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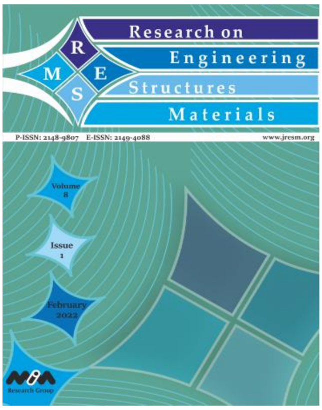

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Online Publication Date: 10 Sep 2021

URL: http://www.jresm.org/archive/resm2021.295st0519.html

DOI: http://dx.doi.org/10.17515/resm2021.295st0519

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article

Bohara BK, Ganaie KH, Saha P. Effect of position of steel bracing in L-shape reinforced concrete buildings under lateral loading. *Res. Eng. Struct. Mater*., 2022; 8(1): 155-177.

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Research Article

Effect of position of steel bracing in L-shape reinforced concrete buildings under lateral loading

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Article Info

Article history:
Received 19 May 2021
Revised 17 Aug 2021
Accepted 22 Aug 2021

Keywords:

Steel bracing;
L shape RC buildings;
Irregular buildings;
Inter-story drift;
Retrofitting, torsional;
Irregularity ratio

Abstract

The level of damage in irregular structures is more compared to regular structures. In this study, L shaped RC buildings are investigated with and without steel bracings in different positions in frames. The response spectrum analysis has been done by using ETABs software. The two cases considered, case I and case II for understanding the effect in inverted V bracing in L shape building. Case II shows the suitable seismic parameters when bracing is used properly. Inter-story drift, displacements, base shear, fundamental time period, torsional irregularity ratio and the capacity ratio of the columns are evaluated. It is also noticed that adding the steel bracing decreases the inter-story drift, displacements of the structure effectively. The torsional irregularity ratio of each 12 models are studied carefully. The capacity ratio of the selected columns is studied to understand the performance of the columns while using the steel bracing in the buildings. The steel bracings are effectively used as retrofitting in L shaped buildings if the position of bracings are considered in the frames appropriately. While designing irregular buildings with steel bracings, the torsional effect should be checked.

1. Introduction

The construction of irregular buildings in India is very common, and it has been observed that during the earthquake, irregular building failures are most common. Since India is also located at highly seismic region in the world and it is because of the historical interaction of the Indian plate underneath the Eurasian plate. The past earthquakes such as Nepal (2015), Sikkim (2011), Kashmir (2005) and Uttarkashi (1990) caused serious loss of life, economical losses as well as damage of structures and even some serious failures to the large number of structures. Even the low magnitude ground motion (earthquake) shows the serious effect on the structural element in the buildings. Sikkim is one of the examples which causes some serious damage during the earthquake [1]. The seismic performance of the building mainly depends upon the shape, size, and arrangement of beams, columns and configurations of the buildings. Irregular buildings may possess seismic vulnerability and failure of the structural member. Mass irregularity, stiffness irregularity, vertical irregularity, geometrical irregularity, and plan irregularity are the common irregularities observed in the structures. Overall, the irregularities of the buildings are divided into two types, vertical and horizontal irregularity. Sudden change in stiffness, geometry, irregularity in strength stiffness and mass along the height known as vertical irregularity. Discontinuities in the horizontal plan, like cut-outs, large opening, asymmetrical plan shape (T, E, F, H, L, etc.) are known as horizontally irregular structures. It is important to relate the relationship between the physical damage of the irregular building and earthquake ground motion which helps to understand the seismic risk assessment of the buildings. The presence of irregularity in the structures, induced stress in the beam,

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DOI: http://dx.doi.org/10.17515/resm2021.295st0519

columns and slab, which makes the important to study the irregularity and its performance during ground motions. As compared to the regular structure the nonlinear and inelastic behaviors of the irregular structures is very complex. Retrofitting of irregular structures is the process of making a structure to resist the earthquake load.

Many researchers observed the seismic effect in the regular and irregular buildings with and without various earthquake resisting elements such as a shear wall, moment-resisting frame, and bracing. Mohammad et al. [2] studied the vertical irregularity in the structure and its effect during the earthquake was analyzed in the ETABs software. Mitesh Surana et al. [3] observed the seismic vulnerability of the hillside building in the Indian Himalayan region. Siva et al. [4] studied the different types of irregularity present in the structures. This research mainly focused on the vertical irregularity in the buildings. The irregular structures have more chances to fail during the earthquake than the regular structures that is the performance of regular structures have better than the irregular structure [5]. Chopra, A. K., & Goel, R. K. [6] studied the pushover analysis methodology for irregular structures and estimated the seismic demand for asymmetric buildings. In another paper, K.C. Anil and K. G. Rakesh [7] provided the model pushover analysis method and procedures to evaluate the seismic performance of the asymmetrical irregular in plan structures. Sachin G., P. S. Pajgade [8] studied the two cases, one with torsional effect and without torsional effect, and the result was compared based on the reinforced provided in the columns. Generally, the torsional effect in the structures is due to the eccentricity induced between the center of mass and the center of rigidity in the asymmetric plan buildings. A. Fredrick C. Dya and A. W. C. Oretaa [9] analyzed the existing structures to identify the seismic vulnerability of the irregular structures (mainly soft story) and observed the seismic effect by using pushover analysis and dynamic analysis. Marco Valente [10] investigated the plan irregular buildings for restrengthening purposes. The columns were retrofitted by using the RC jacketing and FRP to reduce the torsional component and analyzed with nonlinear time history analysis and pushover analysis. The displacement-based seismic design (DBSD) method was also used to analyze the irregular in plan shape structures. F. Mazza [11] and F. Mazza et al. [12] studied the DBSD method for the L shape irregular buildings for a retrofitting purpose. For the retrofitting, the researchers used the hysteretic damped braces.

L shape building possesses two types of problems. One of the problems associated with the opening and closing mode which cases the high-frequency oscillatory mode. It is due to the slender projection of the buildings. Which creates a high-stress concentration at the corners and causes the failure of structural members. Another problem is based on the torsional effect induced in the L shape buildings. Researchers have mainly focused on the seismic behaviors of the L shape building based on the displacements, drift, by using the response spectrum analysis (RSA) and static linear analysis. They focused on the observation of comparative study on the regular and L shape buildings and torsional irregularity ratio (B. Khanal and H. Chaulagain [13], Shehata E. Abdel Raheem et al. [14], Momen M. M. Ahmed et al. [15]). Some other researchers such as S.S. Tezcan, C. Alhan [16], Özmen et al. [17], Ali Koçak et al. [18] were focused on the study of the torsional effect of shear wall buildings. Researchers observed the torsional irregularity ratio of the different shear walls buildings. Prajwal T P [19] studied the regular and re-entrant L-shaped buildings and the analysis was based on the pushover analysis and nonlinear time history analysis to check the vulnerability of the irregular structures. Researchers also performed a comparative study between the pushover analysis and nonlinear time history analysis of the plan irregular buildings [20]. P. Giannakouras, C. Zeris [21] performed the pushover analysis and nonlinear time history analysis with the direct displacement-based seismic design (DDBD) method in the vertically irregular structure to study the performance of the structures. To understand the seismic performance of the irregular structure, the pushover and nonlinear time history analysis help better than linear analysis and it also helps to prevent failure [22], [23].

