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Analysis on Seismic Behavior of Strong Column Weak Beam with Prediction of Storey Drift

Amisha Arjariya[1*z]
Research Scholar, Dept. of Civil Engineering, Ujjain Engineering College, Ujjain, M.P., India
Dr. Savita Maru[2]
Professor, Research Scholar, Dept. of Civil Engineering, Ujjain Engineering College, Ujjain, M.P., India

Abstract- This study investigates the strong column weak beam or capacity-based design of structure that is increasing commonly in earthquake resistance design. For making any structure earthquake resistant strong column weak beam design approach is good to hire because it takes less specialization in earthquake resistant design. Low to medium rise buildings are performing well for the seismic actions. The other method is to provide lateral load resisting element such as shear wall, dampers, base isolators etc. These methods of seismic resistance are costly and requires special attention while installation but the capacity based designed approach requires no extra element in frame although making existing frame elements to be stronger.
In this work, three type of plan irregularity i.e., "L" shape, "T" shape and "H" shape is being taken and those are being imposed over RC frame which has designed as strong column weak beam design criteria for four different heights of G+3, G+5, G+7, G+10 which are analyzed for increasing number of entrant corners and located at seismic zone IV. Linear static, linear dynamic and nonlinear static methods are used to analyze those models with help of ETABS software. Results which are discussed are modal analysis, storey drift, torsional ratio, ductility ratio, performance point and hinge results.
After analysis of results for different irregularly planed structure with different storey heights, it can conclude that irregularity does affect the strong column weak beam failure mechanism. Hence where ever there is an irregular structure to be designed as strong column weak beam design criteria there must be an analysis of it and design provisions should be mention explicitly.

KEYWORDS: Beam Design, Seismic Analysis, Ductility, plan irregularity, ETABS 19, Storey Drift.

I. INTRODUCTION

Seismic activity or earthquakes can be described as the shaking, displacement or cracking of the earth's surface due to movements within its crust. These "earthquakes" are caused by any transmission of a seismic wave through the Earth, and it is this energy that causes the Earth to move, warp, or ripple. Earthquakes are one of the major natural hazards to life on earth and have affected countless towns and villages on most continents. Earthquake damage is mainly man-made frenzied structures. Hundreds of small earthquakes occur around the world every day and every year earthquakes kill thousands of people. Therefore, it is necessary to design earthquake-resistant buildings. Seismic actions, it also reveals the uncertain nature of future seismic actions for which such structures must be designed. Thus, probabilistic concepts related to seismic actions and designs against seismic actions also emerged. Seismologists focus on global seismic problems and are more interested in geological aspects, including prediction of seismic action. On the other hand, seismic engineers are mainly concerned with the local effects of seismic actions that can cause significant damage to the structure. Convert seismic data to a format more suitable for structural failure prediction or safe structure design1.
The higher the ability of the structure to plastically deform without collapse, the greater the resulting ductility and energy dissipation. This leads to a decrease in effective seismic force. The strong column weak beam is based on the deterministic allocation of structural element strength and ductility for successful response and collapse prevention in the event of a catastrophic earthquake by rationally selecting a continuous region of energy dissipation so that pre-decided energy dissipation mechanism would hold throughout the seismic action2. Many researchers have worked in this area, some of them showing noteworthy outcomes are as mentioned in next section

II. LITERATURE REVIEW

Some of researchers have shown noticeable work in this field. **Firdose H. M. A., Kumar A S., Narayana G. and Narendra B. K. (2022**) did study on dynamic behavior of irregular RC framed structures with different location of shear walls. In the recent researches it was found to be the most appropriate loads resisting system in recent and present years is shear walls system. In the high-rise building shear walls are of the most achievable and hence commonly used lateral load resisting components. It is supplied in building from foundation level to through the height of the building. The scope of the present work is to find the optimum location of the shear walls in plan irregular structures with shear walls such as in I frame, L frame, T frame for different zones in G+17 stories each storey height of 3.2 m, Shear walls are given at corners and at periphery of the building. And also, the outcome of results in seismic zones as per IS CODE 1893(Part1): 2016 has been presented. The seismic analysis performed is linear dynamic response spectrum analysis utilizing the well- known analysis and design software ETABS 18.1.0. Seismic performance of the building has been examined based on specification such as storey displacement, Storey drift, Storey Shear, Base shear, Time period of modes**.**
Ma H., Liu C., Li Z., Han J., Chen S. (2021) studied about the influence of seismic input in the oblique direction on

