pump Station#10	RSN2114	7.9	2.7	329	3.26	2.92	1.52	1.19

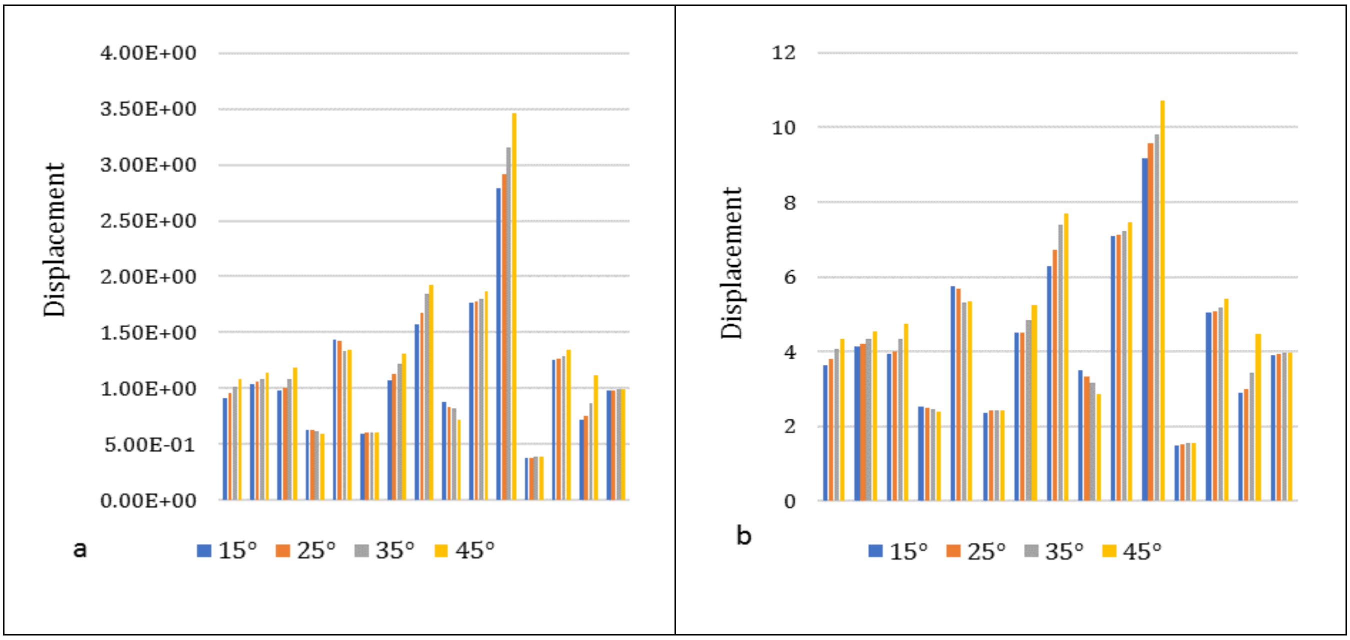
system is 0.25 sec, 0.5 sec, 1.0sec and 2.0sec in short, medium and long period ranges and for asymmetry 0.25 sec and 0.5 sec are considered in short to long period ranges respectively. On the other hand, for most real buildings, the values of uncoupled torsional-to-lateral period ratio (τ) are varied within the range of 0.25-2.0 with an interval of 0.05 with 5% damping also used in previous research [4, 6, 8]. Influence the torsional effect for asymmetric system eccentricity is important criteria to observe the critical response of structural elements with respect on τ. Further, the present study attempts to incorporate the analysis of the bi-directional asymmetric system into a feasible range of eccentric variation. 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 [4-7]. Hence, six combinations of eccentricity are considered along two principal directions in this paper, as listed in Table 2. Asymmetric systems with stiffness and mass eccentricities are considered in this present study. All parameters related to TLD are considered from previous literature [12] and others in practical observation.

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	0.1
5.	0.1	0.2
6.	0.2	0.2

6. RESULTS AND DISCUSSION

The nonlinear dynamic analysis of single-story structural system through mean element displacement under critical inelastic sense for various angle of slopes (15°, 25°, 35° and 45°) are presented with plotting as representative of the trend with the time variation lies between small to large lateral periods (T) that is 0.25sec to 2.0sec for symmetric system. Fig. 7 shows the mean displacement response for symmetric system by nonlinear dynamic analysis. Fig. 7(a) indicates the amplification in mean response for symmetric configuration may be 1.13, 1.16, 1.20 and 1.27 times for sloppy ground terrain 15°, 25°, 35° and 45° at lateral time 0.25sec. Fig. 7(b) indicates the amplification in mean response for symmetric system may be 4.4, 4.5, 4.6 and 4.9 times for sloppy ground terrain 15°, 25°, 35° and 45° at lateral period 0.5sec. Fig. 7(c) indicates the amplification in mean response for symmetric system may be 17.7, 18, 19 and 19.4 times for sloppy ground terrain 15°, 25°, 35° and 45° at lateral period 1.0sec. Finally, Fig. 7(d) indicates the amplification in mean response for symmetric system may be 69, 70, 73 and 76 times for sloppy ground terrain 15°, 25°, 35° and 45° at lateral period 2.0sec. Fig. 7(a-d) clearly shows that as the inclination angle of the sloppy ground increases, the elemental deformation of the symmetric system with respect to lateral periods increases due to 15 NF ground excitation, considering 5% damping and ductility reduction factor (Rμ) = 1.



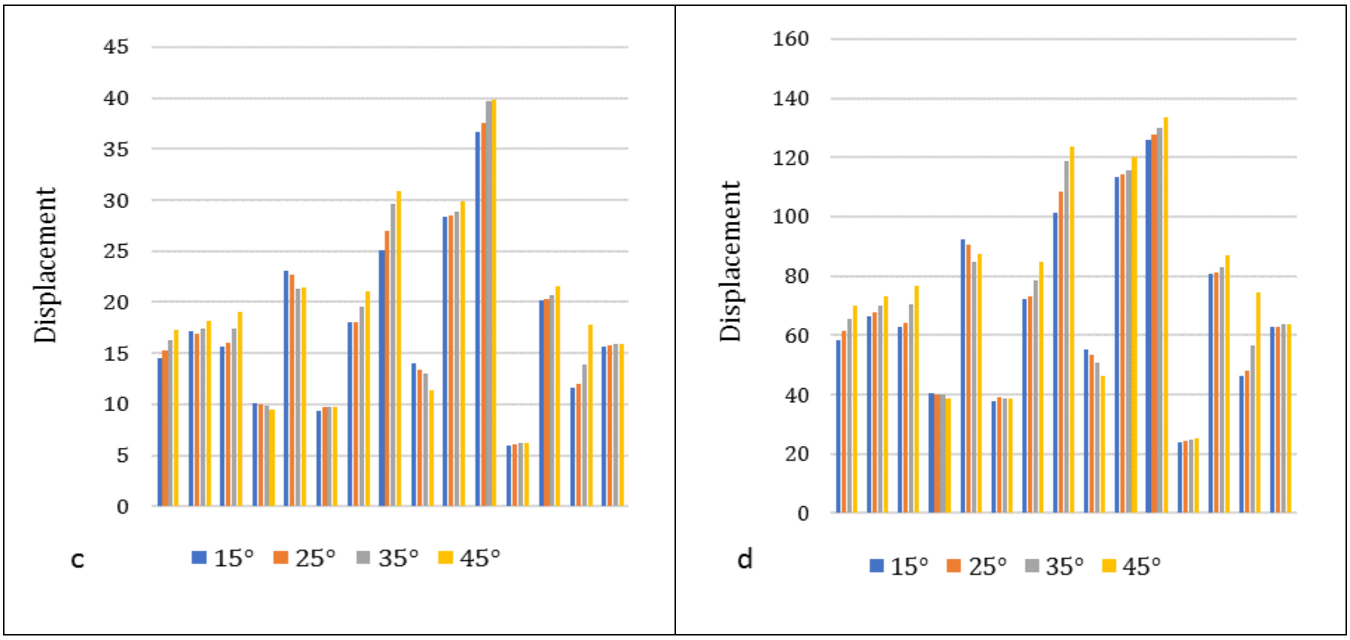
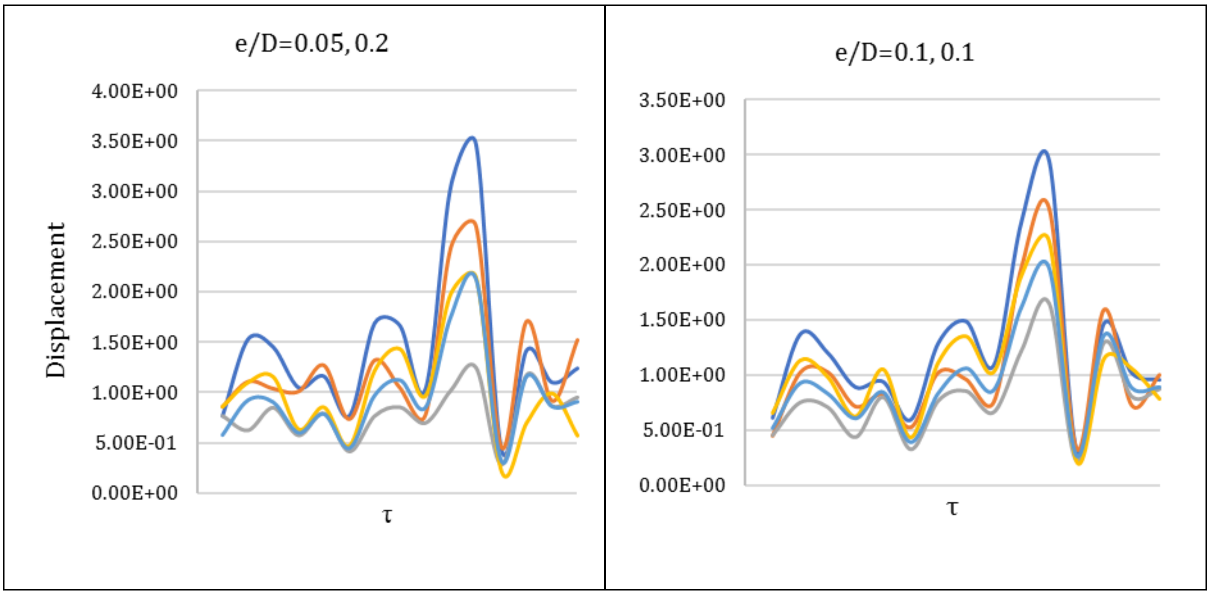


Fig. 7. Mean displacement response of symmetric system for (a) T=0.25sec, (b) T=0.5sec, (c) T=1.0sec, (d) T=2.0sec.



