SEISMIC BEHAVIOUR OF PLAN IRREGULAR BUILDING –AN ANALYTICAL STUDY

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Synopsis

Asymmetric buildings often undergo unfavorable seismic behaviour, which results the irregular concentration of plastic demand in limited or vulnerable portion of the structure and subsequently, invite the early collapse of the structure during seismic vibrations. L-shaped buildings are among those asymmetric structures which are commonly found in the form of school, office, commercial as well as residential buildings. Accordingly, an analytical study is performed to investigate the seismic behaviour of plan irregular buildings. Moreover, to understand the effect of length of projection of the structure on the dynamic characteristics, different projection length lead to different aspect ratios for the same building plan shape have been analyzed here. It is observed that variation in projection length of such buildings have significant effect on the dynamic characteristics. However, the seismic response of few L-shaped buildings are analyzed using nonlinear static method and results have been shown in terms of capacity curve, performance point, interstorey drift, column shear, and plastic hinge formation pattern. Seismic demands of asymmetric systems are found to be potentially high due to its asymmetric distribution of mass, stiffness and strength, which is one of the major sources of damage, as it causes torsional floor rotation.

Keywords: *Pushover, asymmetry, capacity curve, time period, torsion.*

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1. INTRODUCTION

Irregular structures habitually show unfavorable seismic behaviour, characterized by the concentration of plastic demand in a limited portion of the structure, which can cause early collapse under strong seismic motion. The evidence from past earthquake clearly underlined that the irregularity in plan, which can be caused by asymmetric distributions of mass, stiffness and strength, is one of the recurrent cause of severe damage , since it cause torsional floor rotations, localizing the seismic demand in small portions of the building[1-2]. Outsized research efforts were made to study the seismic response of irregular structures, both in plan [3] and in elevation [4]. Collective exertions have also been made to deeply understand its effect on seismic behaviour using nonlinear static procedures, which have been a very practical tool to evaluate performance of structure [5]. However, use of such methods in case of existing plan irregular building has been so far studied by limited authors [6-7].Various efforts have been made towards the comparative study of nonlinear static and dynamic analysis of plan asymmetric building to evaluate the seismic vulnerability of such buildings and the influence of various earthquake direction taken into consideration [8]. However, these studies primarily considered seismic shaking in one principal horizontal direction of the structure though in reality shaking occurs simultaneously in both the horizontal principal directions.

Still the dynamic behaviour of the structures is governed by the fundamental frequency of a building and its damping has a remarkable effect on the magnitude of its response and so, it is very important to understand the fundamental dynamic property and its mode of vibrations at first. In this respect, the present paper is an attempt to evaluate the effect of the length of the projection of L-shape building on the dynamic properties and moreover nonlinear analysis were carried out to compute the seismic behaviour of the L-shape building. Considering these issues, a limited number of L-shape model is analyzed and the obtained results from modal analysis were used to comparing the time period, mode of oscillation and stress concentration and results of the nonlinear static analysis were used to compare the capacity curve, lateral displacement and interstorey drift profile and normalized SF and BM ratios for the considered cases of buildings.

2. DETAILS OF MODELLING

In this study, to investigate the effect of projection to length ratio (referred as Rpl in this paper) on the dynamic properties and the seismic responses of the L-shape building, eighteen different L-shaped RC buildings are considered with different Rpl based on the variation of bays along the length of the projection . The projection to length ratio Rpl can be calculated by using equation 1 and the general representation presented in Fig. 1.

Projection to length ratio is given by,

$$R_{pl} = \frac{A}{L} \qquad (1)$$

The buildings are categorized into three cases based on the increasing number of bays from one to three along the projection’s shorter span as shown in Fig. 2. The projection to length ratio for case 1 are 0.5, 0.67, 0.75, 0.8, 0.83, 0.86 and 0.33, 0.50, 0.60, 0.67, 0.71,0.75 for case 2 and 0.25, 0.40, 0.50, 0.63, 0.7, 0.75 for case 3. All models have five-stories with 3.50 m inter-storey height. Each bay is of length 4 m for all the cases of building considered in both the horizontal direction. For all the models, the dimension of column section, in first and second storey are 450 x 450 mm with 4#25 mm and 16#20 mm as main reinforcement and in third and fourth storey are 350 x 350 mm with 4#20 mm and 12#16 mm as main reinforcement and fifth storey are 350 x 350 mm with 8#16 mm as main reinforcement and the beam has constant cross section of 300 x 300 mm in each storey. A uniform slab thickness of 140 mm and 125 mm thick exterior and interior partition walls are considered for all the cases. The grade of concrete and steel are used as M25 and Fe415 respectively.

Thus, a total 18 different buildings are analyzed under modal and Nonlinear analyses using computer program i.e., SAP2000 [9] (CSI Computer & Structures Inc., 2004) to compute the dynamic properties and structural response. The buildings are assumed to be founded on a medium type of soil and is located in seismic zone V (Z=0.36 according to IS 1893:2002 [10]) and the foundation of the building assumed to be fixed.