the strong-column weak-beam mechanism for RC frame. The main flow of seismic input for building calculations is to conveniently use the X and Y directions. The X and Y directions are the main axes of the building, and the damage mechanism of the strong columns of weak beams is considered only for these main axes. However, the response of the building is higher in the diagonal direction than in the main axis, and the frequency in the diagonal direction of the building is also higher than in the X or Y direction. They discuss how oblique seismic input affects the damage mechanism of strong column weak beams in RC frames from the perspective of dimensional mechanical analysis, repeated load experiments, and finite element analysis of dimensional beam-column connections. Discussing from and taking into account the seismic input in the tilt direction is necessary in future structural planning to achieve actual strong column-weak beam dynamics.

Patil R. D., Mulay B. N., Patil S. K. and Pujari A. B. (2020) did study of torsional effects on unsymmetrical RC framed building. The main purpose of this study is to minimize the torsion ratio to the limit according to IS 1893: 2016 (Part 1) by changing the stiffness of the vertical elements of the planar composition. To this end, IS Code 1893: 2016 (Part 1) specifies guidelines. Following this, an L-shaped G + 15-story model will be created at ETAB 2017, using beam columns and plates, and beam shear wall and plate methods. The reaction reduction method is used for the analysis. The results are based on maximum bullet drift, mode pairs. Frequency and twist irregularities.

Teddy L., Hardiman G., Nuroji N., Tudjono S. (2019) attempts to calculate new method in calculating columns and beams dimensions that meets requirements of the strong column weak beam and non-soft story. This study is a review of three theories: 1) column and beam preliminary design theory, 2) strong column and weak column concept theory, and 3) soft projectile and column thinness theory.

Irfani M. M. A., Vimala A. (2019) tries to find the collapse mechanism of three buildings of 5, 12 and 15 floors for the concept of weak beams into strong columns. The aim of their work was to determine the nonlinear static performance of three buildings of different heights. Six structures were modelled of 5, 12 and 15 floors each with two strong columns with weak beam ratios of 1.2 and 1.4, a nonlinear analysis was performed on these structures and obtain the power curves as well as the collapse mechanism.

Liu Y., Liao Y., Zheng N. & Liu J. (2018) did an analysis on strong column and weak beam behavior of steel-concrete mixed frames. They investigated the pushover method used to analyze the damage mechanism of concrete-filled tubular steel columns (CFST) and reinforced concrete composite beams (CB). Their study analyzes the problem of strong columns and weak beams in CBC FST column composite frames. Describes the effect of the fracture moment ratio (columns and beams) on the structural failure mechanism.

Bento R. and Lopes M. (2018) worked on evaluation of the need for weak beam-strong column design in dual frame-wall structures. They stated that according to the principle of capacity planning for multi-layer frames, it is preferable to forcibly form plastic hinges on the beams in order to disperse the plasticity throughout the structure. This possibility was investigated using two frame structures. Two double frame wall systems were built across the height of the building without strength reserves and all elements were equipped with the same high ductility. Under these conditions, the results show that the formation of hinges at the ends of the beams leads to better seismic performance in both the frame structure and the double frame wall system than if the hinges were developed in support.

Gokdemir H., Gunaydin A. (2018) investigated on strong column – weak beam ratio in multi- storey structures. They investigated the effect of coefficient changes on column and beam moments according to the Turkish seismic code of practice. Using the package program SAP2000, they examined a four-story frame with a beam span of 4 m and a floor height of 3 m. Horizontal loads are calculated using the equivalent static load method. They found that the horizontal displacement of the SCWB (Strong Column Weak Beam) frame under seismic load is relatively small compared to the WCSB (Weak Column Strong Beam) frame under the same load.

Irwan R. J., Sjahril R. A, Yuskar L., and Hendro Y. (2018) did a comparison on fixed and isolated based L shaped planned structure. The selected research subject is, which is known as a lead rubber bearing (LRB) with a damping rate of 27%. Variations in wing length have been proposed to accommodate the study of the L-shaped. Six models serve as a six-story high office building. The three solid-based models are built in a dual system, and another three separate models are built with a linear distribution of lateral forces according to the ASCE 716 code. A3D non-linear time history analysis was performed on the separated model and the contains 7 sets of ground motions matched against the MCR target spectrum from Jakarta under soft ground conditions.