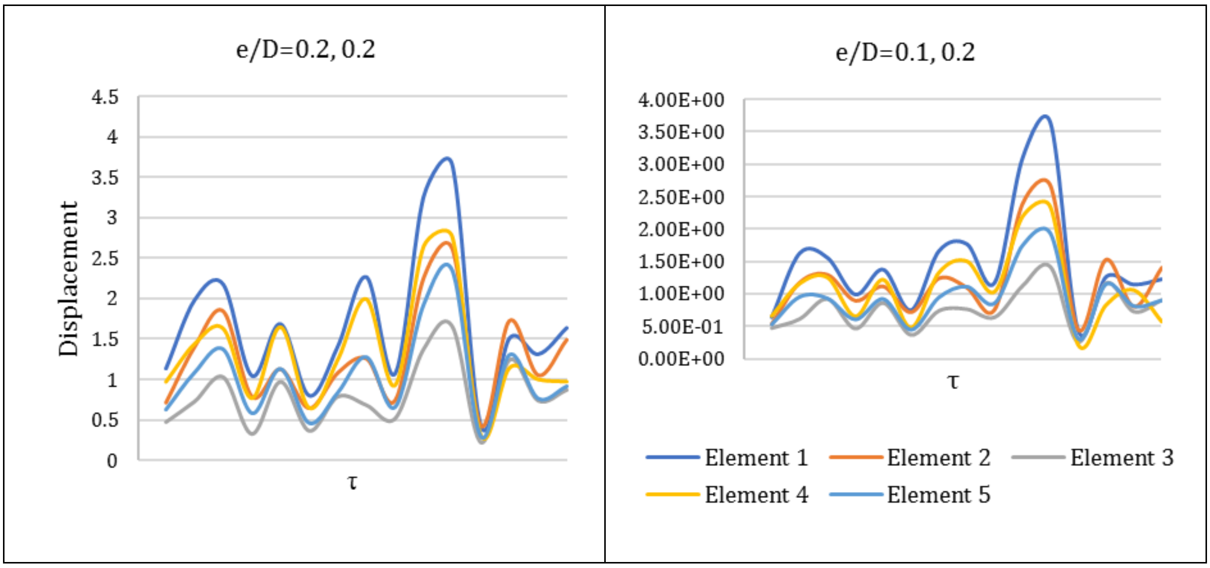
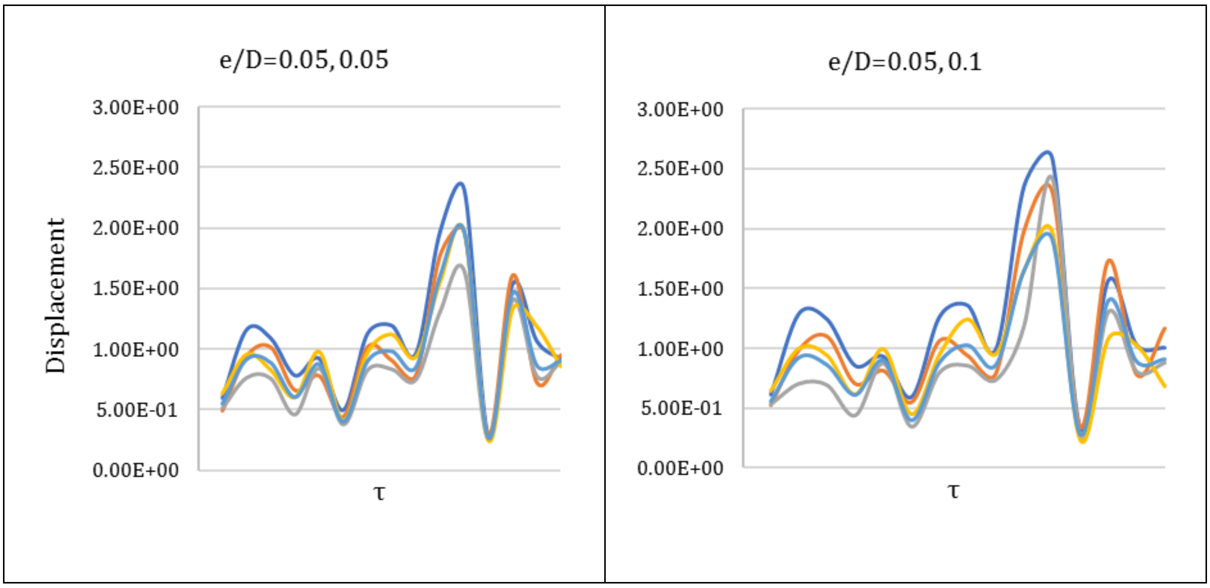


Fig. 8. Mean displacement response of asymmetric system for T=0.25sec at 15°.

Influence of ground motion characteristics on the nonlinear dynamic analysis, the response of symmetric structural system is systematically examined to achieve a fair insight into the behavior of such systems. On the other scenario, asymmetric structure is also a serious issue for nonlinear dynamic behaviour owing to ground motion. In this case, Fig. 8-15 indicates the overall seismic response with small, intermediate and large eccentric condition for different angle of slopes like 15°, 25°, 35° and 45°due to lateral to torsional time ratio (τ) and also consider the lateral periods 0.25sec and 0.5sec. In this case, mid two elements of structure are considered as one (Element 5) and 5% damping is chosen with Rμ=1. The mean of normalized response are computed and presented for corner elements are more vulnerable due to lateral and torsional coupling effect in asymmetric structure. These corner four elements Element 1 is flexible along both principal directions and designated as "flexible, flexible". Element 2 and Element 4 are combined as flexible and stiff for different principal axis, designated as "flexible, stiff" and "stiff, flexible" respectively. Element 3 is stiff along both principal direction and finally designated as "stiff, stiff". The response of all corner elements are developed for physical understanding due to bi-directional system of asymmetry. Fig. 8-15 has six sets of graphs shows the mean of response for a different combination of bi-directional eccentric system. The amplification in response for asymmetric configaration considering lateral period 0.25sec at 15° sloppy ground show in Fig. 8, the 1st Element mean maximum deformation lies 1.7 times and minimum 0.8 times for 3rd Element. In that case, Element 2 and Element 4 carries the almost same response that lies between 1.27 to 1.34 times due to torsional effect.



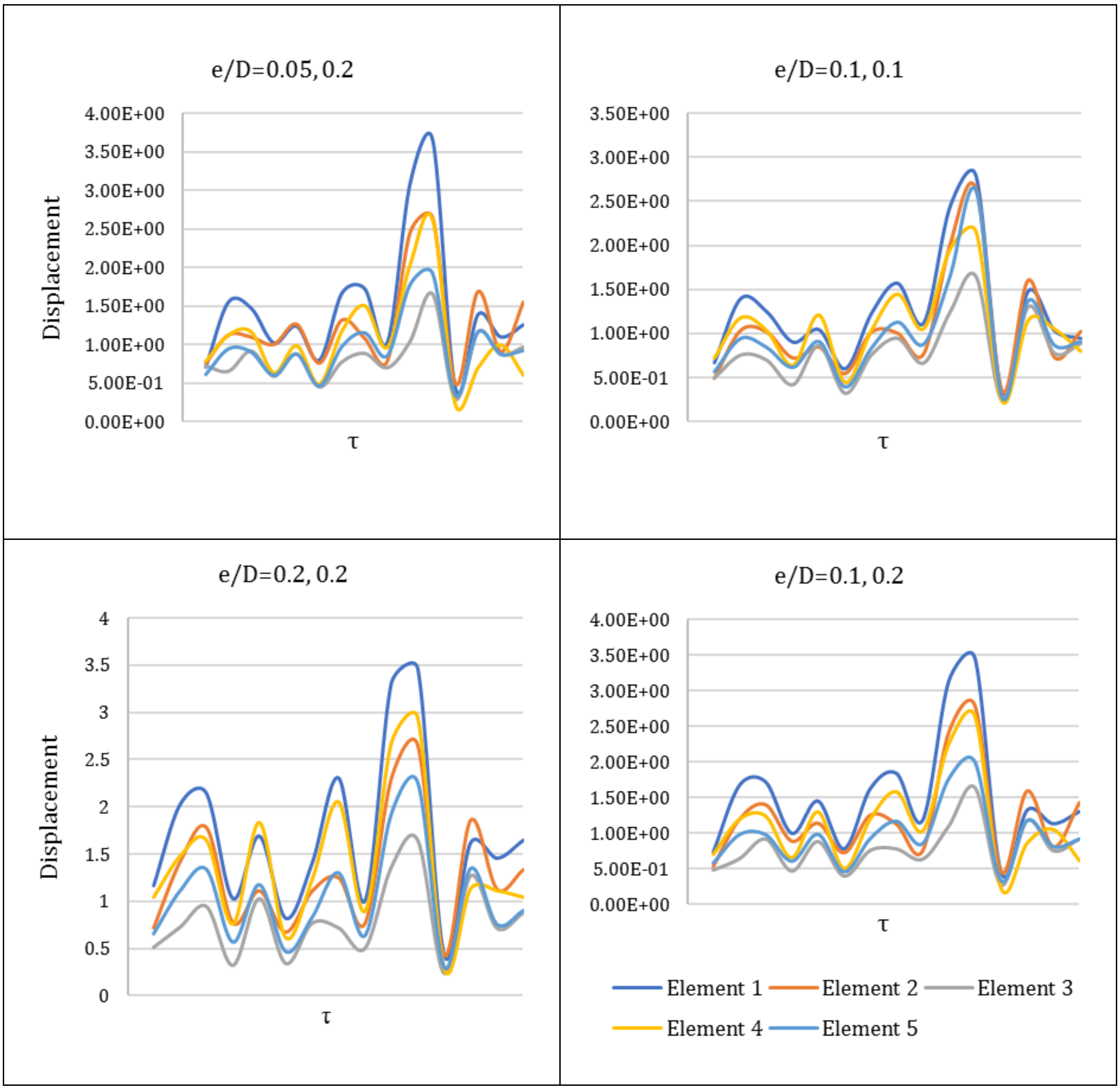


Fig. 9. Mean displacement response of asymmetric system for T=0.25sec at 25°.