Concentrically braced frames and eccentrically braced frames are normally used in both the new construction and retrofitting process. Concentrically braced frames such are V bracing, inverted V–type bracing, diagonal bracing, multi X bracing, X bracing, etc. are used in the structure to resist the earthquake and to improve the drift, displacement, and increases stiffness. Many researchers studied the use of steel bracing in RC frame buildings. Applying the steel bracing in the RC frame improves the seismic performance and ductility of the existing buildings [24]-[29]. A. Rahimi, M.R. Maheri [30], [31] studied the effect of X-type steel bracing in the 2D RC frame to understand the braced and unbraced performance of the structures. The result shows that adding the bracing in the RC frame reduces the inter-story drift and displacement. Steel bracing improves the seismic performance strength and stiffness of the RC building when the inverted V, X shape bracing is used [32]-[34]. A. Hemmati et al. [35] studied the experimental analysis of rehabilitation of RC frame by using concentric and eccentric bracings and observed that the absorbed energy capacity of rehabilitated frames with eccentric and concentric bracings increased about 1.98 and 1.63 times of concrete frame. The compression of regular and irregular buildings with different types of steel bracings were observed by a different researcher, to know the effectiveness of steel bracing [36], [37]. Some other types of bracing such as commonly used high-performance structural elements, the buckling restrained bracing, may be used for lateral force-resisting systems in the structures [38], [39]. Many other techniques are used to improve the seismic behavior of structures such as hysteretic bracing systems [40], high strength diagonal precast panels [41] and for eccentric steel bracings connection (shear links) [42], [43] and these studies to understand the effectiveness of the steel bracings in the structures.

In this study the seismic behavior of the L-shape RC buildings with and without concentrically inverted V bracing. There is a lack of study on L-shape RC buildings with different positioned inverted V-shaped steel bracings. Many studies only focused on either regular RC buildings or vertically irregular buildings with steel bracing. The study focused on the different positioned inverted V bracing used in the RC L shape irregular buildings where steel bracing is used for a retrofitting purpose. The comparative study is presented different positioned steel braced frames based on the seismic performance. The seismic performance such as displacement, drift, shear force, fundamental time period, stiffness, torsional irregularity ratio, the capacity ratio in columns, axial forces and moment in the base columns are studied and compared. Best performed braced configurations are identified in L-shape buildings. The outcomes results help to observe the significant effect of steel bracing in L shape RC frames and reduce vulnerability. After studying the various research it is essentially needed to understand the seismic behaviors for inverted V braced RC structures in different configurations.

2. Proposed Problem

To study the effectiveness of the steel bracing in the existing L-shape RC building, the hypothetical L-shape of 6-story buildings is assumed. The 6-story buildings are designed as a moment-resisting frame. The 6 story building is irregular in plan shape like L shape (see in Table 3 and Fig.13) the 6-story L-shape building having 3.2m height each except the first story which is assumed as 4 m story height normally adopted in India. The overall height of the building is 20m. Each bay width is considered as 6m that is a column to columns span is 6m as shown in Fig 13 in both x and y-direction. The material and final selected cross-sectional property are shown in Table1 and 2 respectively. The columns section is changed every 3 stories of the building.

The L shaped moment resisting building is designed initially and it is assumed that, the column cross-section for all columns are the same (see table 2). The columns (including C1, C2, C3 and C4) consist of almost 3.8% of steel reinforcement for up to 3 stories from ground level and above 3 story and the reinforcement used as 3.08% of its cross-section. Beams and columns are designed according to the Indian standard [44]. The depth of the slab is considered as 120mm and its compressive strength 25MPa. The reinforcement used in the RC members is considered as a grade of 415MPa. For inverted V bracings, a hollow box section (square section) is used for retrofitting process (see table 2). The hollow section with a limited slenderness ratio (KL/r = 65) and compact section is selected to avoid the local buckling failure during lateral loading. The bracing is selected such that, it should be the weakest member of all other members (beam and columns) [32], [33]. The joint between steel and RC member are considered as a pin joint and hence the lateral load transfer through the bracings as an axial loading only (compression and tension).

The inverted V-bracing is used in different bays as shown in Table 3 (bold thick bays represents where the steel bracing is used). Table 3 shows the L shape building with inverted V-bracing (thick bold bays) and a 3D view of the respective model. Almost 12 models are observed and each model is named as L1 to L12 in which the L1 is the original without a braced RC frame. The models from L2 to L12 which are of the different steel braced configurations are shown in the Table 3. The models are further grouped in two categories, L2 to L8 known as the case I and L9 to L12 as case II. The building is designed by using Indian standard codes like for concrete design IS 456:2000 [44] and for seismic design IS 1893:2016 [45] ductile design code [47] used. The building is designed for 5 KN/m^2 as a live load and for the top floor, the live load is considered as 2 KN/m^2. The seismic weight of the structure is taken as 100% of dead load, 50% for live load when the live load is greater than $3KN/m^2$ and 25% of live load when the live load is less than $3KN/m^2$ [44].

The ETABs finite element software is used to study the seismic behaviors of the L-shape building with and without steel bracings. For a seismic design, the building is assumed in India, and the Indian seismic design code is used in this study. The seismic zone factors (z) of the building is 0.36 and 5% damping factor is considered [45]. The soil is medium soil (type ii) and the importance factor is considered as 1. The response reduction factor for the structure is considered as a 5 for the SMRF (Special moment-resisting frame) system of the buildings [45]. For the seismic design of the structure, some assumption is made such as P-Δ effect is considered for each model for both RSA. Soil-structure interaction is not considered in the model and base are restraints in all three X, Y and Z directions. For the RSA, SSRS (square root of the sum of square) and CQC (Complete quadratic Combination) are considered. A sufficient number of modes are considered in the analysis such that to get the sum of the all model mass for all modes assumed 90% of the total seismic mass, according to the IS 1893: 2016 part1 [45].

Table 1. Material properties of the concrete and steel materials

Concrete	Grade	Modulus of elasticity	Poisson's ratio		Density	Stress-strain diagram
	M25	25000 MPa	0.2		7850 Kg/m^3	(Fig 1 (b))
Steel bracing	Grade	Modulus of elasticity	Minimum yield stress	Minimum tensile stress	Density	Stress-strain diagram
	FE250	210 GPa	250 MPa	410MPa	7850 Kg/m^3	(Fig. 1 (a))

Table 2. Specifications of beams, columns and bracing used in the 6 story L-shape study buildings

RC section		Steel section
Columns(mm)	Beam (mm)	Bracing (hollow section in mm)
400X400 (1-3 story) 350X350 (4-6 story)	300X400	200X200X12

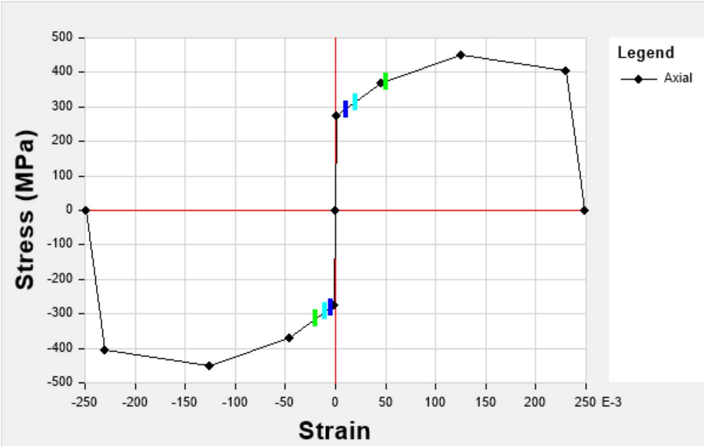
3. Methodology

To study the seismic behaviors of concentric steel braced RC frames and without steel braced RC frames, ETABs software is used for the analysis and design of each model. Linear dynamic analysis (RSA) is used for understanding and analyzing the torsional effect, story drift and story displacements of each model. The RSA is the linear dynamic analysis and is used to find the seismic response based on the vibrational mode shape. The method provides all almost realistic profile of the lateral forces. The comparative analysis is made before and after the steel bracing is used. The beams and columns are analyzed and designed. After the design, the concentric steel bracing is used for a retrofitting purpose. The study is mainly focused on the effect of bracing after applying in the RC building as retrofitting.