Lanjewar D. H. and Khedikar A. (2017) have done seismic analysis on unsymmetrical RCC structure. The 7 layouts of the G+10 storey building was shot with one regular floor plan and the other irregular floor plans (C, E, H, L, T, PLUS, shape). The plan area of each structure is the same, only the geometry is different. The height is the same for all models. Static and dynamic analyses were performed on a computer using STAAD.Pro software with parameters for calculations according to IS 1893 2002 Part1. Estimate the seismic characteristics of structures of various shapes located in the strong earthquake area and the mild earthquake area, and compare the calculated lateral shear force, period, joint displacement, etc. The analysis uses response spectrum analysis.

Wongpakdee N. and Leelataviwat S. (2017) studied about influence of column strength and stiffness on the inelastic behavior of strong column weak beam frames. This study investigates the inelastic behavior of SCWB frames with different distributions of beam and column plastic strengths at different ductility demand levels. They found that the value of beam column capacity ratio (ωr) must be carefully chosen during design to ensure a desirable SCWB behavior because for frames with low ωr values, deformation tended to be concentrated in the lower stories. For frames with high ωr values, the deformation was concentrated in the upper stories. Kim J. and Choi Y. (2017) studied about the seismic performance of a staggered wall structure designed with conventional strength-based design, and compares it with the performance of the structure designed by capacity design procedure which ensures strong column-weak beam concept. They found that structures designed for strength failed mainly due to failure of the outer columns, while in structures designed for capacity, the drop in strength occurs due to the breakdown of the outer columns. Fragility analysis shows that the probability of achieving dynamic instability is highest in structures designed to be loaded and lowest in structures with friction dampers.

III. SEISMIC RESISTANT DESIGN OF STRUCTURES

In seismic design, problems are somewhat complicated by the greater uncertainty surrounding appropriate design load estimates as well as the capabilities of structural members and connections. However, the information accumulated over the past three decades from analytical and experimental studies, as well as the assessment of structural behavior in recent earthquakes, has provided a solid basis for solving the problem, this particular in a more sensible way. As with other growing areas of knowledge, improvements in design approaches can be expected as more information is accumulated about earthquakes and the response of specific structures to seismic-like loads. The design problem of reinforced concrete buildings subjected to earthquakes, such as the design of structures (concrete, steel or other material) for other loading conditions, is essentially the determination of forces and/or deformations expected in a preliminary design and provided for these conditions by properly proportional and detailed allocation of members and their connections.

IV. MODELLING AND ANALYSIS

the 3D building model which is based on capacity-based design (strong column weak beam) criteria analyzed using the Pseudo Static method (Linear static analysis), Response Spectrum method (Linear dynamic analysis) and Push Over analysis (Nonlinear static analysis). The building models of varying plan irregularities having "L" shaped, "T" shaped and "H" shaped plan of different storey height as G+3, G+5, G+7, G+10 is analysed using ETABS v19 software. The seismic codes are unique to a particular region of the country. In India, Indian standard for design of seismic structures IS 1893:2016 is used which is the main standard that provides the outline for the calculation of seismic design forces and for achieving strong column weak beam design concept.

TABLE 1
Nomenclature of different models consider for analysis

SN	Model Name	Height	Irregularity
1.	L 1	G+3	L shaped
2.	L 2	G+5	L shaped
3.	L 3	G+7	L shaped
4.	L 4	G+10	L shaped
5.	T 1	G+3	T shaped
6.	T 2	G+5	T shaped
7.	T 3	G+7	T shaped
8.	T 4	G+10	T shaped
9.	H 1	G+3	H shaped
10.	H 2	G+5	H shaped
11.	H 3	G+7	H shaped
12.	H 4	G+10	H shaped

TABLE 2
Data for Analysis of R.C. Frame

SN	Particulars	Type	Dimension/ Value
1	Plan Area	L shape	720 m^2
		T shape	720 m^2
		H shape	720 m^2
2	Height of the building	G+3	12 m
		G+5	18 m
		G+7	24 m
		G+10	33 m
3	Height of base storey	-	3 m
4	Height of each storey	-	3 m
5	Height of parapet		1.2 m
6	Thickness	Slab	150 mm
		Walls	230 mm
7	Length of Beam	-	4 m
	Seismic zone	-	IV
	Importance factor	-	1.5
	Zone factor	-	0.24
	Damping ratio	-	5%
8	Floor finish	-	1.0kN/m2
	Live load at all floors	-	3.0 kN/m
	Wall load	-	21 KN/m
	Parapet wall	-	9 KN/m
	Density of concrete	-	25 kN/m3
	Density of brick	-	20 kN/m3
9	Grade of concrete	column	M30
		Beam	M30
		Slab	M30
	Grade of	reinforcing steel	HYSD 500
		tie steel	Fe 450
10	Soil condition	-	Medium soil (TYPE II)

