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# Seismic Behaviour of Plan-Symmetric and Plan- Asymmetric Buildings

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**Abstract -** *Seismic analysis of structures has always been an important branch of civil engineering in general and structural engineering in particular. Also the studies conducted regarding the effect of seismic forces on structures with respect to variations in structural properties like mass regularity, plan regularity.., etc. show that there is a large scope of research in the said field. With these points in mind this research in the field of seismic analysis of structures with plan-irregularities and varying diaphragm conditions saw a start. This document discusses a part of the ongoing research work of the authors entitled with the same title as that of this paper. The discussions include the effect of variation in rigidity of diaphragms, effect of orientation of columns and direction of application of forces on the seismic behaviour of various shapes of plan- symmetric and plan-asymmetric buildings considered in the study. This paper particularly discusses the variation in lateral displacement at different strategic positions in the various structural models considered in the study with varying conditions of plan symmetry, diaphragm rigidity and column orientations under the action of incremental horizontal seismic forces along both mutually perpendicular directions. The analysis tool used in this research is ETABS-2015 and the method of seismic analysis used is Non-linear Static Analysis also known as Pushover Analysis.*

***Key Words***: seismic behaviour; pushover analysis; plan irregularities; diaphragm rigidity; and ETABS 2015

## 1.INTRODUCTION

Seismic analysis generally refers to a subset of structural analysis which deals with the calculation of the response of a structure subjected to seismic loads (usually in the form of earthquakes). Seismic analysis of structures has always been an important branch of civil engineering in general and structural engineering in particular. Also the studies conducted regarding the effect of seismic forces on structures with respect to variations in structural properties like mass regularity, plan regularity.., etc. show that there is a large scope of research in the said field. Thus with these points in mind the authors started this research in the field of seismic analysis of structures with plan-irregularities and varying diaphragm conditions. The paper particularly discusses the variation in lateral displacement at different strategic positions in the various structural models considered in the study with varying conditions of plan symmetry, diaphragm rigidity and column orientations under the action of incremental horizontal seismic forces along mutually perpendicular directions (i.e. both X and Y directions). The analysis tool used in this research is ETABS-2015 and the method of seismic analysis used is Non-linear Static Analysis also known as Pushover Analysis. ETABS is an engineering software product that may be used in the design and analysis of multi-storeyed buildings. It is a product of Computers and Structures, Inc. (CSI), a structural and earthquake engineering software company founded in 1975 by Mr. Ashraf Habibullah and based in Walnut Creek, California with an additional office located in New York. ETABS 2015 is an improved version of the earlier software package series named ETABS which also include earlier versions from the years 2009 and 2013, the latest version of the software being that from the year 2016. Professor S K Duggal classifies the seismic analysis methods into two major categories based on the linear and non-linear nature of analysis, and further into two sub-categories under each major category based on the static and dynamic nature of the analysis. In general, linear procedures are applicable in cases where the structure is expected to remain elastic throughout the analysis or in cases of uniformly exhibited non-elastic behaviour. With the increase in the inelastic demands of the performance objectives of a structure, the uncertainty with linear procedures increases to a great extent; usually requiring a high level of conservatism in assumptions of demand and acceptability criteria to avoid unsatisfactory performance and hence generating a need for nonlinear procedures.

Also another point of importance to be considered is that even though dynamic analysis methods are more efficient compared to static analysis methods, the cumbersome nature of these analysis methods discourages one from using them.

Thus the only option left for a good quality non-linear seismic analysis is the non-linear static analysis method which is also known as "pushover" analysis. A pattern of forces is applied to a structural model that includes non-linear properties (such as steel yield), and the total force is plotted against a reference displacement to define a capacity curve.

Even though the pushover analysis method is a static procedure and it cannot directly account for dynamic structural behaviour; nevertheless, nonlinear static analysis can be effectively used for performance assessment and design of many types of structures.

## 2. METHODOLOGY

This section discusses the methodology followed in the course of the research work and the parameters which have influenced the various choices made in the due course of the research.

The analysis tool used in this research is ETABS-2015 and the method of seismic analysis used is Non-linear Static Analysis also known as Pushover Analysis. The models used for analysis include buildings with symmetric plan as well as buildings with asymmetric plans. The symmetric model is a 'box' shaped model (fig-1) and the asymmetric model is an 'L' shaped model (fig-2). Both asymmetric and symmetric models consist of 5 floors each (G+4), with the floor heights being 3.5m each. The dimensions of the columns being fixed at 300mm x 450mm and that of the beams at 230mm x 450mm for both symmetric and asymmetric cases. The column positions have so been fixed, that the spans of all the beams in both X and Y directions are kept same and equal to 5m. The loading conditions for both symmetric models and asymmetric models are similar. Also both the symmetric model and the asymmetric models have been analyzed for rigid and semi rigid diaphragm conditions. In this study the lateral displacement values between the columns at the corner of the building projection (C1) and the re-entrant corner (C2) have been made.