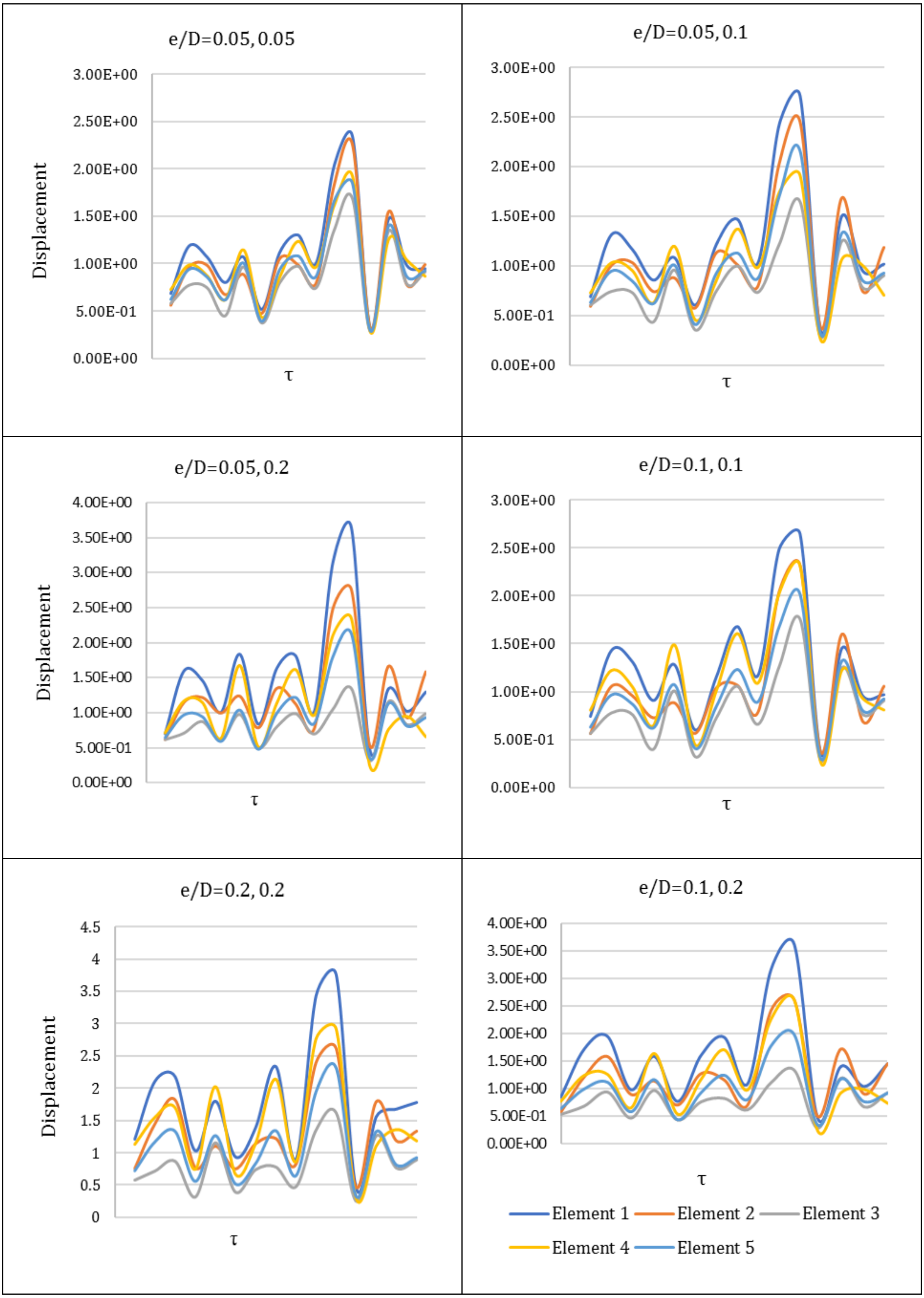


Fig. 10. Mean displacement response of asymmetric system for T=0.25sec at 35°.

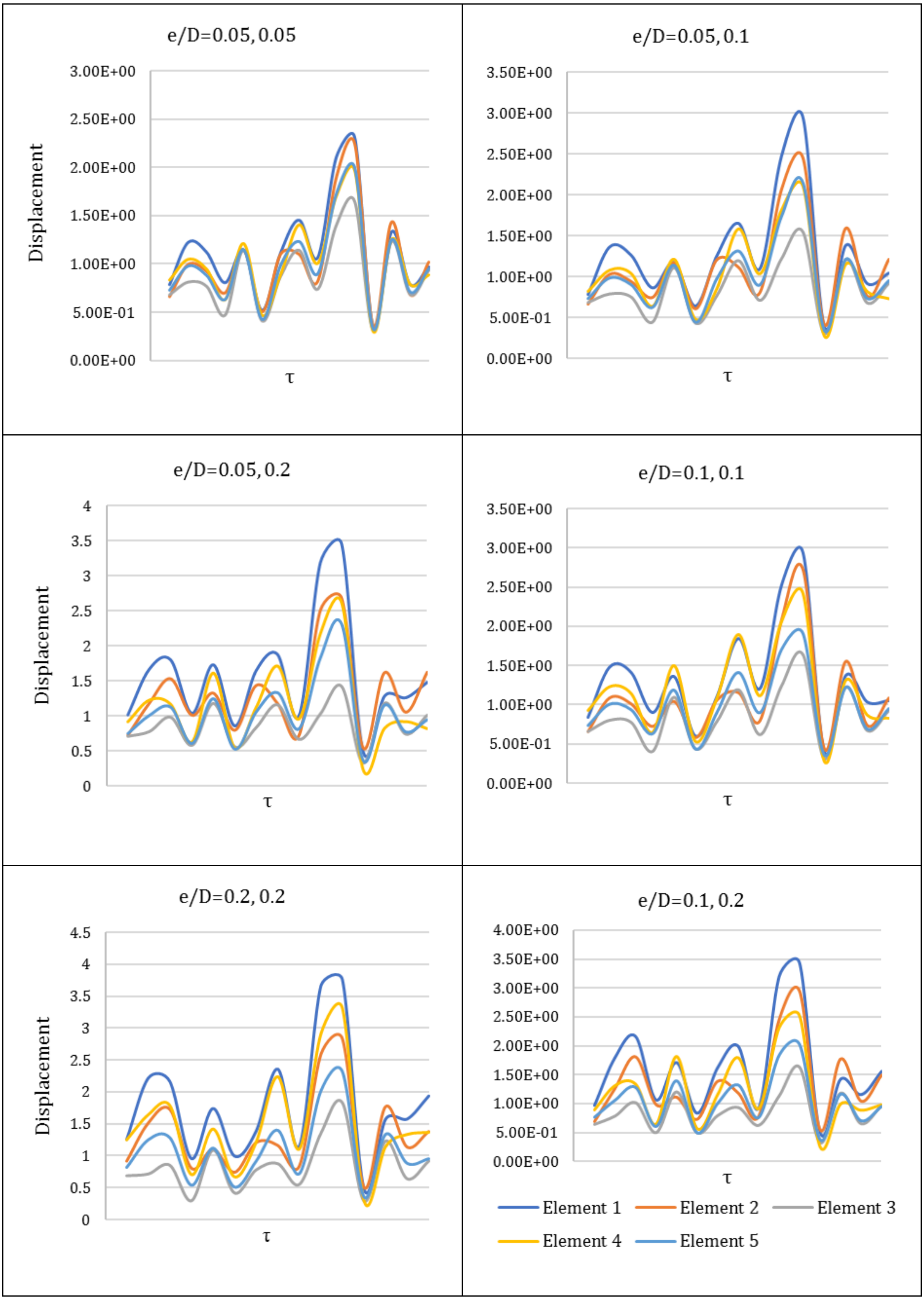


Fig. 11. Mean displacement response of asymmetric system for T=0.25sec at 45°.

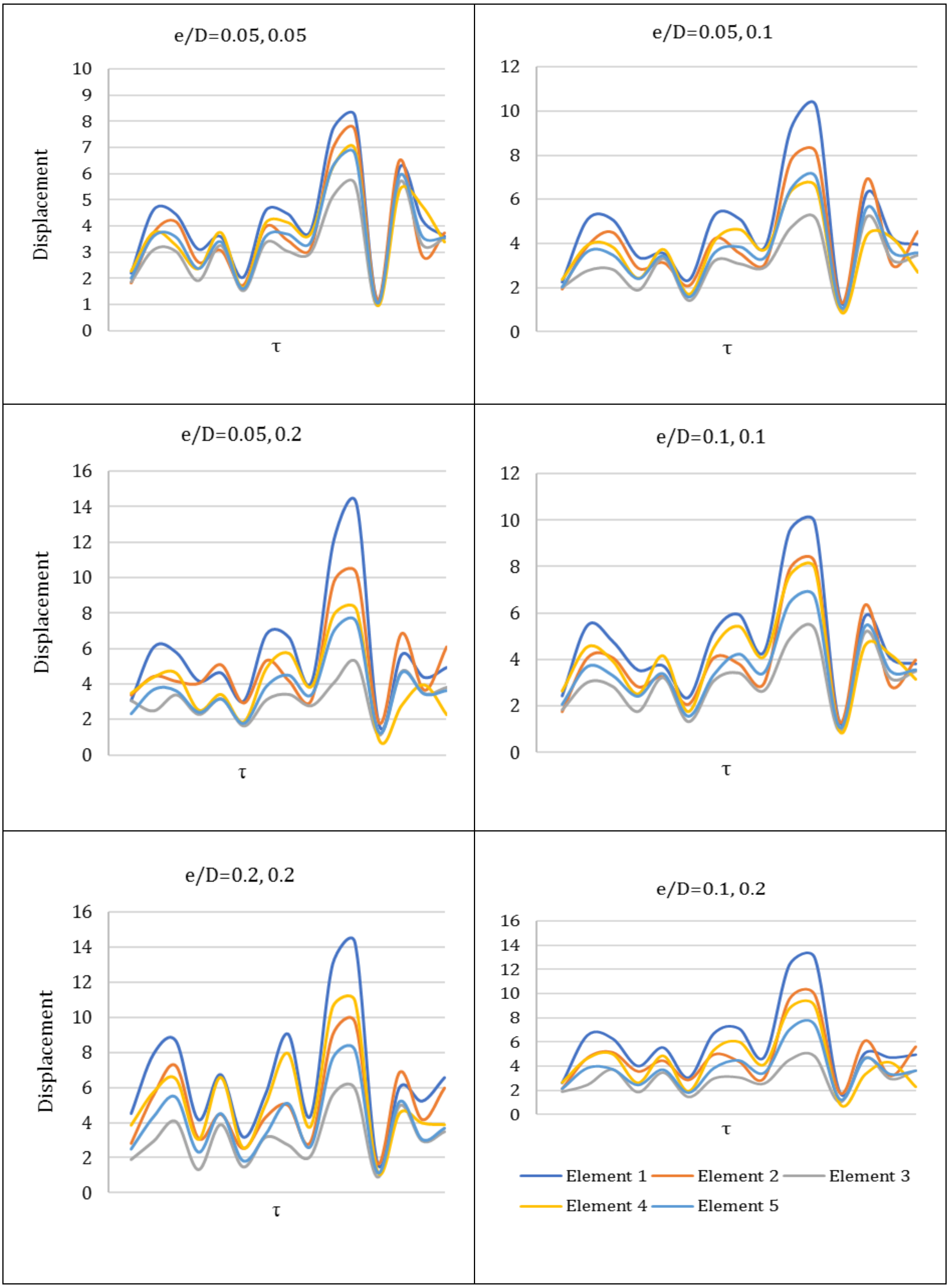


Fig. 12. Mean displacement response of asymmetric system for T=0.5sec at 15°.