TABLE 3
Section Property of Beams and Columns

SN	*Model*	Beam	Column
1.	L 1	200 X 250	450 X 450
2.	L 2	200 X 250	500 X 500
3.	L 3	200 X 300	500 X 500
4.	L 4	200 X 300	700 X 700
5.	T 1	200 X 250	450 X 450
6.	T 2	200 X 250	500 X 500
7.	T 3	200 X 300	525 X 525
8.	T 4	200 X 300	700 X 700
9.	H 1	200 X 300	475 X 475

10.	H 2	200 X 300	500 X 500
11.	H 3	200 X 300	550 X 550
12.	H 4	200 X 300	750 X 750

V. BRIEF DISCUSSION ABOUT MODELLING PROCEDURE FOR ACHIEVING STRONG COLUMN WEAK BEAM IN RC FRAME AS PER IS 13920: 2016

First the general steps are followed in ETABS to made the model for analysis such as defining grids and height of the frame. Then define the materials and section property (beam, column and slab section). Then draw the model and apply the loads as per IS 875: 1987 (Part 1 and 2) for fixed support condition. In the design preferences of concrete frame design, enable the option of P- delta effect and B/C ratio, disable the option of consider additional moments. Then define the mass source of frame system. Then model is analyzed and designed as per IS 456: 2000, IS 1893: 2016 (Part 1) and IS 13920: 2016 for linear static and linear dynamic seismic analysis. Then this model is checked for column beam capacity ratio which should be greater than 1.4 for all joint. After satisfying the column beam capacity ratio for all the joints and members are passed for seismic analysis, push over analysis of displacement control methodology will carry out. In this type of push over analysis procedure first define the dead load as nonlinear static load in load case type. Then define the push in x direction and in y direction of displacement control of 300 mm to 500 mm depends upon the performance point found. Define plastic hinges in beam and column at 10% distance form either side as per ASCE 41-13. After meeting performance point (as per FEMA 440) hinge results are checked for different minimum performance objective (e.g., I.O., L.S., C.P.) as per ASCE 41 and FEMA356. After hinge results, ductility ratio, moment rotation and back bone curves are analyzed. Different analysis results of linear static and linear dynamic are also analyzed for storey drift and mode vs frequency. Since the frame is irregular in plan torsional analysis is also considered.

- **Model L 1**

In this model, “L” shaped plan irregularity with one entrant corner and height of 4 stories (G+3) is being considered for analysis.

- **Model T 2**

For this model, plan irregularity is “T” shaped which has two entrant corners back-to-back. Height of 6 stories (G+5) is being taken.

- **Model H 3**

For this model, 8 story height (G+7) is being adopted for analysis. “H” shaped plan irregularity has four entrant corners.

- **Model L 4**

This model also has L shaped plan irregularity but height is 11 stories (G+10).

Figure 3.7 Showing column beam capacity ratio for model L 4.

Defining mass source as 100 % of dead load and 50% of live load under specified load pattern and named it as “MaSrc1”. Select this mass source for all calculations of push over and seismic analysis.

S. No.	Model Name	Height	Irregularity
1.	L 1	G+3	L shaped
2.	L 2	G+5	L shaped
3.	L 3	G+7	L shaped
4.	L 4	G+10	L shaped
5.	T 1	G+3	T shaped
6.	T 2	G+5	T shaped
7.	T 3	G+7	T shaped
8.	T 4	G+10	T shaped
9.	H 1	G+3	H shaped
10.	H 2	G+5	H shaped
11.	H 3	G+7	H shaped
12.	H 4	G+10	H shaped