3. METHODOLOGY

In this present paper, for all the 18 models modal analysis is performed and for nonlinear static analysis 3 buildings having highest projection to length ratio from each case i.e. 0.86 in case 1, 0.75 in case 2 and 0.75 in case 3 are taken into consideration.

3.1. Modal analysis

In Modal analysis dynamic properties of structures under earthquake excitation are studied and the undamped natural modes of the building are computed. Modes are inherent properties of a structure, and are determined by the building properties (mass, damping, and stiffness). In modal analysis the overall mass and stiffness of a structure is used to compute the various periods at which building will naturally oscillate. The periods of oscillation are very important to understand the behaviour of the structure. The empirical formulas are also mentioned in IS 1893:2002 [10] to calculate the period of vibration and the formulas depends on the building material (RC, steel, etc.), building type (frame, infill, etc.), and overall dimension.

3.2. Nonlinear analysis

Nonlinear static commonly referred as “pushover analysis” directly incorporates nonlinear load deformation characteristics of building component when subjected to increasing lateral loads until a target displacement is exceeded. Lateral loads are applied in proportion to the distribution of inertia forces and shape of the fundamental mode. In this present paper, the capacity spectrum method (CSM ATC40 [11]) is used to evaluate the behaviour and performances of the RC building. The distribution of horizontal force considered as IS load pattern and displacement-controlled pushover analysis is performed.

Performance point is the intersection of the capacity spectrum with the appropriate demand spectrum in the capacity spectrum method. It represents the inelastic or nonlinear displacement that the structure is experience for the given level of earthquake. The structural performance levels are also mentioned on the capacity curve i.e. IO (immediate occupancy), LS (life safety) and CP (collapse prevention). According to FEMA-356[12], IO means the structural damage has occurred very limited in post-earthquake damage state. The life-threatening injury as a result of structural damage is very low. Minor repairs may be required but not prior to reoccupancy. LS means significant damage to the structure has occurred in the post-earthquake damage state but not resulting to partial or total collapse of structure. The overall life-threatening injury as a result of structure damage is low. It would be prudent to implement repairs prior to reoccupancy. CP means a considerable amount of damage to the structure has occurred including strength and stiffness degradation of the lateral force resisting system and large permanent deformation of the structure. The building is on the verge of the experiencing partial or total collapse. The structure may not be technically practical to repair and is not safe for reoccupancy.

4. RESULT AND DISCUSSION

The results obtained from modal analysis are shown in the form of time period, modes of vibration, stress concentration. The results of nonlinear analysis are represented as capacity curve, interstorey drift, displacement profile, and normalized Shear force and bending moment. Details discussion is made on the results on the following subsections.

4.1. Modal analysis

Table 1 shows the first 12 fundamental modes of vibration along with its corresponding time periods. The table shows that primarily diagonal translation and torsional modes are predominant in the first three modes which is not desirable as the section of columns are mostly rectangular and square. These buildings with asymmetric shapes, particularly with long projections and re-entrant corners, exhibit special modes of oscillation in addition to the diagonal and torsional modes. This special modes includes opening-closing mode, which occur only in particular model which has high Rpl such as 0.80, 0.83 in case 1, 0.83, 0.86 in case 2 and 0.70, 0.75 in case 3. The mode shapes are dependent on structural stiffness, thus these special mode of vibration exist in the earlier modes in case 1 and appear lately in case 2 and case 3. The building vibrate in these mode repeatedly, cause reversal stress concentration in the re-entrant corner showed in Fig. 3, collectively causing initiation of failure at the re-entrant corner and significant structural damages which may not be reparable.

4.2. Nonlinear analysis

The capacity curves obtained in both the direction are plotted in Fig. 4 for building considered from each case. It can be observed that in both the horizontal direction using conventional pushover leads to same result. The trend of curve nearly matches for both the horizontal direction. In the three obtained pushover curves, at performance point IO, the displacement of three buildings are nearly same but they show higher base shear values.

Also from Fig. 4, it can be concluded that the building presents a clearly uniform stiffness distribution on the projection in the two directions. However, from Fig. 4 it can also be observed that the range of structural stability is large in case 1 as it attained collapse state after sustaining high displacement than case 2 and case 3.

The lateral displacement profile and the interstorey drift profile studied and are plotted in Figs. 5(a) and 5(b) respectively. The maximum top roof displacement occurred in case 1 building shows in Fig. 5(a), which clearly exhibit its higher flexibility than case2 and case 3. It can be observed that in case 2 building the 3rd and 4th storey level displace equally followed by slight roof displacement. In both the direction same result occur for case 1 and case 2 whereas in case 3 less displacement occur in y-direction compare to x-direction.

The Fig. 5(b) exhibits an increase in interstorey drift upto 2nd storey level for all the three cases, but there is a decrease in drift in case 3 whereas for case 1 and case 2 the drift further increase upto 3rd storey level. It can also be noticed that the interstorey drift is zero in both the direction in between 3rd and 4th storey level as both the level displaced equally.