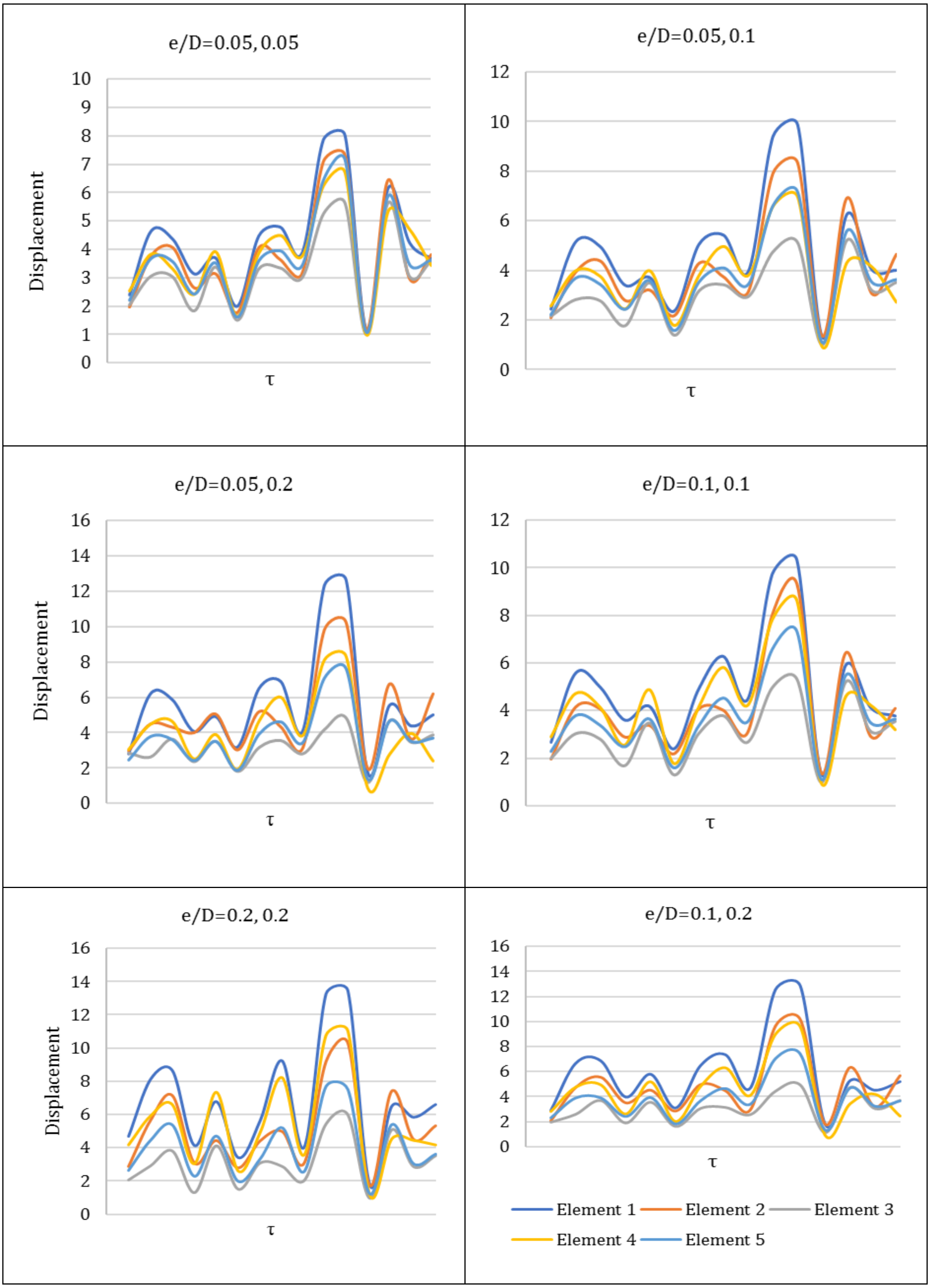


Fig. 13. Mean displacement response of asymmetric system for T=0.5sec at 25°.

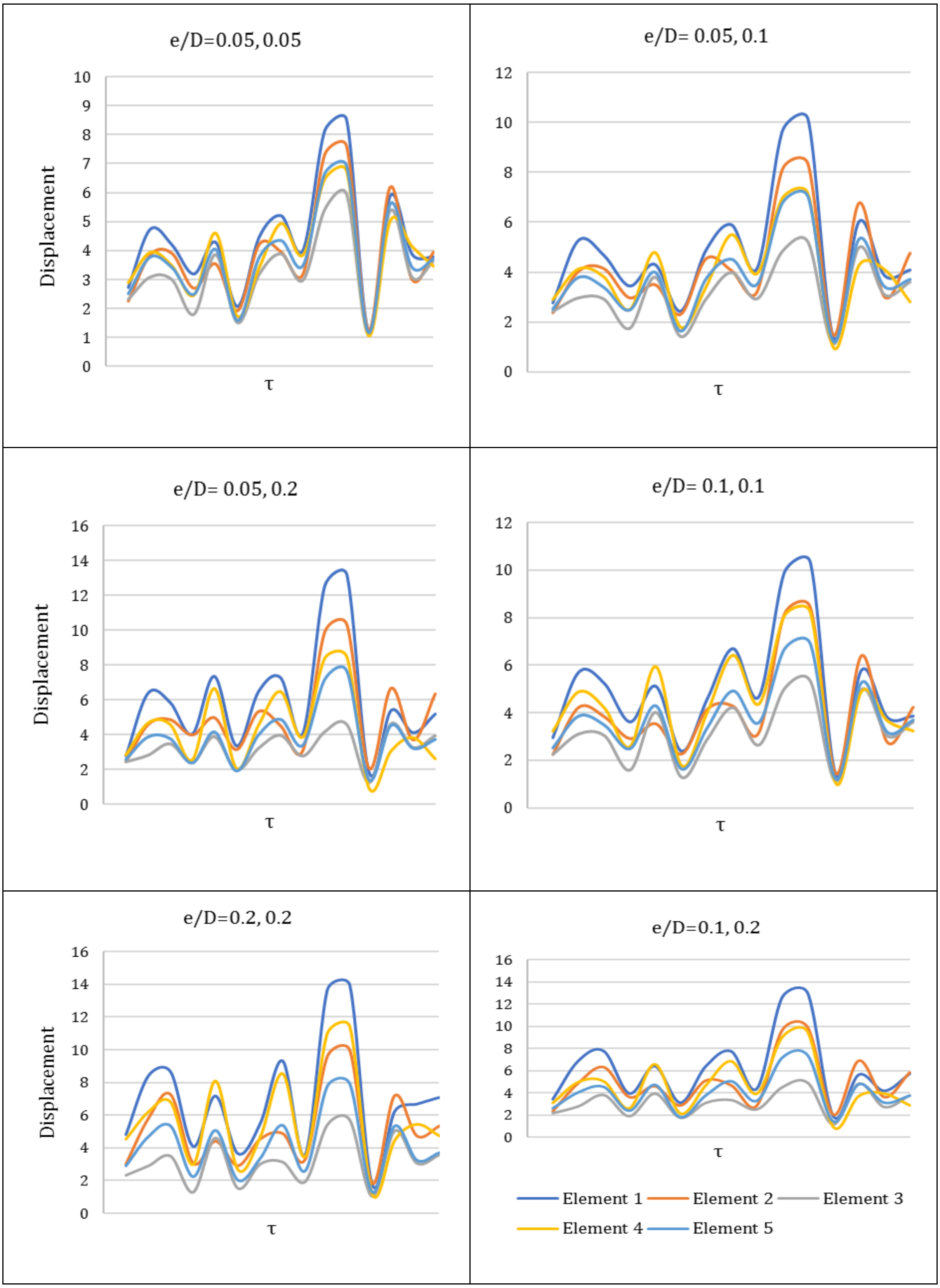


Fig. 14. Mean displacement response of asymmetric system for T=0.5sec at 35°.

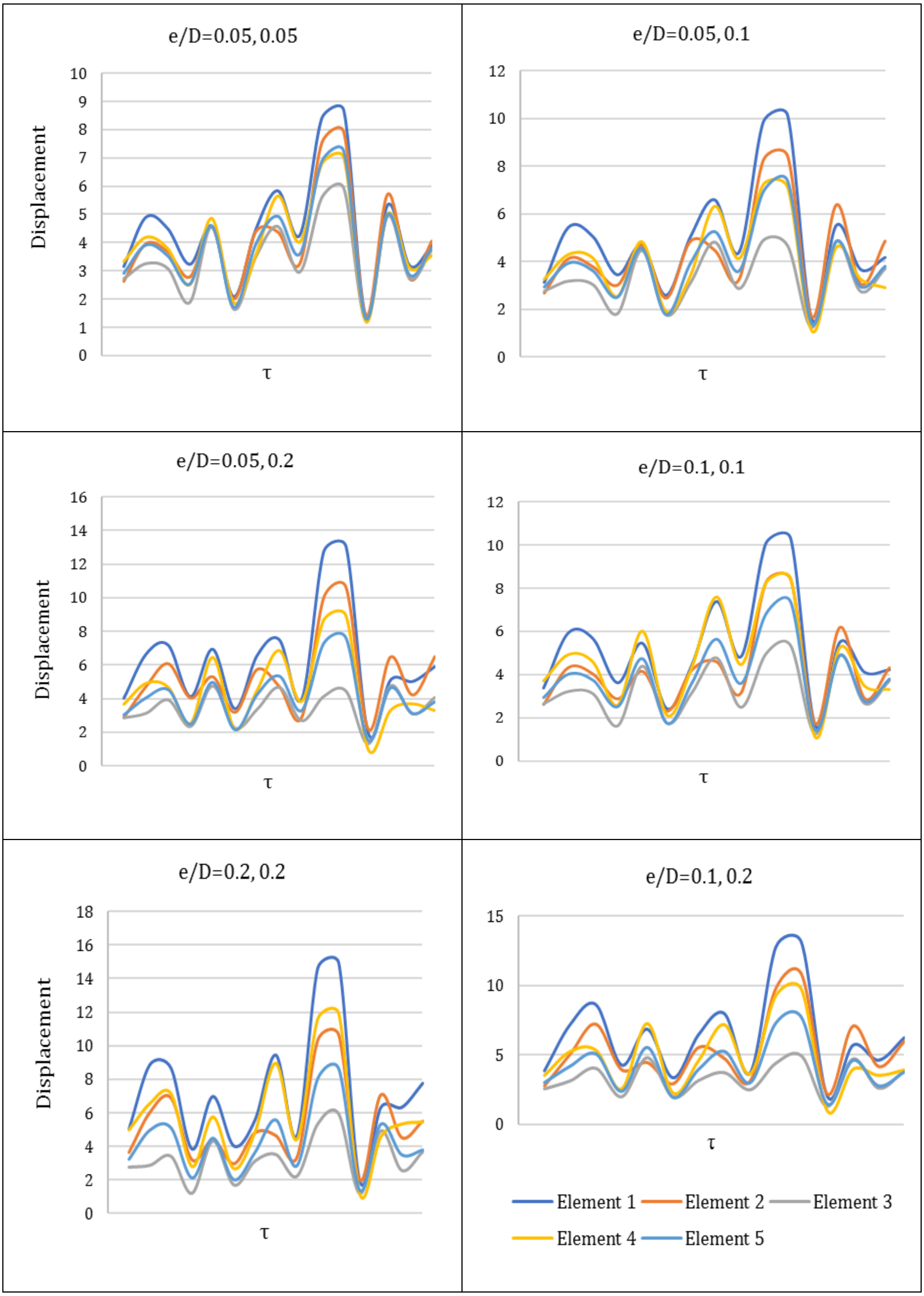


Fig. 15. Mean displacement response of asymmetric system for T=0.5sec at 45°.