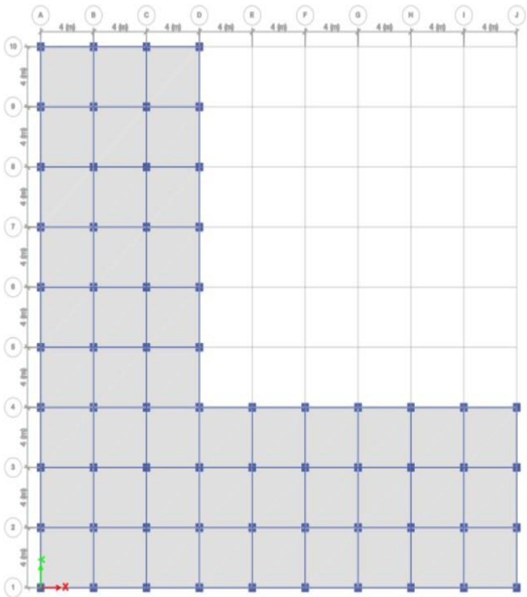

Figure - Showing layout of L shaped irregularity of model.

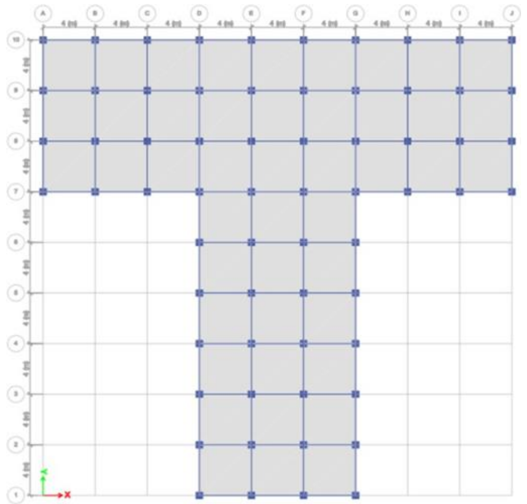

Figure - Showing layout of T shaped irregularity of model.

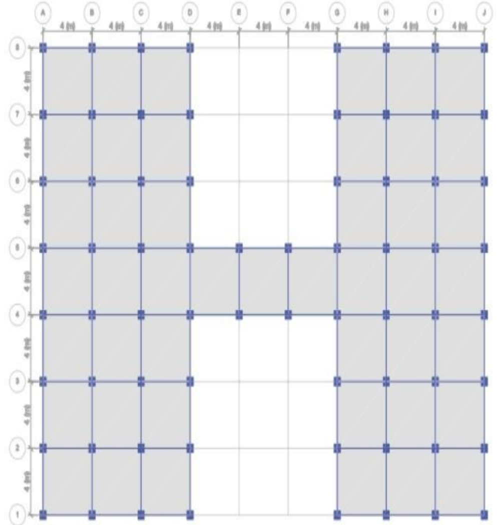

Figure - Showing layout of H shaped irregularity of model.