One comparing the interstorey drift, it shows that buildings with more bays in projection’s shorter span have lesser drift value in the higher storey level than the building with lesser bays in the projection’s shorter span.

The result of the normalized shear force ratio and the normalized bending moment ratio are presented in Figs. 6(a) and 6(b) respectively. The ratios of normalized shear force and bending moment are compared at each storey level for each case of building considered. Such a comparison is performed considering the maximum ratios among all the columns at each storey level. It is clearly evident that, from Fig. 6(a), the shear force ratio reduced by 20-30% for case 2 and case 3 for most of the storey level, whereas in 2nd storey level the shear force ratio increased by 20% for case 2 and in 4th storey level the shear force ratio for both case 2 and case 3 reduced nearly 40%.

The distribution of normalized bending moment ratio represent in Fig. 6(b). The distribution shows the reduction of bending moment in case 2 and case 3 compared to case 1 building. The reduction range fluctuate between 20-30% for case 2 and 50-60% for case 3. This is perhaps due to the reason that with increase in bays, the column possess larger strength as the same force is shared by more number of column. This phenomenon also explain why the hinge pattern, shown in Fig. 7, shows maximum number of collapse state in case 1 than case 2 and case 3.

5. CONCLUSION

The present paper makes an attempt to study the effects of length of the projection of a plan asymmetric structure under unidirectional ground motions. A group of L-shape building models was developed to facilitate the study.

The study present in the paper leads to the following broad conclusion:-

Increase in Rpl can cause special modes of vibration and stress concretion at the re-entrant corner under action of unidirectional ground motion. Hence, this issue can further investigate considering simultaneous action of two orthogonal components of ground motions.

The response and seismic demand of the buildings in this study evaluated by the conventional pushover (CSM ATC40 [11]) only. Therefore various nonlinear static procedures and dynamic procedure can be carried out for same issues to produce wide-ranging definite results.

6. NOTATION

A- Length of Projection
BM- Bending Moment
CP- Collapse Prevention
CSM- Capacity Spectrum Method
IO- Immediate Occupancy
L- Principle dimension of the base
LS-Life Safety
RC- Reinforced Concrete
Rpl- Projection to Length ratio
SF- Shear Force
Ts- Time period
d- Base dimension of the building at the plinth level along the considered direction of the lateral force
h- Height of the building

7. REFERENCES

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TABLE 1. Modes of vibration in buildings with L-plan shape