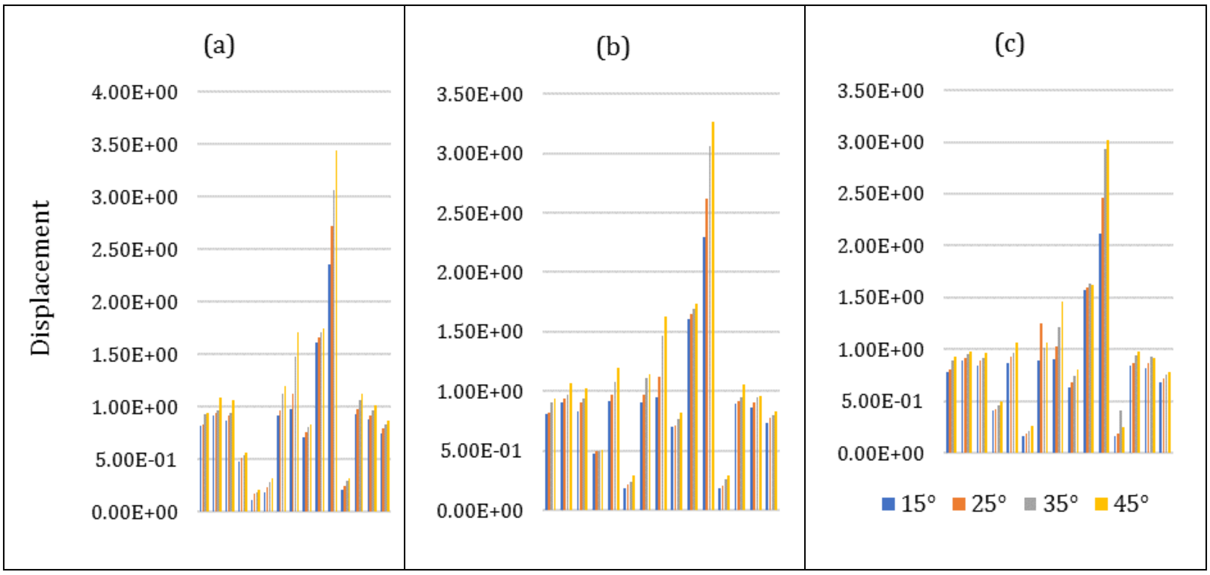


Fig. 16. Mean displacement response of symmetric system for different column layout. (a) Rectangular column to rectangular column joint, (b) Square column to square column joint, (c) Circular column to circular column joint (T=0.25sec).

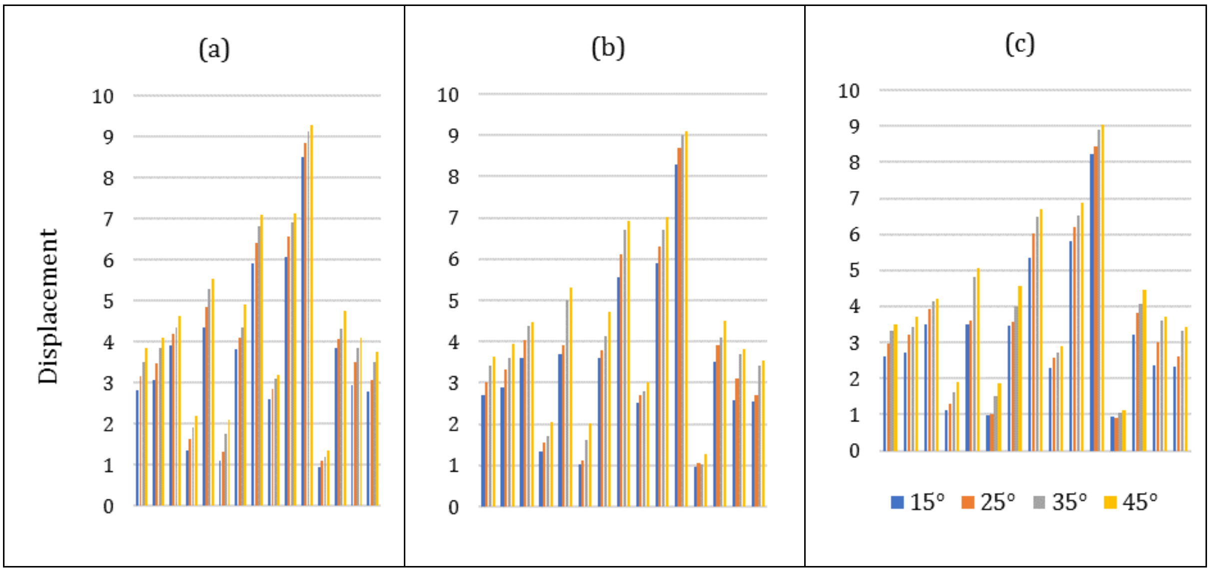


Fig. 17. Mean displacement response of symmetric system for different column layout. (a) Rectangular column to rectangular column joint, (b) Square column to square column joint, (c) Circular column to circular column joint (T=0.5sec).

Considering lateral period 0.25sec at 25° sloppy ground show in Fig. 9, the 1st Element mean maximum deformation lies 1.72 times and minimum 0.86 times for 3rd Element. In that case, Element 2 and Element 4 carries the almost same response that lies between 1.29 to 1.38 times due to torsional effect. Also, for lateral period 0.25sec at 35° sloppy ground show in Fig. 10, the 1st Element mean maximum deformation lies 1.8 times and minimum 0.85 times for 3rd Element. In that case, Element 2 and Element 4 carries near about same inelastic response that lies between 1.31 to 1.43 times due to bi-directional asymmetry. Considering lateral period 0.25sec at 45° sloppy ground show in Fig. 11, the 1st Element mean maximum deformation lies 1.82 times and minimum 0.9 times for 3rd Element. In that case, Element 2 and Element 4 carries the same average inelastic demand that lies between 1.35 to 1.5 times due to torsional effect. Furthermore, the amplification in response for asymmetric configaration considering lateral period 0.5sec at 15° sloppy ground clearly show in Fig. 12, the 1st Element mean maximum deformation lies 6.7 times and minimum 3.0 times for 3rd Element. In that case, Element 2 and Element 4 carries the almost same response that lies between 5.0 to 5.3 times due to torsional effect. Considering lateral period 0.5sec at 25° sloppy ground show in Fig. 13, the 1st Element mean maximum deformation lies 6.81 times and minimum 3.0 times for 3rd Element.

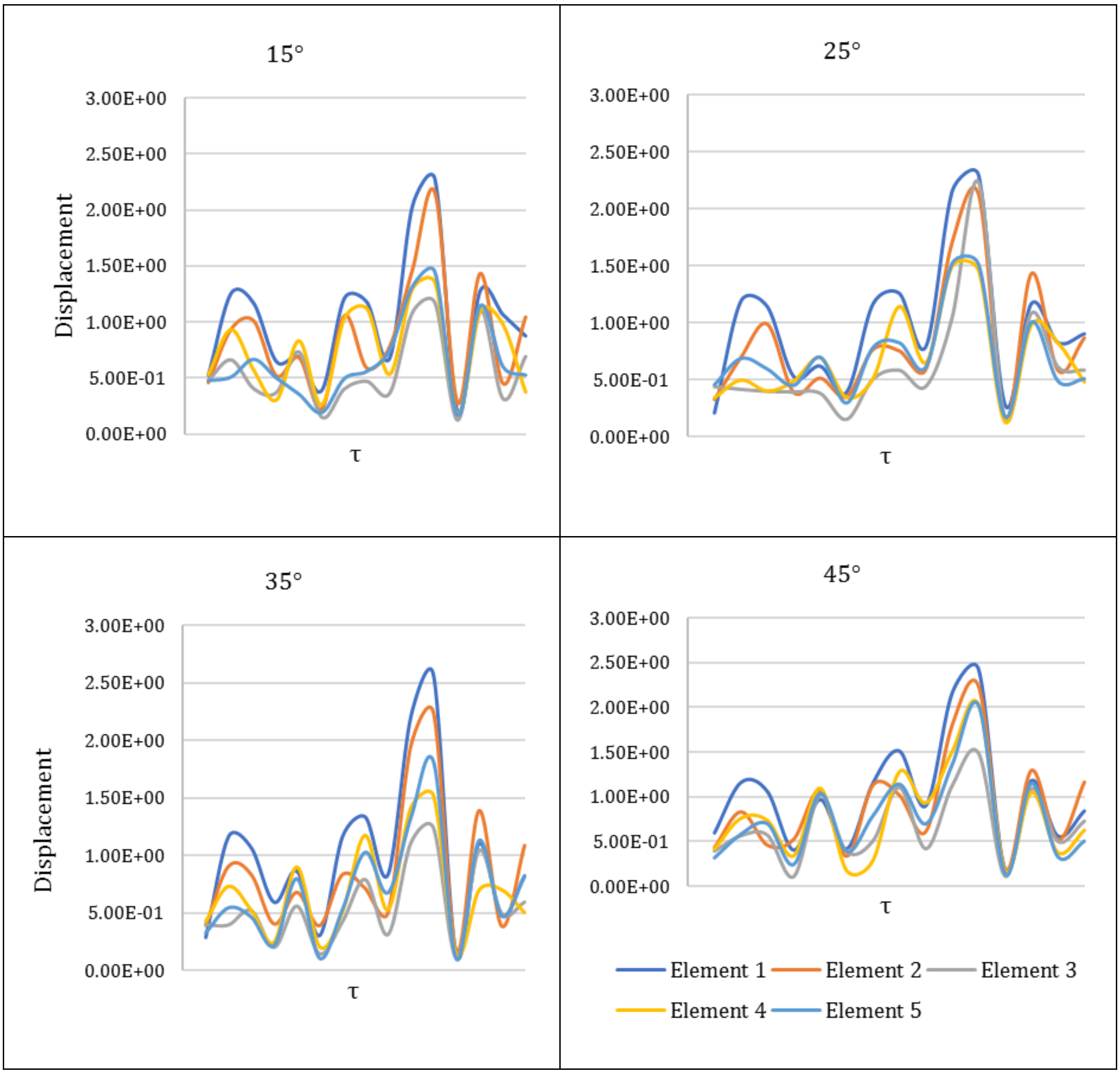


Fig. 18. Mean displacement response of asymmetric system for T=0.25sec at e/D=0.05, 0.1 (circular column to circular column joint).