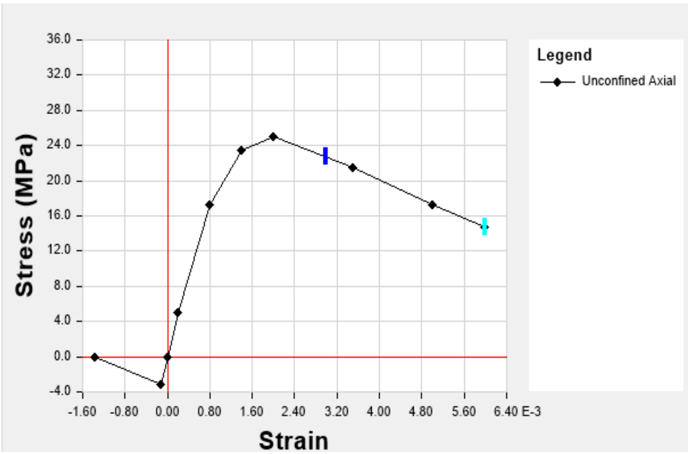
In this study, the soft story is presented in the first story which is the common practice in India [9]. According to the Indian standard [45], the soft story is defined as the story have lateral stiffness that is less than the stiffness of the above story. The height of the first story is taken 4m whereas the rest of the story has 3.2m in height. The stiffness equation ($K=12EI/L^3$) in which it is clear that the height of the story reduced the stiffness. Hence the soft story ratio is defined as the cube of the ratio of first story height and second story height. And the soft story ratio is calculated as 1.95.

If the projection is greater than 15 % of the overall plan dimension in that direction, it is said to be a Re-entrant corner [45]. In the study, the projection is 66% along the x-direction and 57% along y-direction greater than the overall dimension of the plan in each direction. Hence the re-entrant corner is present in the plan configuration. Torsional irregularity is calculated with the help of drift at each corner of the 3D model. Almost every seismic code (IS 1893:2016, UBC 97, ASCE 7–10) has a similar provision for the calculation of the torsional irregularity of the L shape building. For understanding, the accidental torsional effect torsional amplification factor (A_x) [46] shall be observed. The Δ_{max}, Δ_{min} and Δ_{avg} are the maximum, minimum and average drift and calculated when earthquake load is applied from x-direction as shown in Figure 2 respectively. The torsional irregularity coefficient is defined as the ratio of the drift maximum and average drift ($\eta_t= \Delta_{max}/ \Delta_{avg}$). Three conditions are described i) when η_t is less than or equal to the 1.2 then no torsional irregularity exists and A_x is equal to the 1, ii) when η_t is between 1.2 to 2.083 the torsional irregularity exists and A_x is calculated as given formula, iii) When the η_t is greater than 2.083 then η_t=2.083 and A_x equal to 3 [46].

$$A_x = \left(\frac{\Delta_{max}}{1.2\Delta_{avg}}\right)^2$$



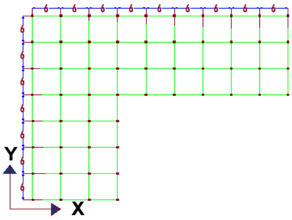
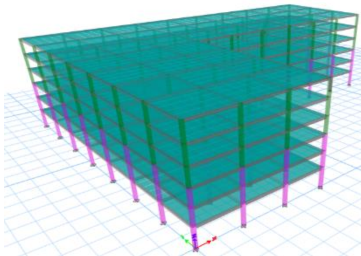
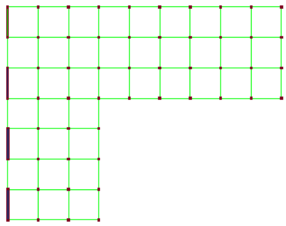
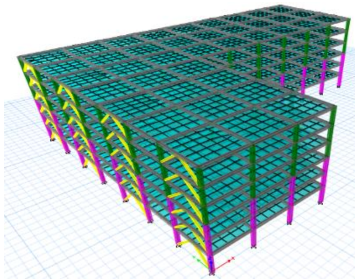
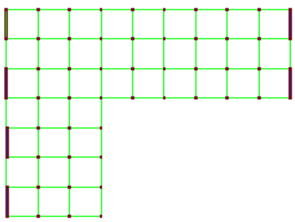
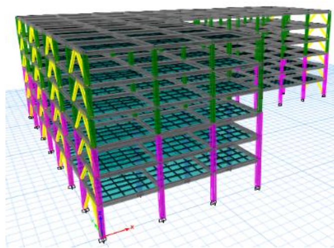
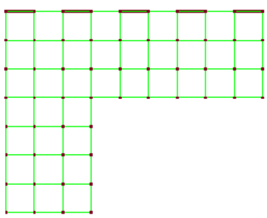
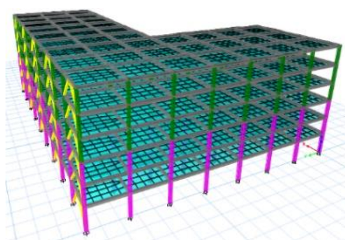
(a) Steel (Fe 250)

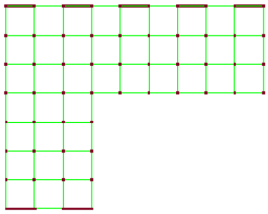
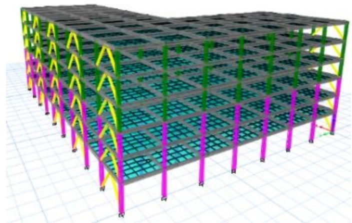
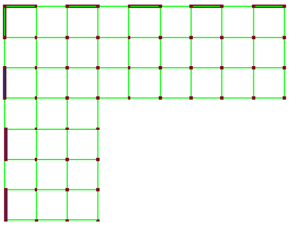
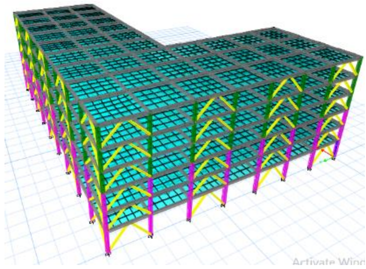
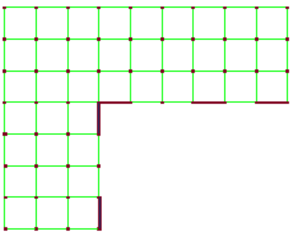
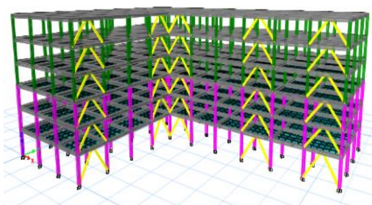
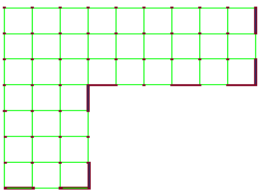
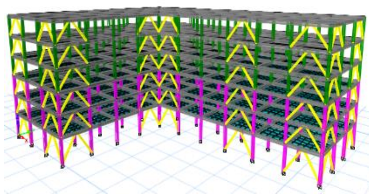
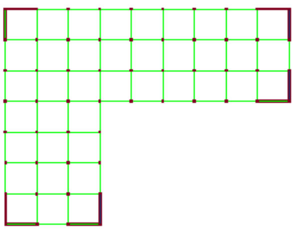
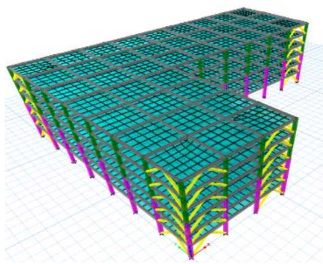