		FIRST TWELVE MODE OF VIBRATION WITH ITS TIME PEROID (IN SEC) IN L-SHAPE BUILDINGS.											
	R_{pl}	1	2	3	4	5	6	7	8	9	10	11	12
CASE 1	0.5	DT(1.46)	DT(1.46)	T(1.09)	2ND DT(0.45)	2ND DT(0.45)	2ND T(0.35)	3RD DT(0.24)	3RD DT(0.24)	3RD T(0.19)	4TH DT(0.16)	4TH DT(0.16)	4TH T(0.13)
	0.67	DT(1.47)	DT(1.47)	T(1.24)	2ND DT(0.45)	2ND DT(0.45)	2ND T(0.39)	3RD DT(0.25)	3RD DT(0.25)	3RD T(0.19)	4TH DT(0.17)	4TH DT(0.17)	4TH T(0.14)
	0.75	DT(1.1)	DT(1.1)	T(0.98)	2ND DT(0.34)	2ND DT(0.34)	2ND T(0.31)	3RD DT(0.18)	3RD DT(0.18)	3RD T(0.17)	4TH DT(0.12)	4TH DT(0.12)	4TH T(0.11)
	0.8	DT(1.5)	DT(1.5)	T(1.4)	2ND DT(0.46)	2ND DT(0.46)	2ND T(0.43)	3RD DT(0.25)	3RD DT(0.25)	3RD T(0.23)	OC(0.2)	2ND OC(0.18)	4TH DT(0.17)
	0.83	DT(1.5)	DT(1.5)	T(1.4)	2ND DT(0.47)	2ND DT(0.47)	2ND T(0.43)	OC(0.29)	3RD DT(0.25)	3RD DT(0.25)	3RD T(0.24)	2ND OC(0.23)	3RD OC(0.17)
	0.86	DT(1.1)	DT(1.1)	T(1.0)	2ND DT(0.35)	2ND DT(0.35)	2ND T(0.33)	OC(0.27)	2ND OC(0.22)	3RD DT(0.19)	3RD DT(0.19)	3RD T(0.18)	3RD OC(0.15)
CASE 2	0.33	DT(1.14)	DT(1.14)	T(0.93)	2ND DT(0.36)	2ND DT(0.36)	2ND T(0.35)	3RD DT(0.19)	3RD DT(0.19)	3RD T(0.16)	4TH DT(0.12)	4TH DT(0.12)	4TH T(0.11)
	0.5	DT(1.15)	DT(1.15)	T(1.0)	2ND DT(0.36)	2ND DT(0.36)	2ND T(0.35)	3RD DT(0.20)	3RD DT(0.20)	3RD T(0.17)	4TH DT(0.13)	4TH DT(0.13)	4TH T(0.11)
	0.6	DT(1.15)	DT(1.15)	T(1.04)	2ND DT(0.36)	2ND DT(0.36)	2ND T(0.33)	3RD DT(0.20)	3RD DT(0.20)	3RD T(0.18)	4TH DT(0.13)	4TH DT(0.13)	4TH T(0.12)
	0.67	DT(1.16)	DT(1.16)	T(1.07)	2ND DT(0.37)	2ND DT(0.37)	2ND T(0.34)	3RD DT(0.20)	3RD DT(0.20)	3RD T(0.18)	4TH DT(0.13)	4TH DT(0.13)	4TH T(0.12)
	0.71	DT(1.16)	DT(1.16)	T(1.09)	2ND DT(0.37)	2ND DT(0.37)	2ND T(0.35)	3RD DT(0.20)	3RD DT(0.20)	3RD T(0.19)	4TH DT(0.13)	4TH DT(0.13)	OC(0.13)
	0.75	DT(1.17)	DT(1.17)	T(1.10)	2ND DT(0.37)	2ND DT(0.37)	2ND T(0.35)	3RD DT(0.20)	3RD DT(0.20)	3RD T(0.19)	OC(0.17)	2ND OC(0.16)	4TH DT(0.13)
CASE 3	0.25	DT(1.16)	DT(1.16)	T(1.0)	2ND DT(0.37)	2ND DT(0.37)	2ND T(0.32)	3RD DT(0.20)	3RD DT(0.20)	3RD T(0.17)	4TH DT(0.12)	4TH DT(0.13)	4TH DT(0.13)
	0.4	DT(1.18)	DT(1.18)	T(1.04)	2ND DT(0.37)	2ND DT(0.37)	2ND T(0.33)	3RD DT(0.20)	3RD DT(0.20)	3RD T(0.18)	4TH DT(0.12)	4TH DT(0.13)	4TH DT(0.13)
	0.5	DT(1.18)	DT(1.18)	T(1.07)	2ND DT(0.37)	2ND DT(0.37)	2ND T(0.34)	3RD DT(0.20)	3RD DT(0.20)	3RD T(0.19)	4TH DT(0.13)	4TH DT(0.13)	4TH T(0.12)
	0.63	DT(1.18)	DT(1.18)	T(1.11)	2ND DT(0.38)	2ND DT(0.38)	2ND T(0.35)	3RD DT(0.21)	3RD DT(0.21)	3RD T(0.19)	4TH DT(0.13)	4TH DT(0.13)	4TH T(0.13)
	0.7	DT(1.18)	DT(1.18)	T(1.14)	2ND DT(0.37)	2ND DT(0.37)	2ND T(0.36)	3RD DT(0.21)	3RD DT(0.21)	3RD T(0.20)	OC(0.17)	2ND OC(0.16)	4TH DT(0.14)
	0.75	DT(1.19)	DT(1.19)	T(1.15)	2ND DT(0.38)	2ND DT(0.38)	2ND T(0.37)	OC(0.26)	2ND OC(0.21)		3RD DT(0.21)	3RD T(0.20)	3RD OC(0.16)

DT- Diagonal Translation, T-Torsional, OC-Opening and Closing

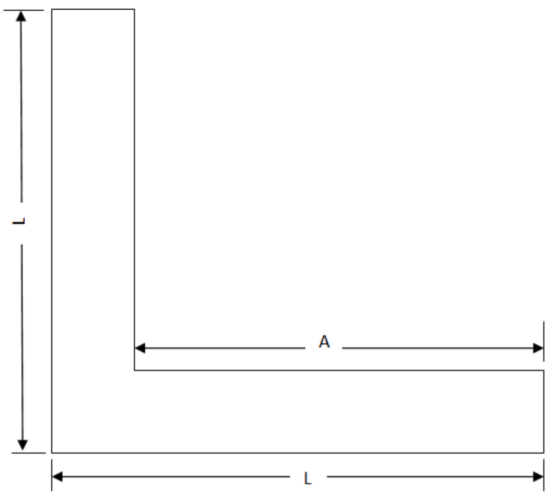


Fig. 1. General representation of L-shape demonstrating notation of length of projection and principle dimension.