In that case, Element 2 and Element 4 carries the almost same inelastic response that lies between 5.14 to 5.5 times due to torsional effect. Taking into consideration, lateral period 0.5sec at 35° sloppy ground show in Fig. 14, the 1st Element mean maximum deformation lies 7.0 times and minimum 3.14 times for 3rd Element. In that case, Element 2 and Element 4 carries the average inelastic demand that lies between 5.2 to 5.7 times. Considering lateral period 0.5sec at 45° sloppy ground show in Fig. 15, the 1st Element mean maximum deformation lies 7.2 times and minimum 3.5 times for 3rd Element. In that case, Element 2 and Element 4 carries the near about same inelastic demand that lies between 5.3 to 5.9 times. In this case, with increasing the angle of slopes, the response of Element 2 and Element 4 are quickly deferred. In this context, it is needed to observe from 15 earthquake data that is plotted for two different extreme combinations of eccentricities along X and Y directions. However, in this point, the observation for inelastic seismic demand of RC asymmetric system in small to large combination of different eccentric conditions that assemble an effective scenario in hilly areas for suitability. Furthermore, it is also important criteria that to observe the serviceability of such systems due to critical orientation of earth surface besides of seismic response. In this content, the column section of structures for both cases are joined using simple beam concept to reduce the elemental deformation with standard depth. Fig. 16 represent the mean displacement demand of symmetric system for different column layout within beam-column joint. In this case, it is clearly showing that the mean displacement response for rectangular column-beam joint lies 0.85 times for 15°, 0.92 times for 25°, 1.1 times for 35° and 1.24 times for 45° at T=0.25sec Fig. 16(a). Also, for square column-beam joint lies 0.81 times for 15°, 0.9 times for 25°, 1.0 times for 35° and 1.1 times for 45° at T=0.25sec Fig. 16(b). Finally, for circular column-beam joint lies 0.8 times for 15°, 0.89 times for 25°, 0.9 times for 35° and 1.0 times for 45° at T=0.25sec Fig. 16(c). On the other hand, Fig. 20 (b) represent the different shape of columns with standard dimensions that might be used in hilly areas for SDOF system. Considering T=0.5sec, mean displacement response for rectangular column-beam joint lies 3.6 times for 15°, 3.9 times for 25°, 4.2 times for 35° and 4.5 times for 45° show in Fig. 17(a). Also, for square column-beam joint lies 3.4 times for 15°, 3.7 times for 25°, 4.1 times for 35° and 4.4 times for 45° at T=0.5sec Fig. 17(b). Finally, for circular column-beam joint lies 3.2 times for 15°, 3.5 times for 25°, 3.9 times for 35° and 4.2 times for 45° show in Fig. 17(c) rival to Fig. 16. Considering circular column to circular column joint in lateral period 0.25sec for asymmetric system where, e/D = 0.05, 0.1, the mean displacement response of such system clearly shows in Fig. 18. In Fig. 18 at angle of slope 15°, the 1st Element mean maximum deformation lies 1.0 times and minimum 0.57 times for 3rd Element. In that case, Element 2 and Element 4 carries the same average inelastic demand that lies between 0.88 to 0.8 times due to torsional effect. In Fig. 18 at angle of slope 25°, the 1st Element mean maximum deformation lies 1.0 times and minimum 0.63 times for 3rd Element.

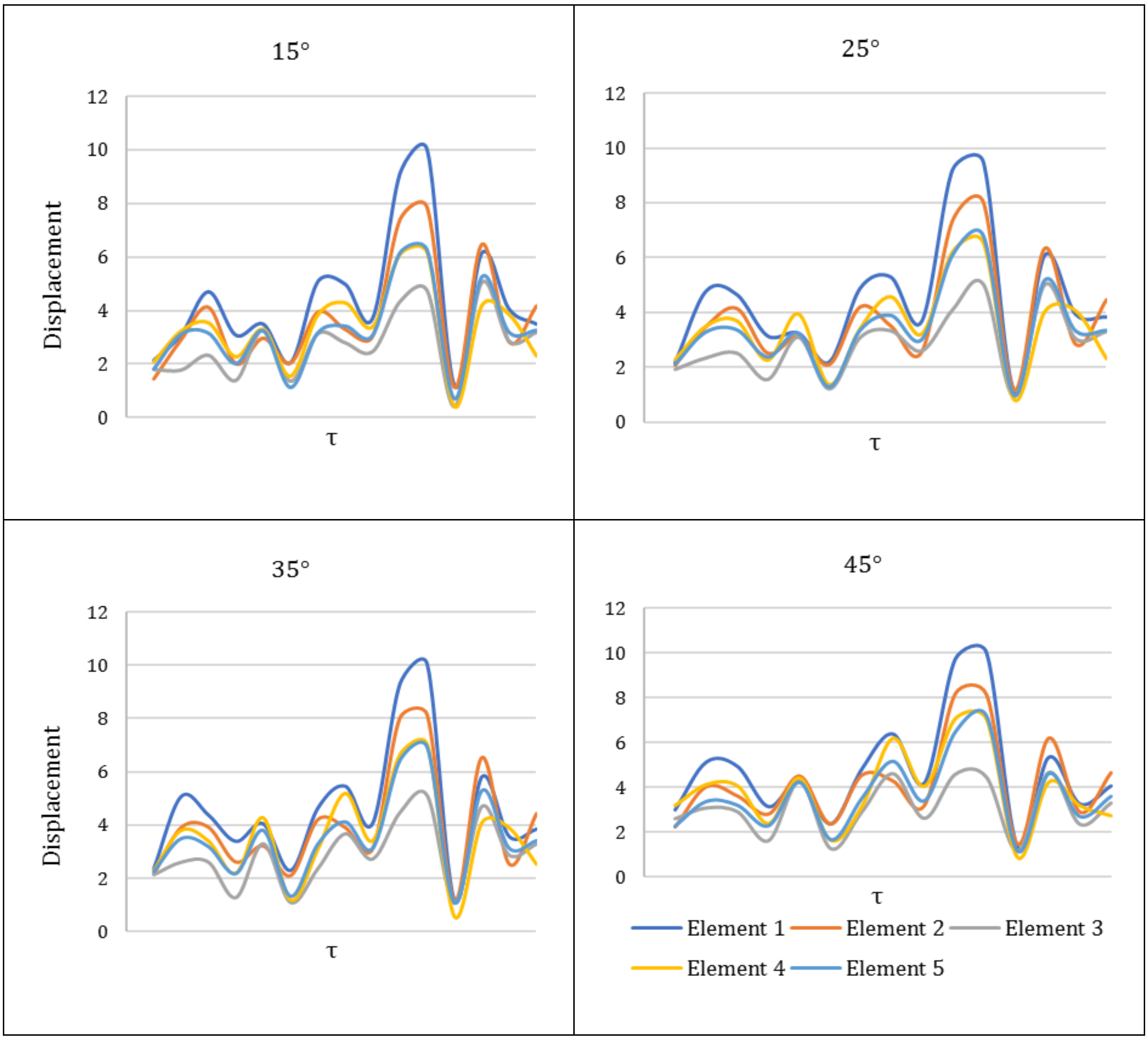


Fig. 19. Mean displacement response of asymmetric system for T=0.5sec at e/D=0.05, 0.1 (circular column to circular column joint).

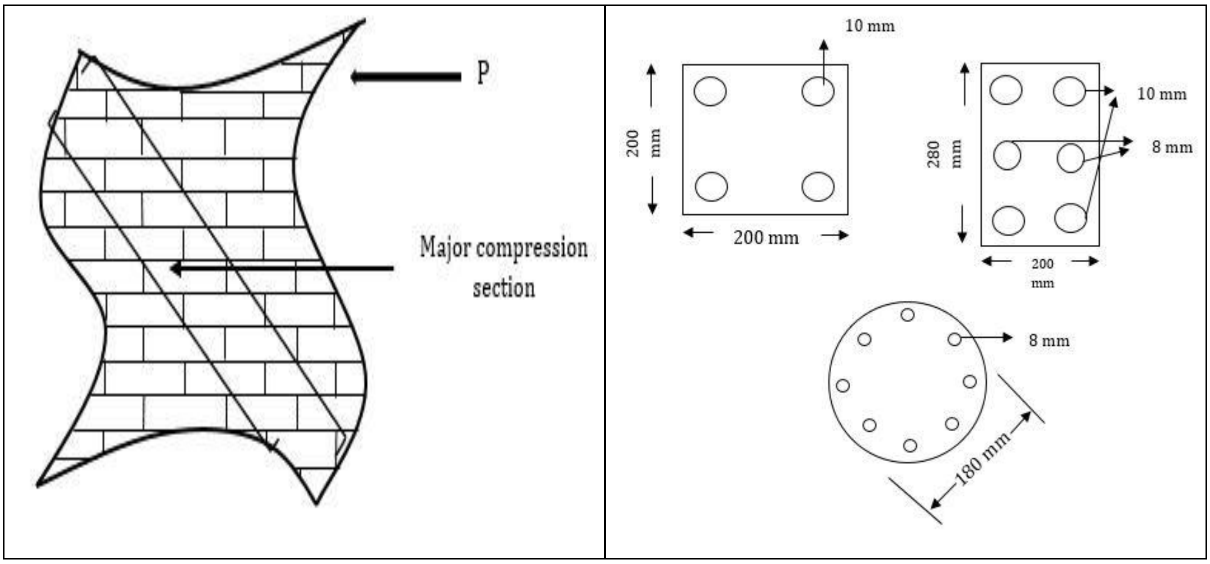


Fig. 20. (a) Deformed shape of brick infill under compression in both directions and (b) cross sectional area of square, rectangular and circular column.