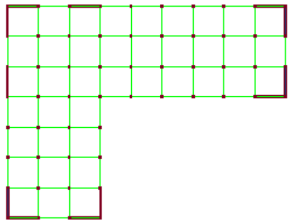
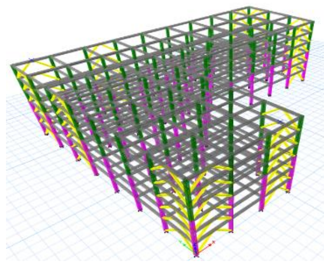
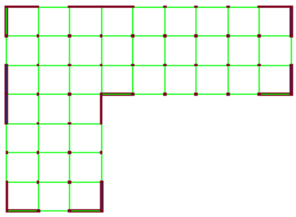
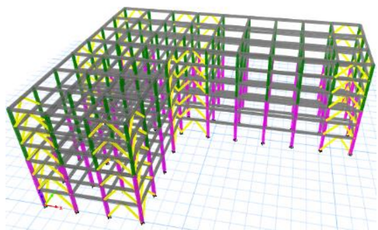
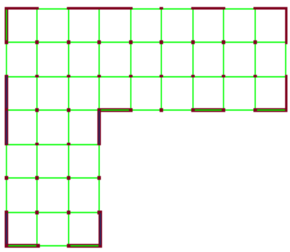
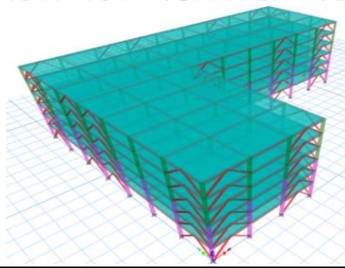
(b) Concrete (M25)

Fig. 1 Stress-strain diagram for a) steel and b) concrete.

Table 3. Plans and 3D views of proposed buildings

Models	Plan View	3D view	Remarks
L1			#Without braced moment-resisting frame. # Dimension in meter (m)
L2			# Inverted V bracing are applied only left portion side as shown in Fig L2. # Bracings are used in four bays
L3			# Bracings are applied in the left portion side (same as L2) and right portion side (2 bays) shown in plan view.
L4			# Bracings are applied upper portion (5 bays) of the plan view only.

L5			# Same as L4 but additional 2 bottom bays are braced.
L6			# Bracings are used left and an upper portion only. # It is the Combination of L2 and L4 configurations of bracings.
L7			# Bracings are applied as shown in Fig L7.
L8			# Bracings are applied right and bottom portion of L shape buildings.
L9			# Bracings are applied only outer corner portion of L shape buildings.

L10			# Same as L9 and additional 2 bays (see fig L10 plan views) are braced. # Slabs are hidden.
L11			# Bracings are used symmetrically and a total of 16 bays are braced.
L12			# Same as L11 and additional 2 bays are braced. # Total 18 bays are braced.

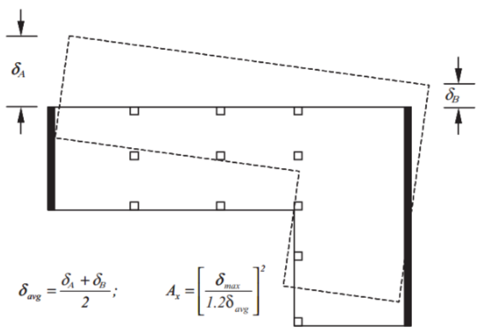


Fig. 2 Torsional irregularity calculation of the L shape buildings [46].

4. Result and Discussion

The L shape buildings are analyzed with different braced configurations by using the ETABs software. The various seismic parameters are observed such as Fundamental time periods, base shear, inter-story drifts, and torsional irregularity, stiffness and column forces to understand the effect of inverted V bracings in L shape RC buildings.

4.1. Design Base Shear Variations

The base shear is the lateral total force at the base of the structures induced due to the earthquake ground motions and it depends upon the plan shape of the structures, fundamental time periods and soil types of the sites. It also depends upon the seismic weight of the structures. in the study, the two cases are analyzed where the in case I, the inverted V bracings are used such a that it only applied in the incomplete ways or only added the bracings in a single axis of the structures and in case II the bracings are applied in both the directions as shown in Table 3. In both cases, the design base shear is observed in both directions as shown in Fig 3. It is observed that adding the steel bracings increases the base shear values of the structure and similar results also observed in [28], [31]. In model L3, the bracings are added in such a way that it resist the lateral load along the y-axis. So the in the L3 models the base shear values are more along the y-axis as compared to the x-axis. In models L4 and L5, bracings are added to resist the lateral load along the x-axis only so that only along the x-axis, the base shear values are more as compared to the y-axis. However in the model L1, which is represented without braced frame L shape buildings. In the L1 model, almost the same design shear forces are observed. In the models, L9 to L12 (case II) almost similar base shear values are observed in both the x and y-axis.

4.2. Fundamental Time Periods (FTP)

The seismic behaviors of the structures depend upon the FTP of the structures and the base shear of the structures also depends upon the natural time period of the buildings. Normally to calculate the FTP of the buildings, the code provided the empirical formula is used but in this study program based natural period of building is considered. However the formula is only for regular structures, the code-provided formula does not give accurate FTP for structures when the buildings are irregular and braced [13], [15]. Fig 4 shows the variation of the fundamental time period of the structures on both the x and y-axis. Fig 4 it is clear that where the steel bracings are used to resist the lateral load, the fundamental time period at that axis is decreased however the base shear at that axis increases. When the steel bracings are provided in both axis, in models L9 to L12, the fundamental time period of the structures is decreased and observed minimum in the L12 model.

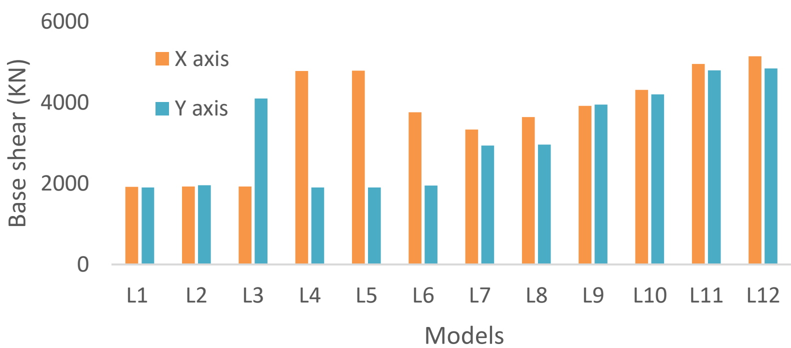


Fig. 3 Base shear variations along the x and y-axis in different models.