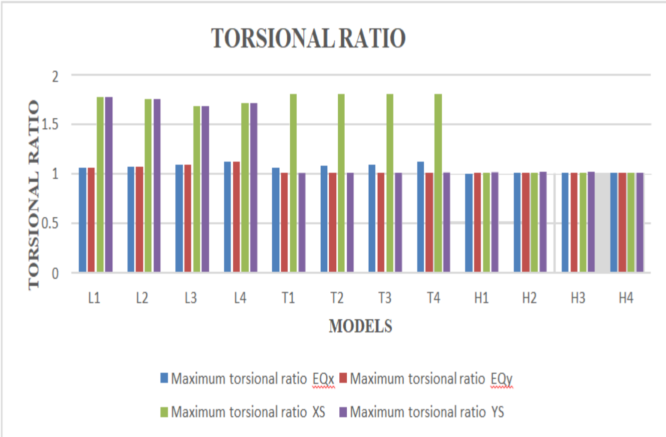

Figure - Showing torsional ratio for all twelve models

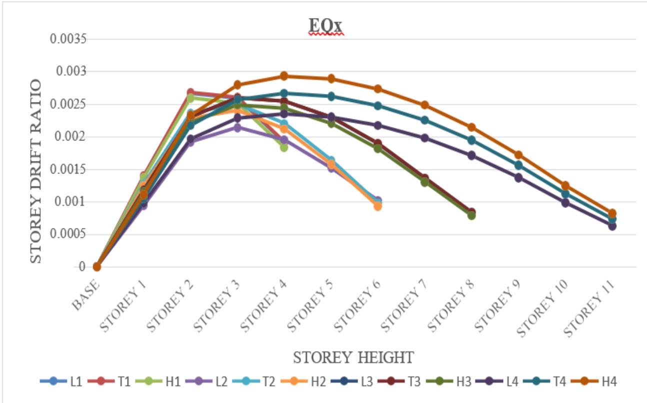

Figure - Showing storey drift ratio in X direction for linear static analysis

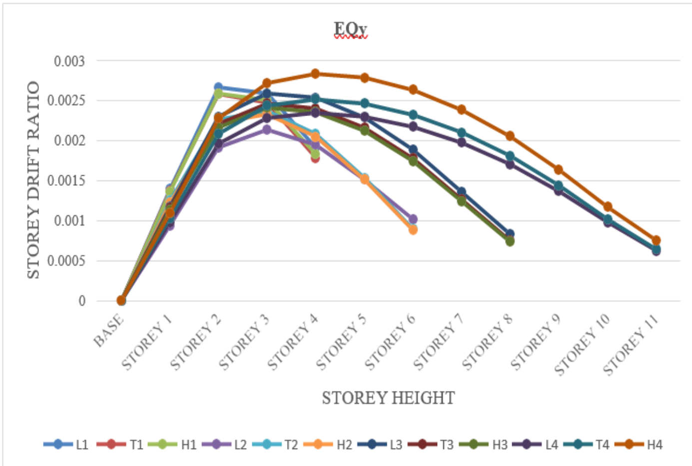

Figure 4.4 Showing storey drift ratio in Y direction for linear static analysis

RESULTS

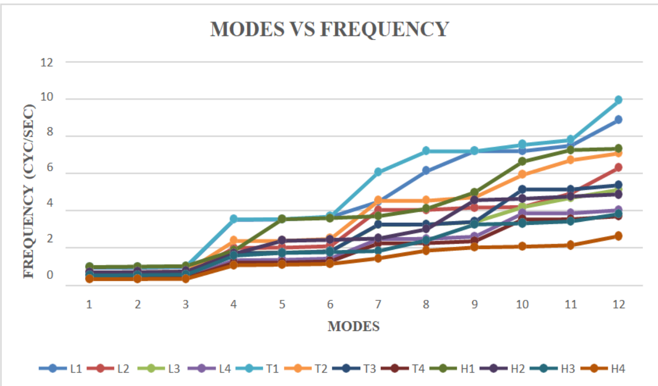

Figure - Showing frequencies of models for all 12 modes

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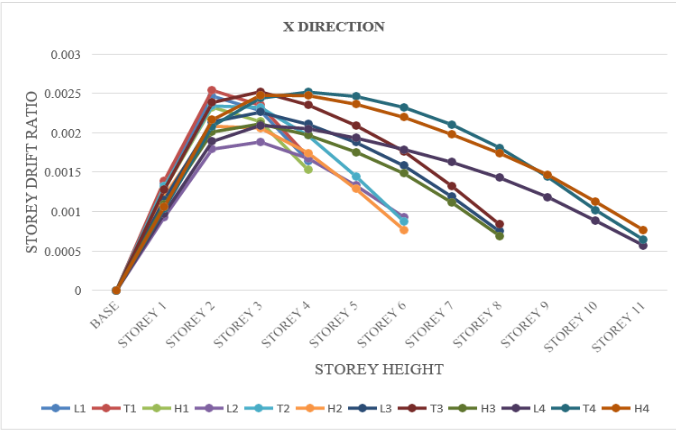