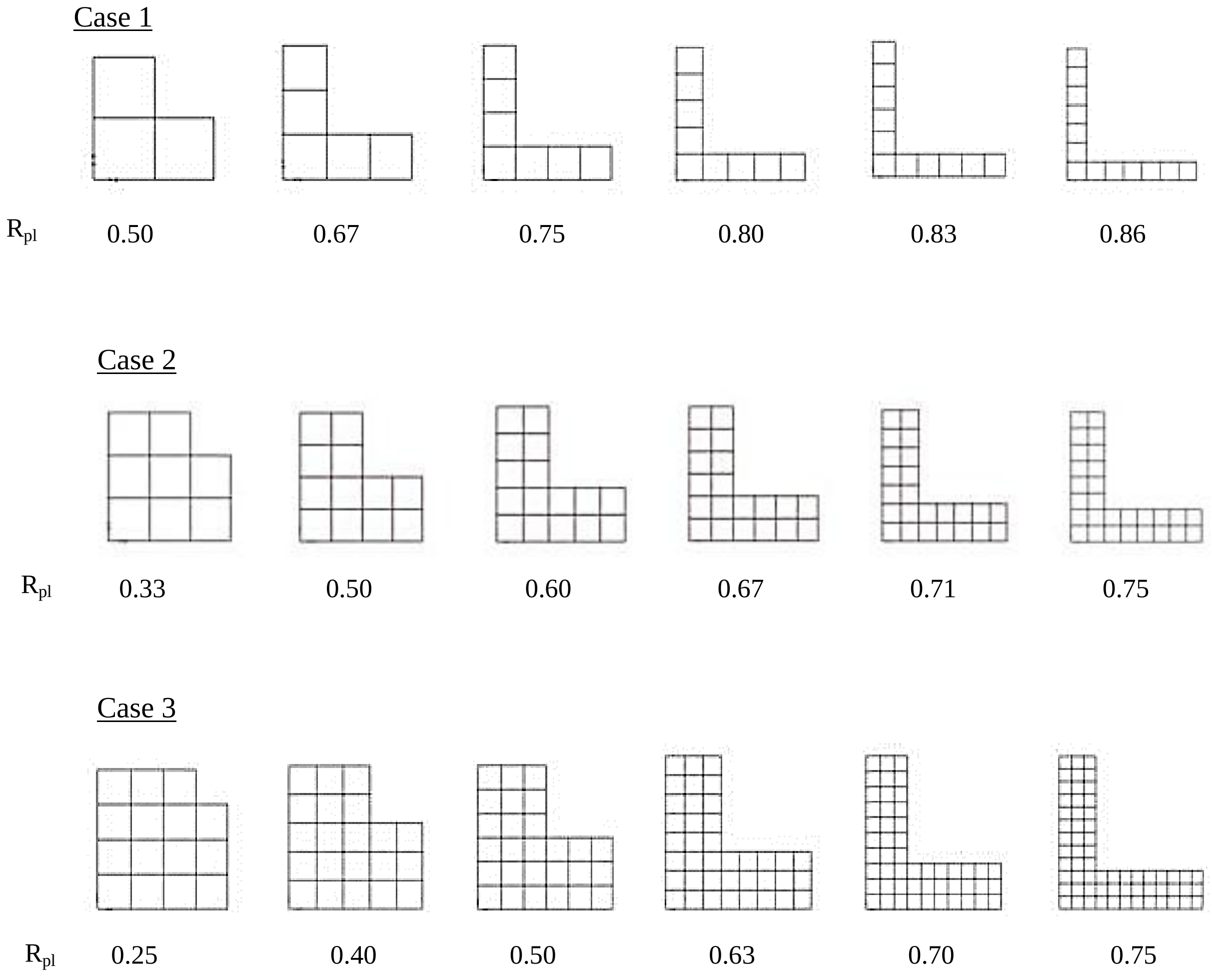
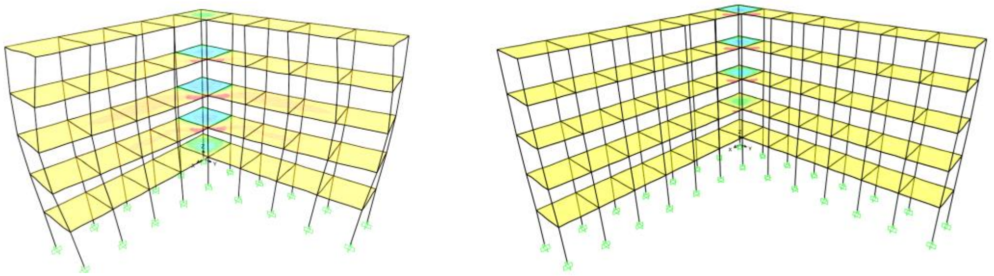
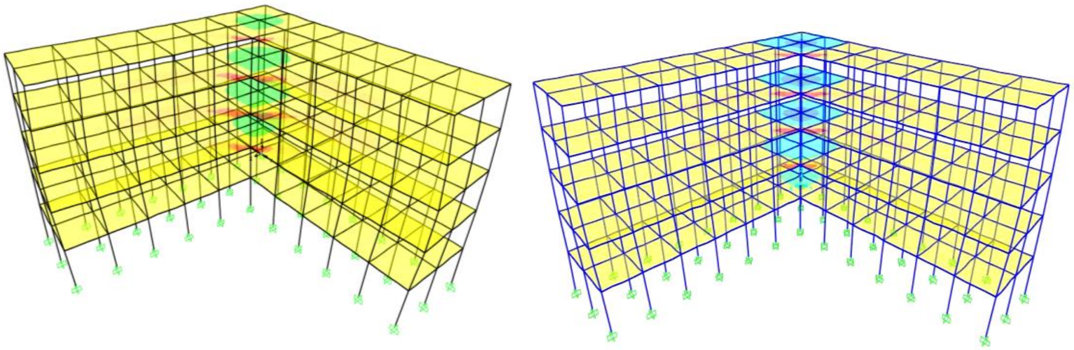


Fig. 2. Plan view of analyzed L-shape buildings with different projection to length ratio.