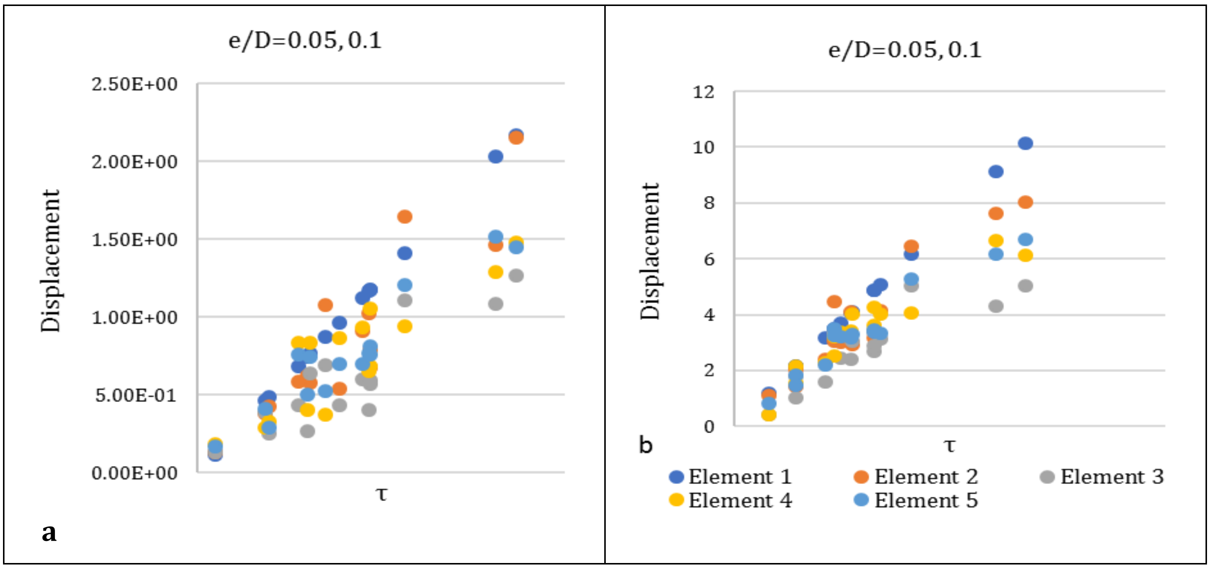


Fig. 21. Mean displacement response of asymmetric system for double layer brick infill at 15° sloppy ground. (a) T=0.25sec, (b) T=0.5sec.

In that case, Element 2 and Element 4 carries near about the same average inelastic demand that lies between 0.8 to 0.7 times due to torsional effect. In Fig. 18 at angle of slope 35°, the 1st Element mean maximum deformation lies 1.0 times and minimum 0.6 times for 3rd Element. In that case, Element 2 and Element 4 carries the same average inelastic demand that lies between 0.9 to 0.7 times due to torsional effect. In Fig. 18 at angle of slope 45°, the 1st Element mean maximum deformation lies 1.1 times and minimum 0.7 times for 3rd Element. In that case, Element 2 and Element 4 carries almost the same average inelastic demand that lies between 0.9 to 0.8 times. In Fig. 19 at angle of slope 15° for lateral time 0.5sec, the 1st Element mean maximum deformation lies 4.4 times and minimum 2.7 times for 3rd Element. In that case, Element 2 and Element 4 carries the same average inelastic demand that lies between 3.7 to 3.4 times due to torsional effect for e/D = 0.05, 0.1. In Fig. 19 at angle of slope 25°, the 1st Element mean maximum deformation lies 4.5 times and minimum 2.9 times for 3rd Element. In that case, Element 2 and Element 4 carries near about the same average inelastic demand that lies between 3.9 to 3.5 times due to torsional effect. In Fig. 19 at angle of slope 35°, the 1st Element mean maximum deformation lies 4.6 times and minimum 2.9 times for 3rd Element. Element 2 and Element 4 carries the same average inelastic demand that lies between 4.0 to 3.6 times. Finally, in Fig.

19 at angle of slope 45°, the 1st Element mean maximum deformation lies 4.8 times and minimum 3.1 times for 3rd Element. In that case, Element 2 and Element 4 carries almost the same average inelastic demand that lies between 4.2 to 3.9 times due to torsional effect that rival to Fig. 18. Effect of masonry infill is another important issue throughout the globe. Reinforced concrete frames with masonry brick infill walls are one of the most common types of construction in recent past.

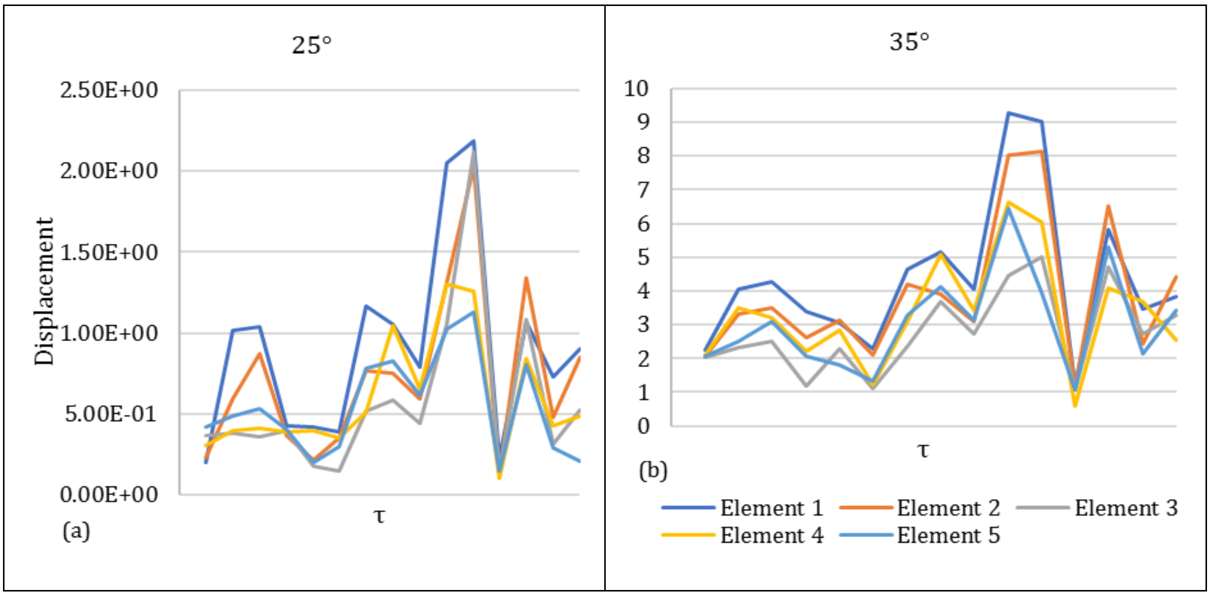


Fig. 22. Mean displacement response of SDOF system using TLD (a) T=0.25sec, (b) T=0.5sec (e/D=0.05, 0.1).

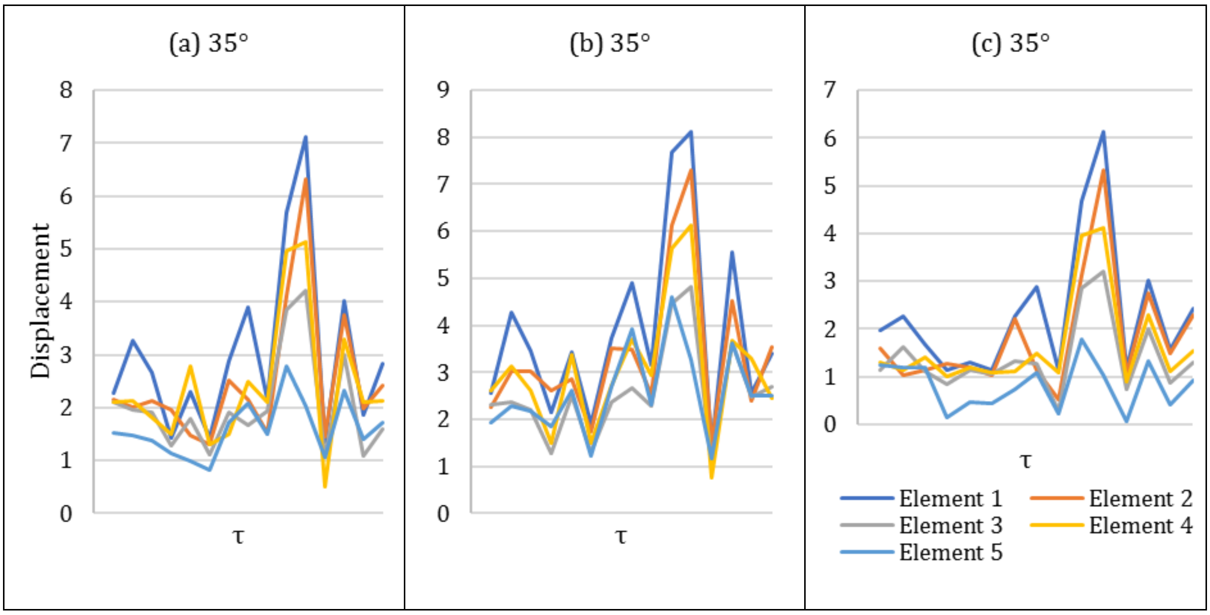


Fig. 23. Mean displacement response of SDOF system using both beam-column joint and TLD at T=0.5sec (a) Square column, (b) Rectangular column, (c) Circular column (e/D=0.05, 0.1).

A brick wall can counteract considerable compressive stress but very less amount of tensile stress. The wall provides additional stiffness rising from compressive strut effect show in Fig. 20(a) due to bi-directional excitation. Owing to the lateral deformation of a critical rectangular panel caused by seismic excitation, the panel tends to achieve the shape of a parallelogram causing elongation of one direction and shortening of other. The shortened diagonal will convey a compressive load and behave like a compressive strut in the identical perception. Several researchers have proposed different modelling techniques to estimate the response of the masonry brick infill panels of RC frames on their serious observation [9-11]. However, in the present research is adopted an equivalent compression diagonal strut model show in Fig. 20 for various angle of slope in hilly areas that incorporate the effect of masonry brick infill in their fundamental period due to ground motion. Fig. 8 represent the response of load resisting elements with single panel brick masonry wall. Keeping in mind the damage of the structure, the brick wall is adopted in double layer panel in 254mm for serviceability from ground motion. Fig. 21 represent the mean displacement response of asymmetric structural system for double layer brick infill wall panel at lateral period 0.25sec Fig. 21(a) and lateral period 0.5sec Fig. 21(b) for e/D = 0.05, 0.1 and initially 15° sloppy ground respectively. Fig. 21(a) shows the 1st Element mean maximum deformation lies 1.0 times and 0.6 times for 3rd Element. Element 2 and Element 4 carries almost same response that lies between 0.9 to 0.7 times that also a rival to Fig. 8. Also, Element 1 show the mean maximum deformation that lies 4.5 times and 2.8 times for 3rd Element. Element 2 and Element 4 carries nearabout the same response that lies between 3.8 to 3.4 times due to torsional effect show in Fig. 21(b), rival to Fig. 21(a) and Fig. 12 respectively. Fig. 22 represent the mean displacement response of SDOF system only using the vibration control tuned liquid damper (TLD) for T=0.25sec at 25° angle of slope and T=0.5sec at 35° where e/D=0.05, 0.1 for both cases.