IS 1893(Part-1):2002, The criteria for earthquake resistant design of structures majorly classifies the irregularities found in the structure into 2 types, i.e. plan irregularities and vertical irregularities. Of these, this research focuses only on the effect of variations in plan configuration along with different diaphragm conditions on the seismic behaviour of the structure.

Typical column position layouts for 'Box' shaped buildings and 'L' shaped buildings used in the analysis are as shown in figures 3 and 4 respectively.

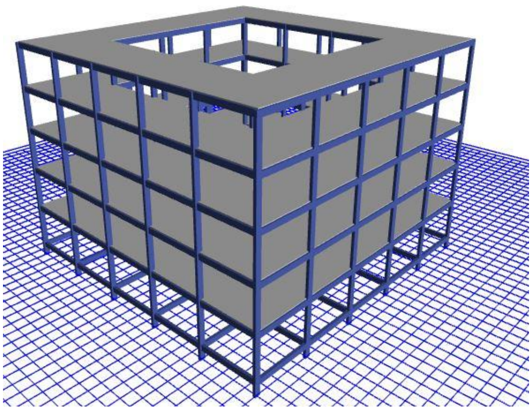

**Fig-1:** 3D View of Box- Shaped Building

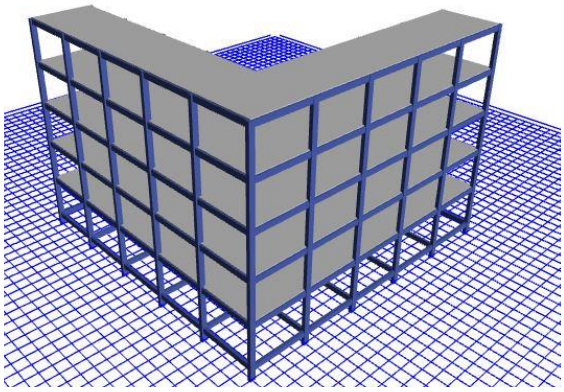

**Fig-2:** 3D View of L- Shaped Building

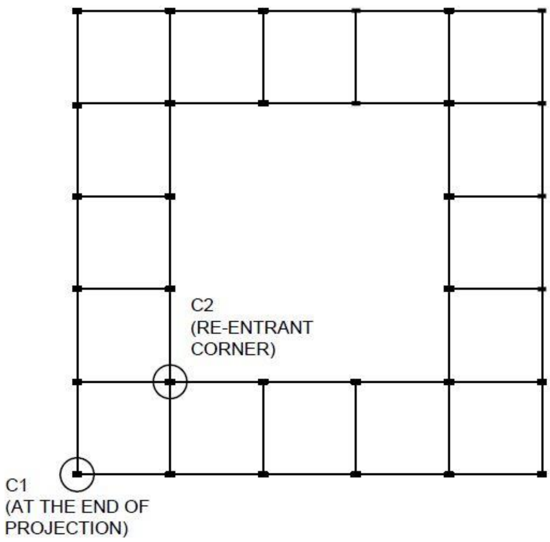


**Fig-3**: 'Box' Shaped Model

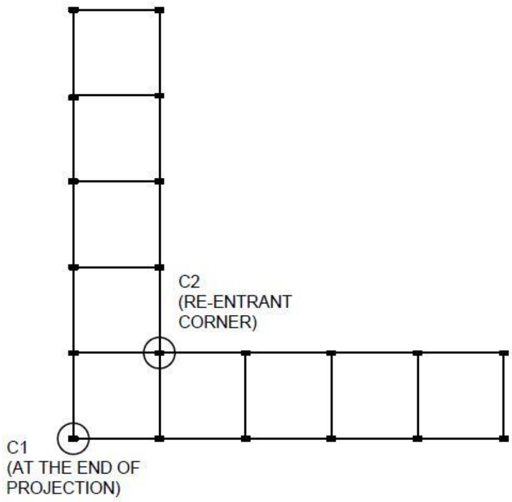


**Fig-4**: 'L' Shaped Model

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### 3.ANALYSIS

The software package ETABS-2015 was used throughout the course of research for the design and analysis of the building models. ETABS-2015 is an integrated structural analysis and design software package and is an improved version of the earlier ETABS software packages.