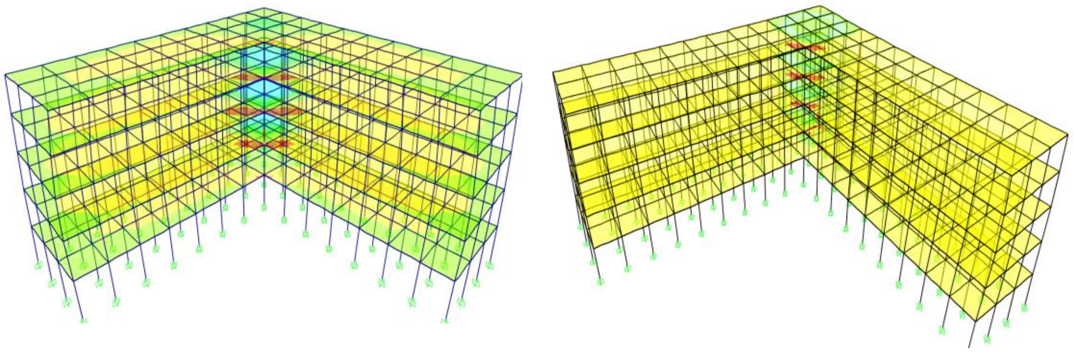
(a)

X direction Y direction



(b)

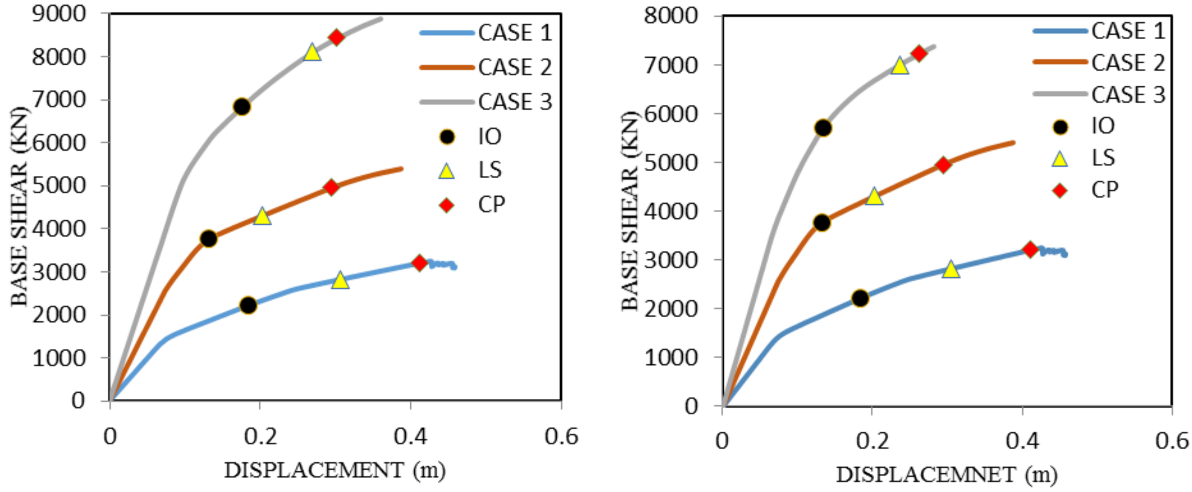
X direction Y direction



(c)

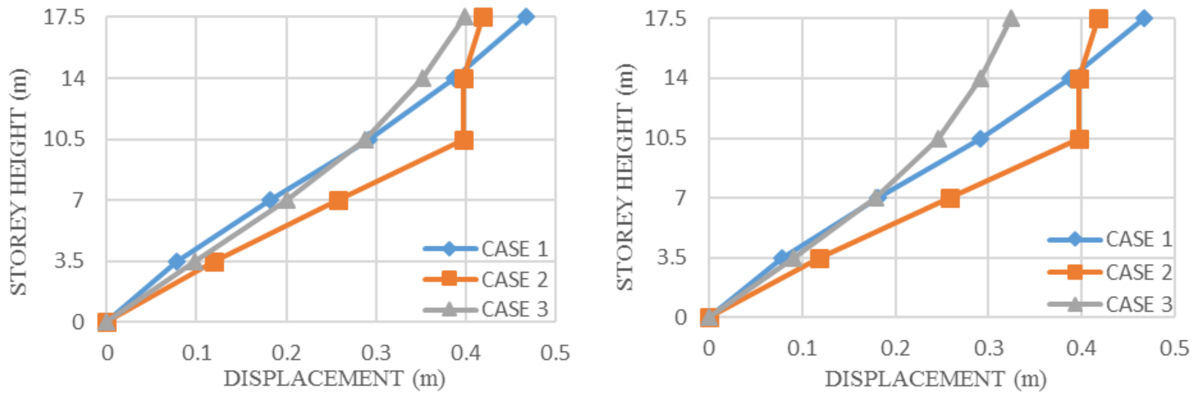
X direction Y direction

Fig. 3. Stress concentration at re-entrant corner in L-shape building during opening-closing mode (a) case 1 (b) case 2 (c) case 3.