Figure - Showing storey drift ratio in X direction for linear dynamic analysis

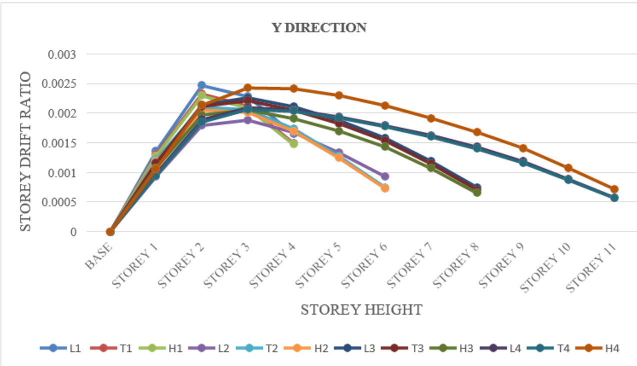

Figure - Showing storey drift ratio in Y direction for linear dynamic analysis

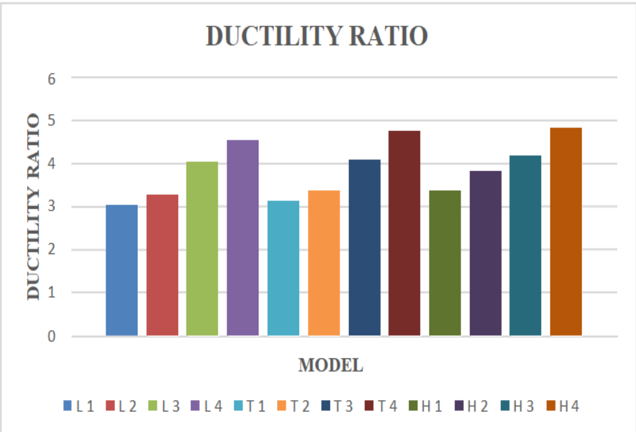

Figure - Showing ductility ratio of all twelve models for push Y

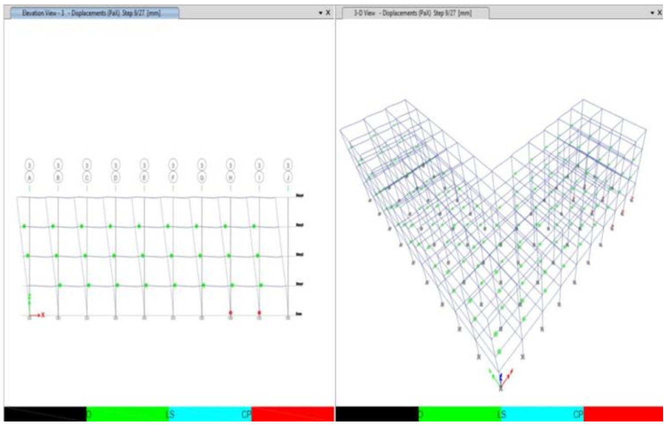

Figure - Showing hinge results of models L 1 for push X

Step	Monitored Displ (mm)	Base Force KN	A-IO	IO-LS	LS-CP	>CP	Total
0	0	0	2752	0	0	0	2752
1	-22.5	2323.9228	2752	0	0	0	2752
2	-45	4647.8455	2752	0	0	0	2752
3	-58.746	6067.5697	2752	0	0	0	2752
4	-66.402	6619.776	2752	0	0	0	2752

	d Displ (mm)	Force KN	O	S	P		al
0	0	0	2752	0	0	0	2752
1	-22.5	2323.9228	2752	0	0	0	2752
2	-45	4647.8455	2752	0	0	0	2752
3	-58.746	6067.5697	2752	0	0	0	2752
4	-66.402	6619.776	2752	0	0	0	2752

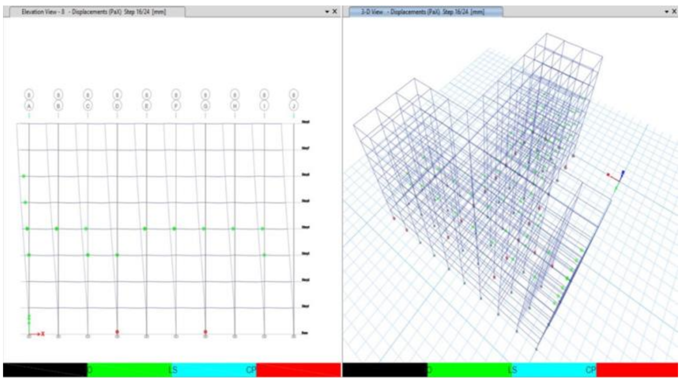

Figure - Showing hinge results of models T 3 for push X

VI. CONCLUSION

- Frequency of models increases from irregularity type "L" to type "T" and decreases form type "L" to type "H". Average increment of frequency on irregularity type "L" to type "T" for average three fundamental modes is 6.8% and drastic decrease over type "T" to type "H" by 75%. Explanation to this decrease because of stiffness and stability achieving from the type of irregularity "H" possesses.
- In a similar manner, average decrease in frequency of irregularity type "L" is 18.2%, for irregularity type "T" decrease is 17.03% and for type "H" it is 4.5% as the height increases. This result leads to a conclusion that type "H" irregularity behaves as a stable and stiff structure for all three fundamental modes.
- All twelve models are showing torsional ratio less than 1.5 in linear static seismic analysis.
- For linear dynamic analysis in X direction spectral acceleration average increase in torsional ratio for irregularity type "L" to type "T" is 4.05% and torsional ratio increment for irregularity type "T" to type "H" is 79%.

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