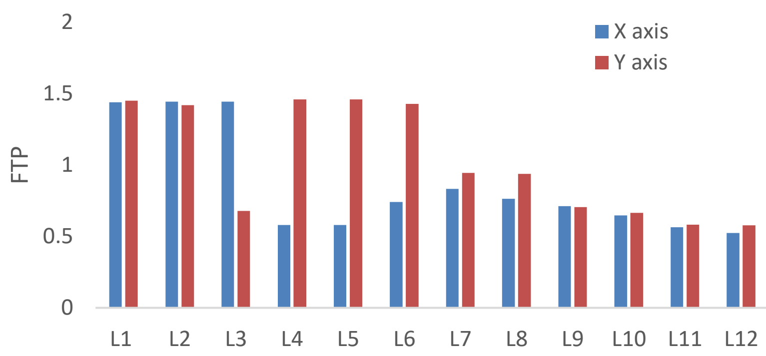


Fig. 4 Fundamental time periods of the different models

4.3. Maximum Displacements Response

The story displacements of the irregular structures subjected to lateral loadings are a significant parameter for buildings design. The top story displacements response of the structures helps to understand the damage level of the structures [31]. While designing the structures, the lateral deformation and drift of the structures should be considered carefully, avoiding excessive deformation in the structures. In irregular structures, excessive deformations damage the structural and nonstructural members in the buildings. Fig. 5 and Fig. 6 show the maximum displacements in the L shape buildings.

Fig.5 shows that the maximum displacements in the different models in both x and y directions. It is noticed that adding steel bracings in different positions, affected the maximum displacements of the structures. In case I (L2-L8) adding the steel bracing in the model L1, does not show as much effective control in the maximum displacements. Even due to the torsional effect, in the model L4 along with the x directions, the maximum displacements increase as compared to the L1 references model. In the L4 models as shown in Fig. 1, the bracings are added that to resist lateral load along the x-axis, however, due to the torsional effect, it amplified the displacements which is not good. The re-entrant corner behavior amplified the displacement along the x-axis [17]. It is noticed that in the case II (L9-L12) models, the steel bracings effectively reduced the maximum displacements [31] as shown in Fig. 5 and 6. In the models L9, L10, L11 and L12, it can be noticed that the maximum lateral displacements are decreased by 40%, 47%, 51% and 54% along the x-axis and 42 50 46, and 46 along the y-axis after adding (retrofitting) the steel bracing in L1 models respectively. The steel bracings are added along the x and y-axis properly shows good seismic behaviors and reduced displacements effectively. In case I the maximum displacements are observed as 43mm along with x directions due to the lateral-torsional vibration coupled behavior in the L shape of soft-story buildings. In case II the displacement gets its maximum value of 15.5mm for the L9 model, and the minimum value of 12 mm for the L12 model along the x-axis. And the similar response is observed in y directions as shown in Fig 5 and 6. By comparing the maximum displacements of 6 story L shape soft-story buildings with different braced configurations (see Table 3), it is observed that inverted V bracings used properly in the L shape RC buildings reduce the maximum lateral story displacements in the models.

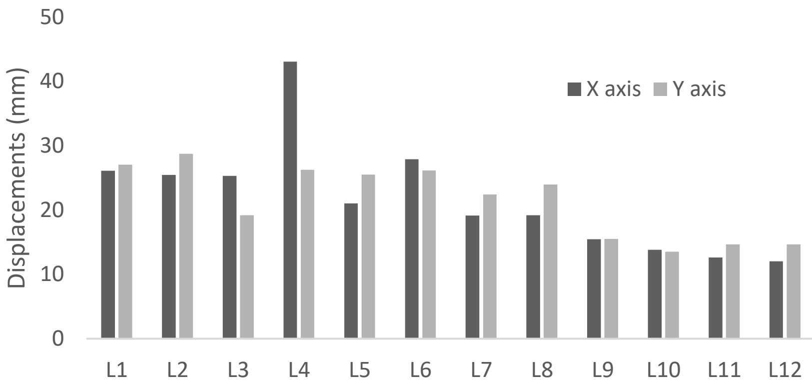
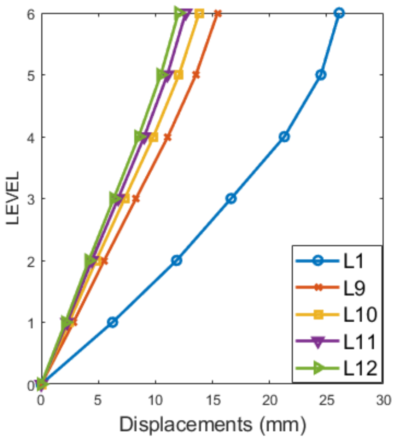
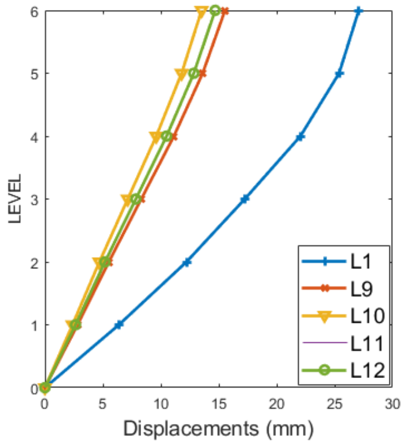


Fig. 5 Maximum top story displacements along the x and y-axis.



a) Case II (x axis)



b) Case II (y axis)

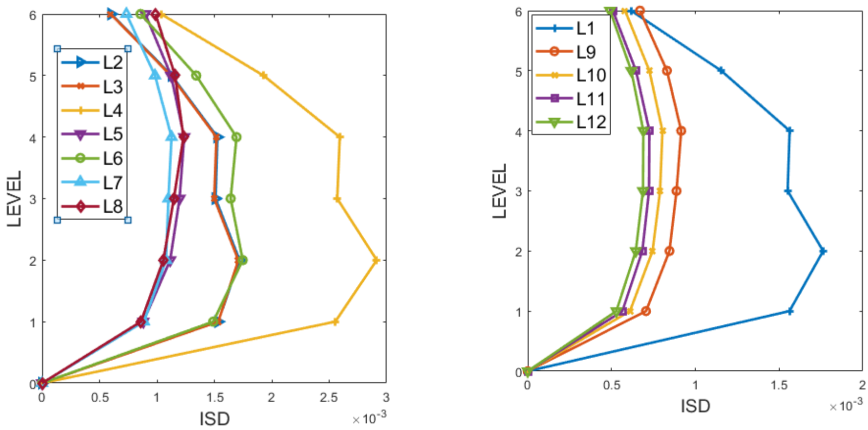
Fig. 6 Maximum story displacements in case II along both axis.

4.4. Inter Story Drift Ratio

Inter story drift is another important significant parameter for examining the structural behaviors effectively. The inter-story drift (ISD) is the more reliable parameter to observe the structural and nonstructural damage as compared to the displacements [31].