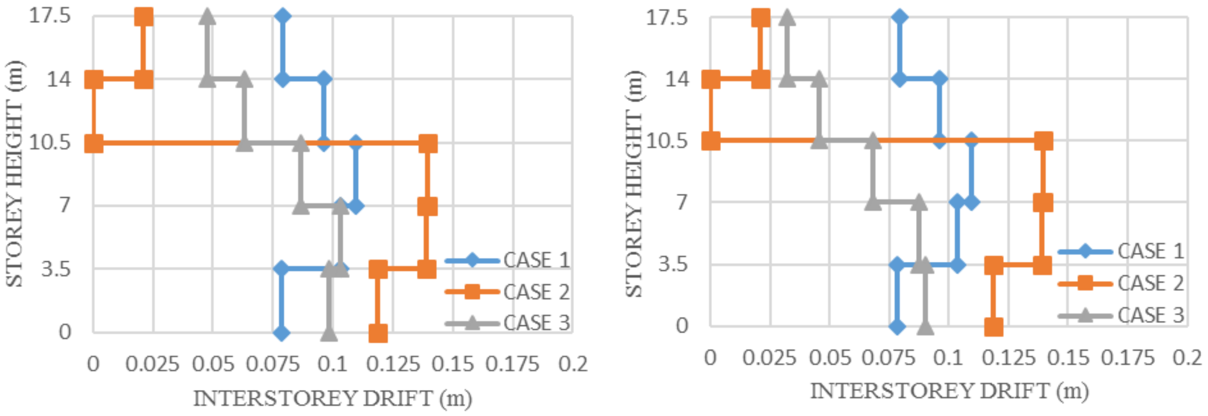
(a) (b)

Fig. 4. Capacity curve: (a) in X direction (b) in Y direction.



X direction Y direction

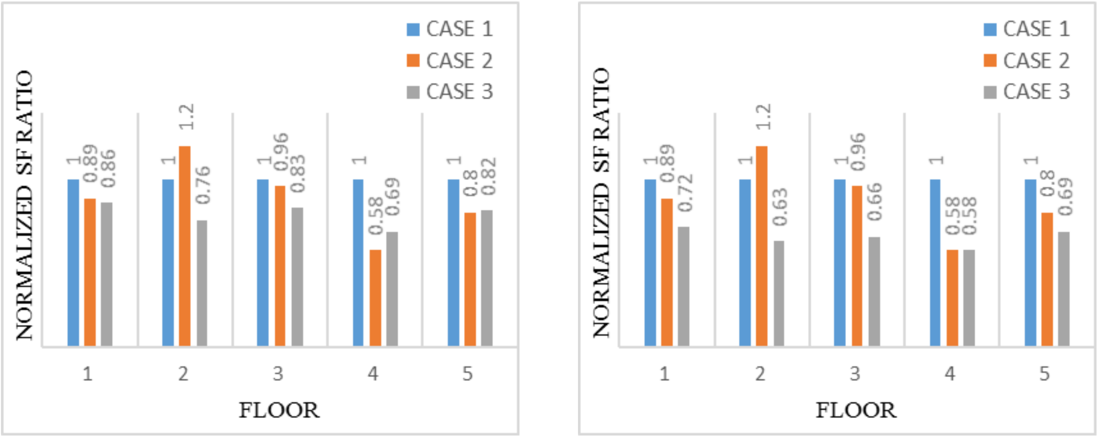
(a)



X direction Y direction

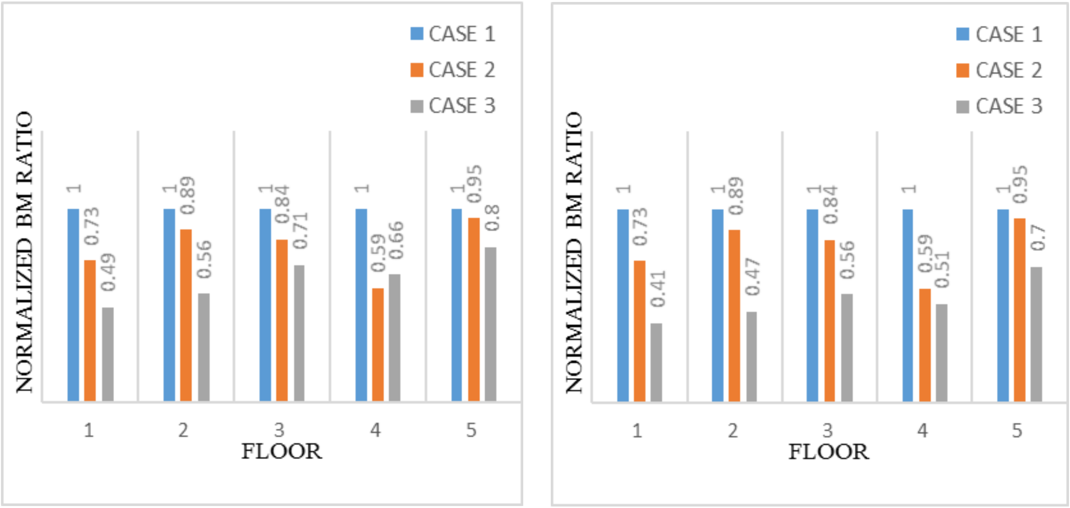
(b)