The building systems were directly modelled onto the ETABS modelling screen. Then the buildings were subjected to the usual dead and live load sets as per the Indian standards. This is to be done in order to check the capacity of the preliminarily fixed dimensions of the structural members. If all the members pass the design check, then the next part of analysis i.e. seismic analysis is carried out or else the member sizes are revised and the procedure is taken forward. Then the static non-linear load patterns and load cases required for carrying out pushover analysis are defined for both X and Y directions. After the member sizes are fixed, all the columns and beams (frame members) are assigned hinges based on the hinge properties from tables given in ASCE 41-13. After this the model is checked for errors and then finally it is analyzed under the action of lateral pushover loads applied under displacement control method. After the analysis is complete, the push over results like: the push over curve, the deflected shape of the model along with the formation of hinges, force and moment plots,.., etc. may be reviewed.

The various parameters considered for the purpose of modelling may be summarized as given in table-1.

**Table -1:** Parameters Considered in the Present Study

| | |
|---|---|
| Structure Type | Ordinary moment resisting frame |
| No. of storey | G+4 |
| Typical storey height | 3.5m |
| Type of building use | Public cum office |
| Foundation type | Isolated footing |
| Seismic zone | V |
| Soil type | Medium |
| **Material properties** | |
| Grade of concrete | $M_{20}$ |
| Young's modulus of concrete, | $25x10^6$ kN /m³ |
| Grade of steel | Fe415 |
| Density of concrete | 25 kN /m³ |
| Poisson's ratio of concrete | 0.20 |
| **Member properties** | |
| Slab thickness | 0.125m |
| Beam size | 0.23m x 0.45 m |
| Column size | 0.3m 0.45m |
| Wall size | 0.23m |
| **Dead load intensities** | |
| Roof finishes | 2 kN/m² |
| Floor finishes | 1 kN/m² |
| Partition wall load | 1 kN/m² |
| **Live load intensities** | |
| Roof | 2.5 kN/m² |
| Floor | 3.5 kN/m² |
| **Earthquake live load on slab as per clause 7.3.1 and 7.3.2 of IS: 1893(Part-1) 2002** | |
| Roof | 0.25 x 2. 5kN/m²= 0.635kN/m² |
| Floor | 0.5 x 3.5kN/m²= 1.75 kN/m² |

### 3.1 Results and Discussions

The following section discusses the results obtained from the analysis with regards to the lateral displacements of the columns at the re-entrant corner and at the end of the projection of the structure (i.e. C2 and C1 as shown in figures 1 and 2) . Chart-1 to chart-12 shows the variation of lateral displacement at the different storey levels. In all the cases the lateral displacement is more at the top storey and it goes on reducing as it reaches the bottom storeys. It is also observed that the lateral displacement values for rigid and semi rigid diaphragm roof modelling conditions are almost same for the Push-X load case for both box-shaped and L-shaped buildings. Whereas for Push-Y load case a huge reduction in lateral displacement may be noticed in the case of models with semi rigid roof modelling as compared to the lateral displacement values of the models with rigid roof modelling for both box shaped and L-shaped buildings. Also it may be observed that the L shaped building experiences a slight lateral displacement in Y direction even though the Push-X load is applied in X direction. This shows that the behaviour of the plan-asymmetric buildings is different than that of the plan symmetric buildings.

**Table-2:** Distribution of Lateral displacement of structures at end of projection (C1 Column)

| Model Type | Storey No. | PUSH X | | | |
|---|---|---|---|---|---|
| | | Rigid | | Semi Rigid | |
| | | Ux | Uy | Ux | Uy |
| BOX Shaped | 5 | 166.42 | 0 | 179.35 | 0 |
| | 4 | 157.33 | 0 | 169.51 | 0 |
| | 3 | 132.91 | 0 | 143.36 | 0 |
| | 2 | 90.86 | 0 | 98.73 | 0 |
| | 1 | 40.67 | 0 | 45.32 | 0 |
| L Shaped | 5 | 186.99 | 6.65 | 214.46 | 7.08 |
| | 4 | 176.56 | 5.46 | 196.62 | 5.3 |
| | 3 | 149.02 | 4.08 | 160.34 | 3.75 |
| | 2 | 102.67 | 2.75 | 106.85 | 2.49 |
| | 1 | 47.56 | 1.5 | 47.34 | 1.49 |

**Table -3:** Distribution of Lateral displacement of structures at end of projection (C1 Column)

| Model Type | Storey No. | PUSH Y | | | |
|---|---|---|---|---|---|
| | | Rigid | | Semi Rigid | |
| | | Ux | Uy | Ux | Uy |
| BOX Shaped | 5 | 0 | 1733.88 | 0 | 426.5 |
| | 4 | 0 | 1621.82 | 0 | 410.64 |
| | 3 | 0 | 1406.58 | 0 | 359.42 |
| | 2 | 0 | 1168.46 | 0 | 265.32 |
| | 1 | 0 | 670.96 | 0 | 137.12 |
| L Shaped | 5 | 4.52 | 222.74 | 4.02 | 177.97 |
| | 4 | 3.85 | 217.13 | 3.38 | 172.43 |
| | 3 | 2.8 | 192.42 | 2.49 | 151.56 |
| | 2 | 1.77 | 138.00 | 1.6 | 106.88 |
| | 1 | .81 | 64.72 | .73 | 48.3 |