The story drift of the L shape 6 story irregular buildings is observed with steel bracing in different configurations. The graph is plotted for both case I and case II as shown in Fig. 7 and 8. It is observed that the ISD of all models are under the drift limits 0.004 as the Indian code [45] suggested. In all cases, the maximum drift is observed in the second floor or third-floor level and it is due to the soft story in base level. It is also noticed down the uniform drift is observed where the steel bracings are used for resisting the lateral load. Without steel braced frames L1 and braced frames L2 to L12, RC L shape buildings are compared. The inter-story response decreased in case II when the steel bracings are used. It is observed that in the L shape buildings in case II the maximum ISD of 0.000888, 0.00079, 0.000724 and 0.000688 along the x-axis and 0.000887, 0.00077, 0.000845 and

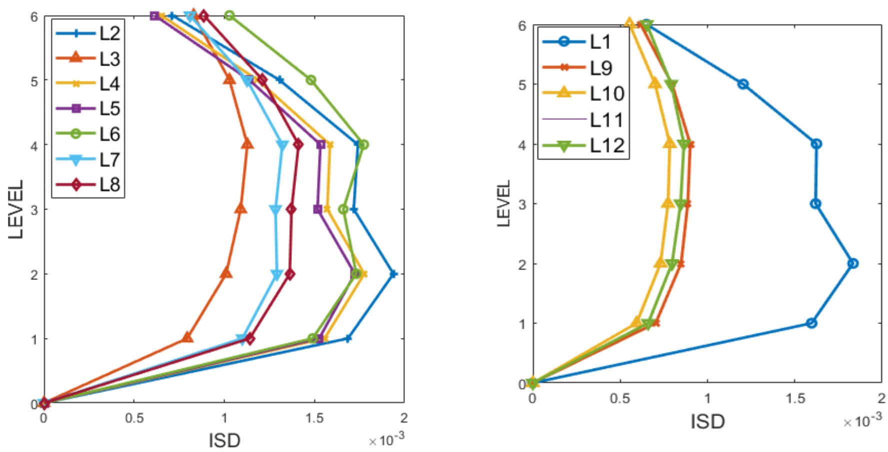
0.000846 along the y-axis for models L9, L10, L11 and L12 respectively. As increased numbers of bays with steel bracings in the frames in both directions, the ISD of the models decreases more. Similar to the maximum displacements in case I, model L4 show a maximum ISD of 0.0026 along with the x directions as shown in Fig 7(a). Which is greater than the drift limit of 0.002 for inverted V bracings in RC buildings [32], [34]. Overall in case II Fig 7(b) and 8(b) shows that adding the steel bracings properly in the RC buildings decreased the ISD of the structures effectively. However the case I should be shows unpredictable ISD of the structures due to the torsional behaviors in these models.



a) Case I

b) Case II

Fig. 7 Inter story drift of the L shape buildings along x axis in both cases



a) Case I

b) Case II

Fig. 8 Inter story drift of the L shape buildings along the y-axis in both cases.

4.5. Story Stiffness Response

Story stiffness of the buildings depends upon the size, shape and length of the columns or bracings. Fig.9 represents the variation of story stiffness of each model. The maximum x-direction story stiffness demands almost the same for L1, L2 and L3 models. The maximum story stiffness of the model L4 is increased by 2.18 times of L1. Similarly for L5 to L12 story stiffness increased by 5, 2.8, 3, 4, 4.9, 5.6, 7 and 8.25 times of L1 respectively along x-direction (see Fig. 9). Along the y-direction, the story stiffness observed in L1, L4 and L5 are almost equal. The maximum story stiffness along the y-axis of models L2 and L3 are increased by 1.5 and 5.12 times of L1. And similarly, for models L6 to L12, the maximum story stiffness are increased by 1.6, 2.4, 2.9, 5, 5.7, 6.7 and 6.8 times of L1 respectively along y-direction (see Fig. 9). It is noticed that adding the steel bracings in the models to resist the lateral loadings, increases the story stiffness of the buildings. In case II, the increasing the stiffness of the story in each direction, noticed more uniform. The minimum story stiffness is observed in the model L1 and maximum in L12, which is retrofitting by steel inverted V bracings.

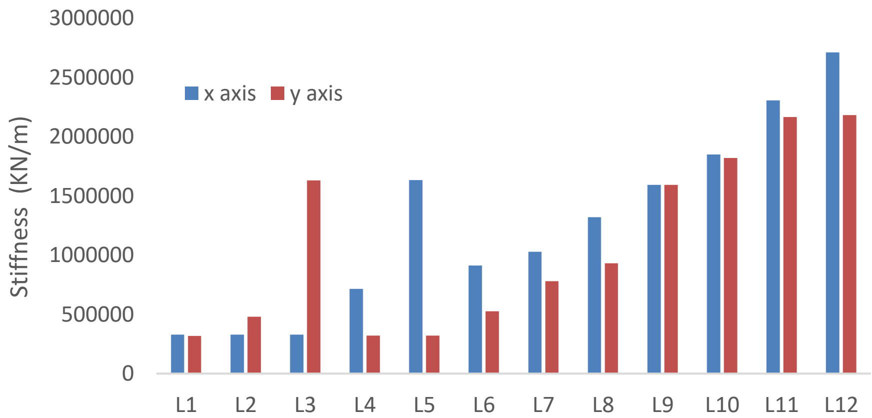


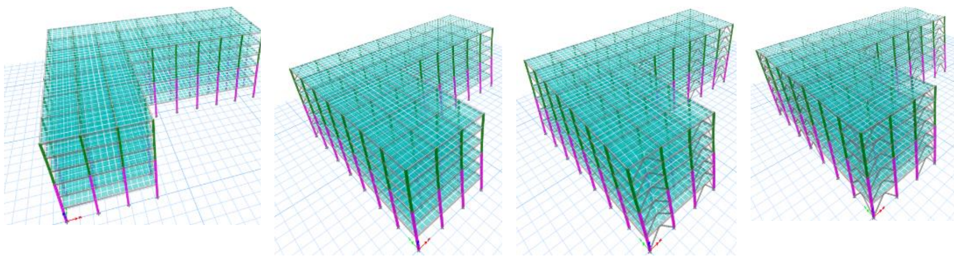
Fig. 9 story stiffness of the models

4.6. Torsional Irregularity Ratio

The torsional irregularity ratio of the structures gives the most important information about buildings' damages levels during earthquake loading. It is an analytical index, created based on the structural response, multidirectional response of the asymmetry structure. The different studies studied the limit of torsional irregularity ratio which is 1.2 [13], [14] and [17]. It means when the torsional irregularity ratio limits exceed such structures is affected by differential displacements in the plan. It affects the seismic behaviors of the structure. When the torsional irregularity ratio is less than 1.2, there is no torsional irregularity exist in the buildings [46].