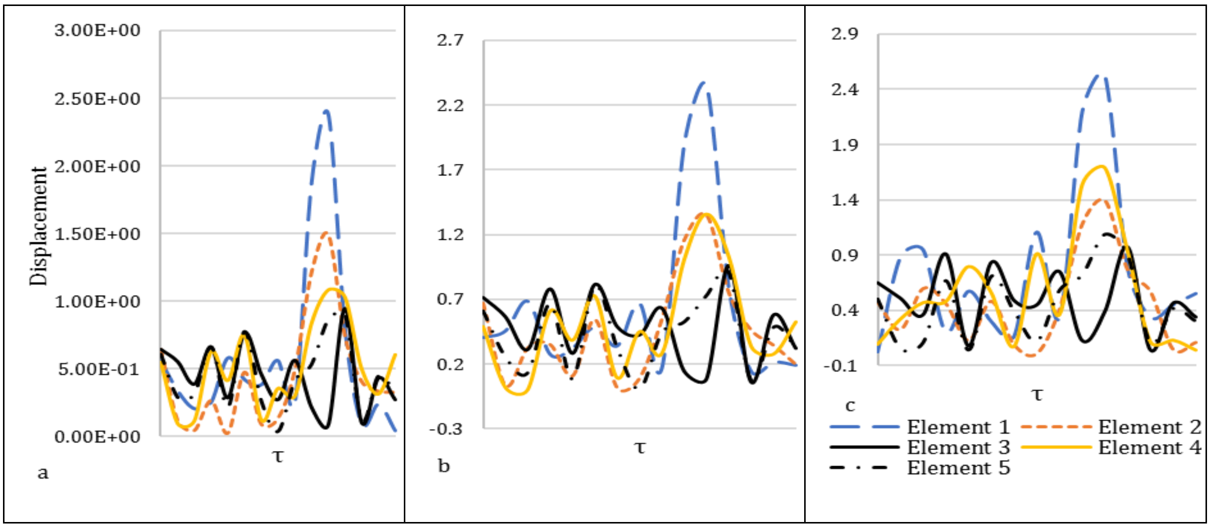


Fig. 24. Mean displacement response of asymmetric system using both beam-column joint and TLD at 35° for T=0.25sec (a) (e/D=0.05, 0.2), (b) (e/D=0.1, 0.2), (c) (e/D=0.2, 0.2).

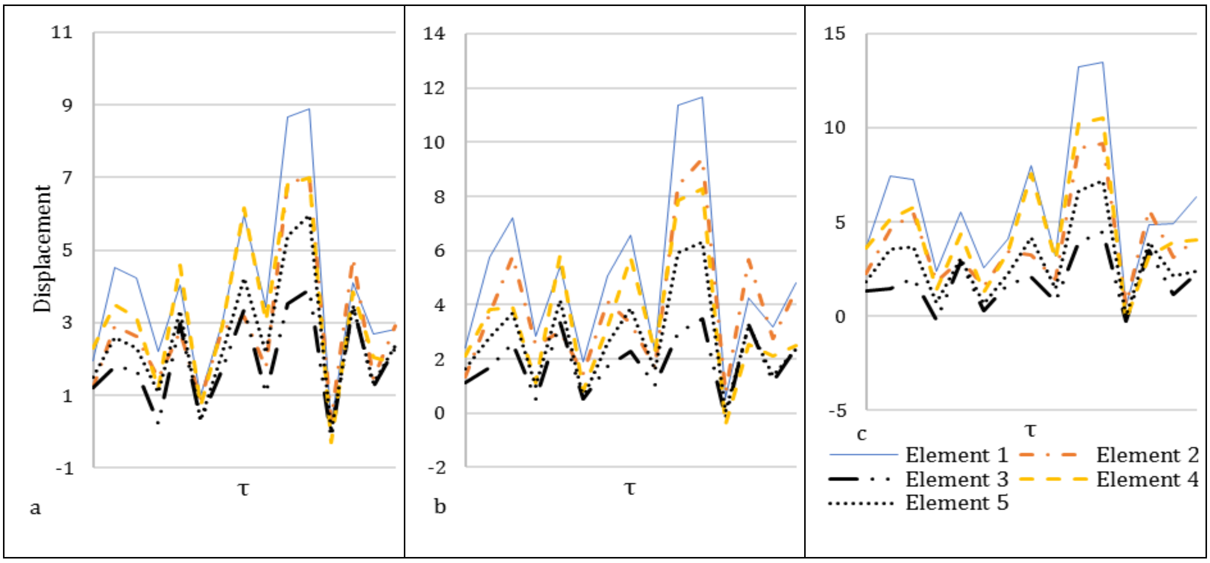


Fig. 25. Mean displacement response of asymmetric system using both beam-column joint and TLD at 45° for T=0.5sec (a) (e/D=0.1, 0.1), (b) (e/D=0.1, 0.2), (c) (e/D=0.2, 0.2).

Fig. 22 shows the minimum deformation response of load resisting elements than Fig. 9 and Fig. 14 that deals average inelastic demand with 2.3 times and 9.2 times for flexible element majorly owing to torsional effect respectively. Fig. 23 represents the mean displacement response of SDOF system for both condition using beam-column joint and TLD at lateral period 0.5sec, where the eccentric condition considered e/D=0.05, 0.1. In this plotting, different column like square, rectangular and circular are chosen with TLD at 35° sloppy angle. It is clearly shown that the elemental deformation controlled by using the both condition that lies for square column 7.1 times, rectangular column 8.2 times and for circular column 6.1 times respectively subjected to bi-directional ground motion excitation. Fig. 24 represents the mean displacement response of asymmetric system using both beam-column joint and TLD at 35° for T=0.25sec, where e/D=0.05, 0.2, e/D=0.1, 0.2 and e/D=0.2, 0.2; clearly shown that the elemental deformation controlled by using both beam-column joint and TLD that decrease between 1.2-1.35 times than actual condition. Fig. 25 represents the mean displacement response of asymmetric system using both beam-column joint and TLD at 45° for T=0.5sec, where e/D=0.1, 0.1, e/D=0.1, 0.2, e/D=0.2, 0.2; clearly shown that the elemental deformation controlled by using both beam-column joint and TLD that decrease between 1.4-1.5 times than actual condition. All plotting is clearly shown with respect the system parameters based on individual conditions.

7. CONCLUSIONS

The emphasis in this paper is to study the inelastic seismic performance of a single-story RC symmetric and asymmetric model plan structures with various angle of slopes in hilly areas in India owing to bi-directional ground excitation and also major land slide. The results are also indicated the performance evaluation with different column sections and the brick infill capacity of asymmetric system for better understanding the serviceability of load resisting elements and by the by modern technique TLD for controlling the major vibration. The following broad conclusions emerge.

1. Consideration of symmetric configuration effect is owing to simultaneous bi-directional shaking may produce the inelastic demand. The result analysis implies for both cases amplifies the response considerably. For seismic safety measurement, the vulnerability resistance of symmetric structure in the inelastic range of sloppy ground lies between 10° to 25°, whereas above 25° to create elemental deformation. But in hilly areas sloppy ground doesn't depend in any circumference, so safety measurement can be considered column to column joint with beam where the depth of beam shall be minimum 0.152×0.305m. It is possible to protect the vulnerability of the structure lies percentage of 90% even if it doesn't depend on sloppy ground. Besides that, the columns will be kept in both square 0.152m to 0.203m and circular 0.127m to 0.152m manner.

2. Consideration under inelasticity, the bird's eye observation represents the performance of asymmetric system due to ground excitation. In the case of asymmetric structure, a torsional effect has been created in an inelastic range, where the maximum deformation of six elements with respect to different eccentric conditions have been clearly observed and appropriately applicable for elemental deformation of a structure for increasing different lateral periods. The stability by using column-beam joint in symmetric structure is also suitably applicable for asymmetric structure but the shape of the column shall be square and circular and for rectangular column it shall be lie between the dimension of 0.152m to 0.254m that omitted the major torsional effect about 85%. The critical observations that have been obtained with increasing the different eccentric condition with angle of slopes on asymmetric structures which are dependent not only the land slide movement but also the less magnitude ground motions that influence the elemental deformation in less time interval before reaching the ultimate inelastic phase.

3. In hilly areas, light weight structures are acceptable for abnormal ground orientation [6]. Land slide is a sudden disaster phenomenon that satisfies the depth of foundation higher. On the other hand, it may be protected by using column-beam joint. In spite of this guideline, major risk factor is remained due to uncontrolled land slide. The exterior section of the structure may be damaged if the effect of the land slide is above or below the position of the structure and also in foundation. Therefore, by omitting the land slide for safety measurement, to prevent the collapse of the structure at the initial position, it is possible to protect the torsional effect of an asymmetric structure by providing a circular column to column joint on the sloppy ground where beam and column lies in one directional only not under inclination angle.

4. Consideration of bi-directional interaction for symmetric and asymmetric structural system, the compressive load induces in the mid-section of brick masonry walls also produce the stiffness degradation on the load resisting elements. As a result, brick masonry infill walls are easily collapse for single-story structure highly. Therefore, the thickness of the masonry infill brick walls can be increased to a minimum of 254mm, response for collapsing is much less and will prevent major damage subject to bi-directional ground motion. Also, material quality shall be maintained and 1st class brick shall be considered which has more flexibility.

5. It can be said for sure that the response received by TLD is better than that of approaching beam-column joint, highly dissipates the energy almost 87% against major vibration also resists the stiffness degradation about 75-80% through sloshing and wave breaking in the TLD for future uncertain ground motions. In this regard, only the individual approach is not enough to control a large amplitude harmonic excitation for this type of SDOF asymmetric system in critical seismic hilly station, but it can be controlled cooperatively that signifies more effectiveness, reduces the elemental deformation can be achieved almost 90-95% with highly suitable angle of slope 35°-45° for general eccentric conditions under different lateral times.

Thus, the present scenario 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 undergoing seismic excitation without collapse may be assessed to plan for the post-earthquake strategy. Such a symmetric and asymmetric structures in hilly areas serve various functional and architectural requirements causes 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 for 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 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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