Fig. 5. (a) Lateral displacement profiles (b) Interstorey drift profile



X direction Y direction

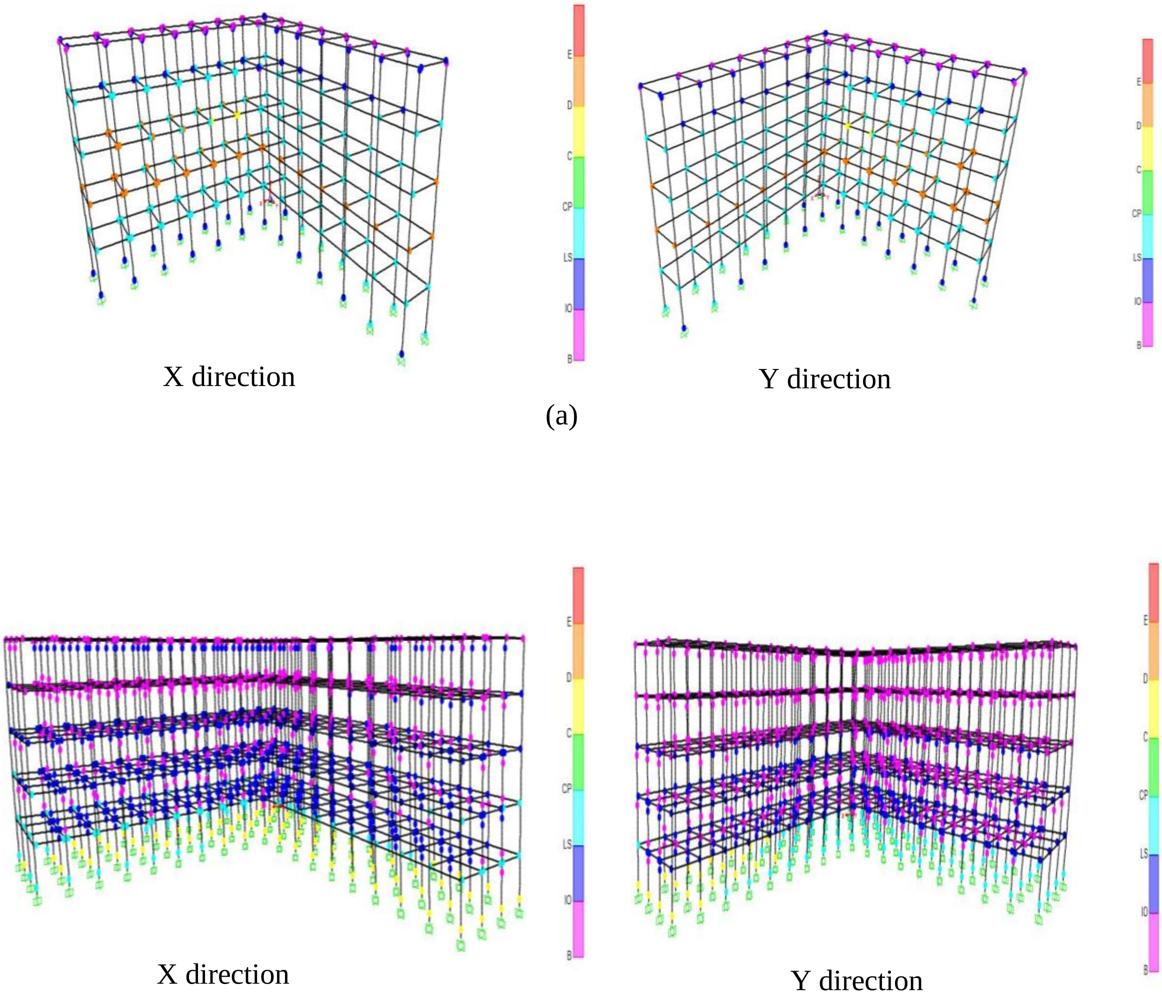
(a)



X direction Y direction

(b)

Fig. 6. (a) Comparing the normalized shear force at each floor for different cases considered (b) Comparing the normalized bending moment at each floor for different cases considered.



X direction

Y direction

(a)

X direction

Y direction

(b)

Fig. 7. Hinge pattern of L- shape building in X and Y direction: (a) case 1 (b) case 3.