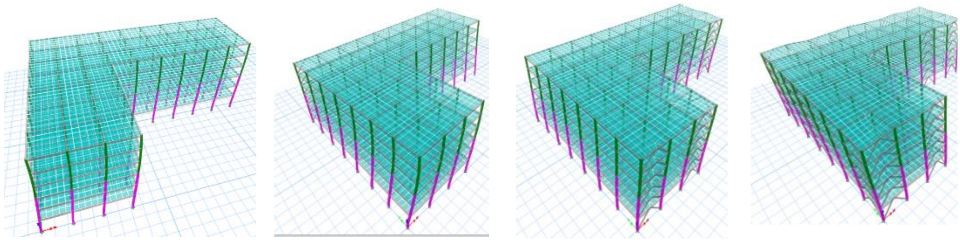
Figure 10 shows the first mode and second mode of vibration for the selected models L1, L4, L8 and L12. The models are selected every fourth model and also these models possess a considerable torsional irregularity ratio. This mode shape shows the analytical fundamental time period for the first and second mode of vibration. These 3D views also show the torsional behaviors of the structures. Fig 11a and 12a show the torsional irregularity ratio for L shape braced and without braced frames along with the story of the buildings. The torsional irregularity ratio changed over the building story height. In some models lower story shows a more torsional irregularity ratio than the upper story. It may be due to the L shape projection of the buildings and the lower story is created as a soft story. The maximum torsional irregularity ratio when unidirectional spectrum used along the x-axis for the case I are 1.01, 1, 1.53, 1.43, 1.44, 1.11 and 1.25 for models L2-L8 respectively. It is observed that model L4 shows the maximum torsional irregularity ratio in case I. However for models L1 show the safe torsional irregularity ratio (less than 1.2). In case I, L5, L6 and L8 have torsional irregularity ratios are greater than 1.2 along the x-axis and along the y axis L2, L3, L6 and L8 have torsional irregularity ratios that are more than 1.2 (see Fig 11 and 12). In case I, these models represent the incomplete braced frame configurations, hence shows torsional irregularity in the structures. The model L4, along the x-axis, further studied the torsional amplification factors because the model L4 has a greater torsional irregularity ratio (>1.2). Table 4 shows the amplification factors for L4 models and the torsional amplification factors are greater than 1 and less than 3. Similarly for model L3 in Table 5 shows the torsional amplification factors.

In case II, only the L12 model shows the Torsional irregularity ratio greater than 1.2 and its torsional amplification factors are given in Tables 6 and 7, which are within the limits. Fig 11b and 12b show the L12 buildings have maximum torsional irregularity ratios are 1.33 and 1.51 for the x and y-axis respectively. Other models L9, L10 and L11 show better torsional behavior within limits. Models L9-L11 have provided suitable bracing along the x and y-axis. It is observed if carefully bracings are applied in the L shape RC buildings shows good seismic behaviors. The buildings shows torsionally safe and have minimum displacements and drifts. The steel bracings improve the stiffness and torsionally safe (if properly applied) have also better to use for a retrofitting purpose in irregular buildings.



L1, T= 1.457 Sec L4, T=1.46 L8, T=0.939 L12, T=0.578

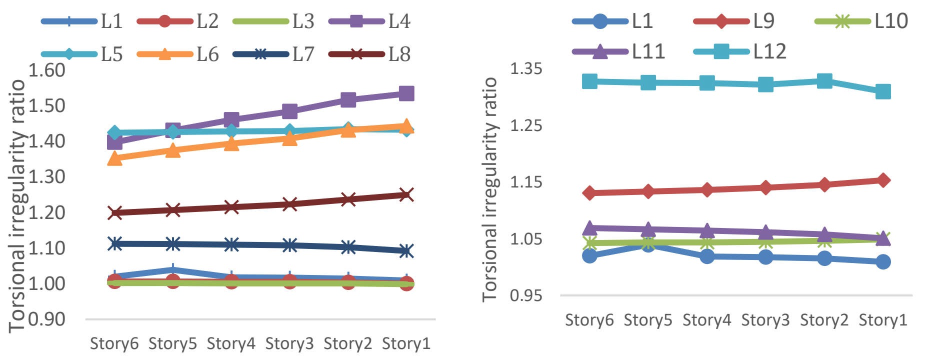
a) first mode shape



L1, T=1.441 sec L4, T=1.39 sec L8, T=0.764 sec L12, T=0.523 sec

b) Second mode shape

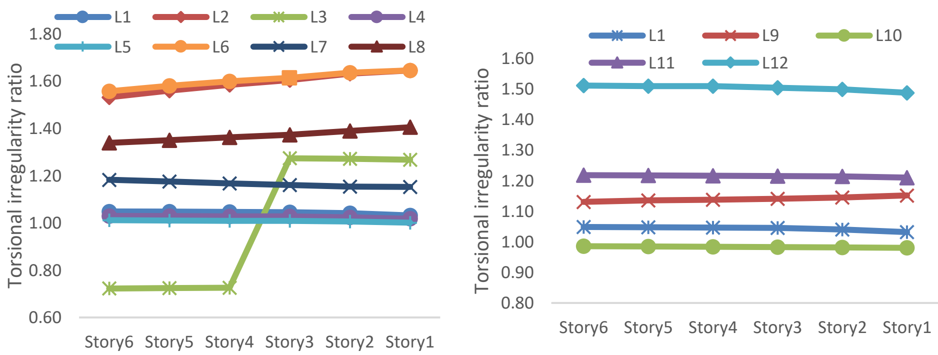
Fig. 10 View of mode shape of the studied buildings.



a) Case I

b) Case II

Fig. 11 Torsional irregularity ratio along the x-axis



a) Case I

b) Case II

Fig. 12 Torsional irregularity ratio along the y-axis

Table 4. Calculation of torsional irregularity and torsional amplification factors for L4 along x axis.

Δ_{max}(mm)	Δ_{min} (mm)	Δ_{avg}(mm)	$\eta_t = \Delta_{max}/\Delta_{avg})$	A_x
43.1	18.5	30.8	1.40	1.36
40.4	16.0	28.2	1.43	1.42
35.1	13.0	24.0	1.46	1.48
27.5	9.5	18.5	1.48	1.53
19.5	6.2	12.8	1.52	1.60
10.2	3.1	6.7	1.53	1.64

Table 5. Calculation of torsional irregularity and torsional amplification factors for L3 along y axis.

Δ_{max}(mm)	Δ_{min} (mm)	Δ_{avg}(mm)	$\eta_t = \Delta_{max}/\Delta_{avg})$	A_x
10.9	19.2	15.0	0.72	0.36
9.4	16.6	13.0	0.72	0.36
7.6	13.4	10.5	0.73	0.37
9.8	5.6	7.7	1.27	1.13
6.4	3.7	5.0	1.27	1.12
3.2	1.8	2.5	1.27	1.12

Table 6. Calculation of torsional irregularity and torsional amplification factors for L12 along x axis.

Δ_{max}(mm)	Δ_{min} (mm)	Δ_{avg}(mm)	$\eta_t = \Delta_{max}/\Delta_{avg})$	A_x
12.0	9.1	10.5	1.33	0.90
10.5	7.9	9.2	1.33	0.90
8.5	6.4	7.5	1.32	0.90
6.4	4.8	5.6	1.32	0.90
4.2	3.1	3.7	1.33	0.90
2.1	1.6	1.9	1.31	0.89

Table 7. Calculation of torsional irregularity and torsional amplification factors for L12 along y axis.

Δ_{max}(mm)	Δ_{min} (mm)	Δ_{avg}(mm)	$\eta_t = \Delta_{max}/\Delta_{avg})$	A_x
14.7	9.7	12.2	1.51	1.01
12.8	8.5	10.7	1.51	1.00
10.5	7.0	8.7	1.51	1.00
7.8	5.2	6.5	1.50	1.00
5.2	3.5	4.3	1.50	1.00
2.6	1.8	2.2	1.49	0.99

4.7. Columns Design Property

The reference model L1 and other braced models L2-L12, the columns, beams slabs and imposed loads are the same. The rebar in the columns is also fixed for all models all base columns have 3.8%. The columns are designed and sized properly in the L1 model. After adding the steel bracings in model L1 in a different way and named these models as L2 to L12. It is essential to study the columns for their safety based on capacity ratio, design moments and design axial loads [30]. The effect of steel inverted V bracing in the column is observed by investigating the capacity ratio, axial load and moment in the selected columns (corner columns may or may not be directly connected to the bracings) as shown in Fig 13. C1, C2, C3 and C4 are the corner base column and their design parameter variation are observed in models L1 to L12 to compare each other.

Table 8 shows the design axial load, design moment and capacity ratio in each selected column in models L1 to L12. It is observed that when the columns are connected to the bracings, the axial load in the columns increase. The axial load in model L1 is 1778 KN and model, L12 has 2200 KN for C1 columns, which shows the bracing increases the axial load in the columns. When the columns are near the bracing configurations, the design moment in the column decreased. In table 8, observed that in the columns directly connected to the bracing, the design moment in the columns decreases and it also decreases the main rebar demand in columns. The capacity ratio of the columns indicates the stress condition. The capacity ratio of the model L1 is 0.738, 0.52, 0.51 and 0.51 for C1, C2, C3 and C4 respectively. Maximum stress is induced in the C1 columns, it is due to the re-entrant effect in corner columns. It is noticed that model L4 is overstressed. However for case II, properly braced models, the capacity ratio of the columns slightly decreased in columns and increases in C2, C3 and C4 columns. To reduce the torsional hazard level in the L shape buildings, the steel bracings should be used symmetrically to balance the torsional effect. If only one direction, the bracing has used some columns may be overstressed and fail. To design the L shape braced RC buildings the torsional effect should be considered carefully.

Table 8. selected columns for study and design parameter

Columns	Columns design parameters	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	L11	L12
C1	Axial force (KN)	1778	1778	1778	1785	1778	2194	2667	2696	2194	2194	2241	2200
	Moment (KN-m)	122	121	121	146	121	45	81	62	45	45	46	45
	Capacity ratio	0.74	0.74	0.74	0.80	0.74	0.69	0.88	0.86	0.69	0.69	0.71	0.69
C2	Axial force (KN)	649	645	1387	335	1955	987	622	1050	1797	1804	1721	1739
	Moment (KN-m)	137	170	59	206	62	150	120	72	51	46	47	46
	Capacity ratio	0.52	0.637	0.822	1.02	0.66	0.938	0.467	0.723	0.59	0.581	0.559	0.565
C3	Axial force (KN)	644	752	1972	1300	1964	1392	604	593	1980	1887	1782	1738
	Moment (KN-m)	135	132	40	115	46	42	94	96	53	46	36	35
	Capacity ratio	0.51	0.53	0.62	0.97	0.633	0.789	0.419	0.499	0.643	0.605	0.56	0.547
C4	Axial force (KN)	643	1409	1975	509	1534	831	576	1580	1861	1803	1649	1685
	Moment (KN-m)	135	73	40	305	66	121	94	97	53	44	42	34
	Capacity ratio	0.51	0.53	0.62	1.28	0.916	0.79	0.434	0.629	0.61	0.577	0.53	0.529

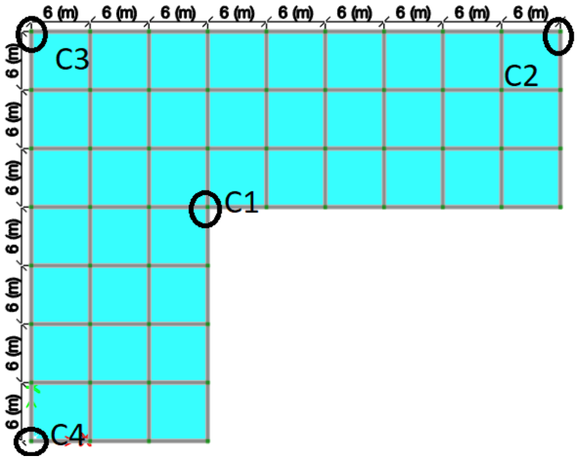


Fig. 13 Plan view with selected columns for study

5. Conclusions

The L shaped six-story building with the soft story in base level buildings are considered with and without inverted V steel braced RC buildings. A total of 12 models are considered which have been categorized into two cases, case I and case II. This study aims to understand the effect of steel bracings in irregular plan shape RC buildings. The modelling of the building is done in the ETABs software to determine the seismic parameter such as base shear, fundamental time period, maximum displacements, inter-story drift, stiffness, torsional irregularity ratio and columns forces (axial forces, moment and capacity ratio). The RSA is used in every 12 models and results are compared to each other in order to understand the effect of bracing in L shaped buildings. The followings conclusions are noticed in this study:

- As studying the effect of inverted V bracing in RC buildings the lateral base shear value is increased in the L shape buildings when the steel bracing is used. Especially in case II, the base shear value increases as increases the number of braced bays along the both directions. The fundamental time period of the structures decreased when the steel bracing used in the L shape buildings are effective.
- Providing the steel bracings in the L shaped RC buildings, reduced the maximum displacements in the buildings. The case II models shows the effective reduction of maximum displacements in the models. It is noticed that nearly 50% reductions in maximum displacements are observed as compared to the L1 model. If the bracings are provided symmetrically, it reduces the maximum displacements properly with a minimum torsional effect.
- As expected, adding the steel bracing as a retrofitting in the L shaped RC buildings, it decreased the ISD of the structures effectively if bracing is used properly. The maximum ISD of the structures is under the permissible limit (0.004 as IS suggested) is noticed. In case II, models show the minimum ISD of the structures. The maximum ISD is observed in the middle story of the structures.
- The steel bracings in the L shape buildings increase the story stiffness of the structures effectively. When the number of bays are braced, it also increased the stiffness of the buildings.

- The torsional irregularity ratios are studied in both case I and case II and it is found that case I shows an unexpected torsional effect. However, case II shows good seismic behaviors except for L12 models. As providing the steel bracing in L shape buildings (case II) shows the accepted torsional irregularity ratio. While using the steel bracings in the irregular building, the torsional irregularity ratio should check carefully.
- Column C1 shows the maximum axial forces and capacity ratio in the RC L shape structures. It is observed that incomplete adding bracing in the RC buildings affected that capacity ratio in the columns which is directly attached with bracings. In the C1 column adding steel, bracings reduced the capacity ratio in case II models. However, in C2, C3 and C4 columns, the capacity ratio of the columns increases slightly. It is also observed that adding the steel bracings in the models, increases the axial load and decreases the moment.
- As a general conclusion, it can be stated that retrofitting of 6 story L shape RC frame structures with inverted V bracing is beneficial to the structure if the position of steel bracing (L9-L12) is effectively used.
- The steel bracing is effectively used as retrofitting in L shape buildings if bracings are applied in the models appropriately. While designing irregular buildings with steel bracings, the torsional effect should be checked by the designer.

This research focuses on the effect of inverted V bracing in L shape RC structure with linear seismic response only. Therefore, the result from this study are limited to this case. However, further study is needed with nonlinear dynamic and static analysis methods. Also, it is necessary to study the interaction of columns and steel bracing connections and their effect in the overall structures. Indeed, future study is needed to ensure the ductility design of L shape RC buildings with inverted V bracing.

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