**Table -4:** Distribution of Lateral displacement of structures at re- entrant corner (C2 Column)

| Model Type | Storey No. | PUSH X | | | |
|---|---|---|---|---|---|
| | | Rigid | | Semi Rigid | |
| | | Ux | Uy | Ux | Uy |
| BOX Shaped | 5 | 166.42 | 0 | 179.36 | 0 |
| | 4 | 157.32 | 0 | 169.51 | 0 |
| | 3 | 132.91 | 0 | 143.36 | 0 |
| | 2 | 90.86 | 0 | 98.74 | 0 |
| | 1 | 40.67 | 0 | 45.32 | 0 |
| L Shaped | 5 | 191.41 | 2.24 | 219.44 | 2.03 |
| | 4 | 180.19 | 1.83 | 200.26 | 1.66 |
| | 3 | 151.74 | 1.38 | 162.93 | 1.19 |
| | 2 | 104.50 | 0.93 | 108.60 | 0.76 |
| | 1 | 48.6 | 0.52 | 48.45 | 0.38 |

**Table -5:** Distribution of Lateral displacement of structures at re- entrant corner (C2 Column)

| Model Type | Storey No. | PUSH Y | | | |
|---|---|---|---|---|---|
| | | Rigid | | Semi Rigid | |
| | | Ux | Uy | Ux | Uy |
| BOX Shaped | 5 | 0 | 1733.88 | 0 | 426.51 |
| | 4 | 0 | 1621.82 | 0 | 410.65 |
| | 3 | 0 | 1406.56 | 0 | 359.43 |
| | 2 | 0 | 1168.46 | 0 | 265.29 |
| | 1 | 0 | 670.96 | 0 | 137.15 |
| L Shaped | 5 | 1.3 | 25.96 | 1.14 | 180.84 |
| | 4 | 1.1 | 219.88 | 0.99 | 174.82 |
| | 3 | 0.9 | 194.45 | 0.76 | 153.22 |
| | 2 | 0.6 | 139.311 | 0.53 | 107.88 |
| | 1 | 0.27 | 65.35 | 0.25 | 48.74 |

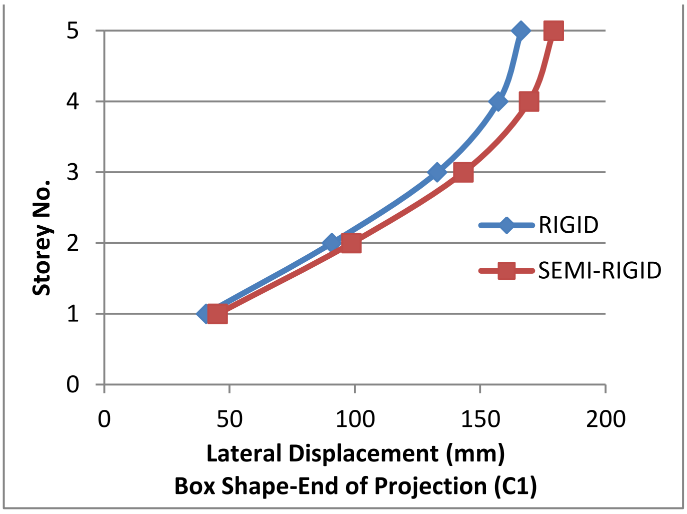


**Chart -1:** Variation of lateral displacement due to Push X (X - direction)

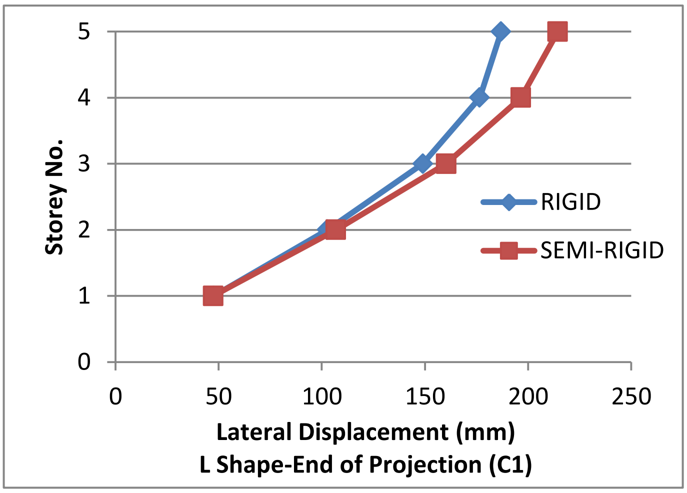


**Chart -2:** Variation of lateral displacement due to Push X (X-direction)

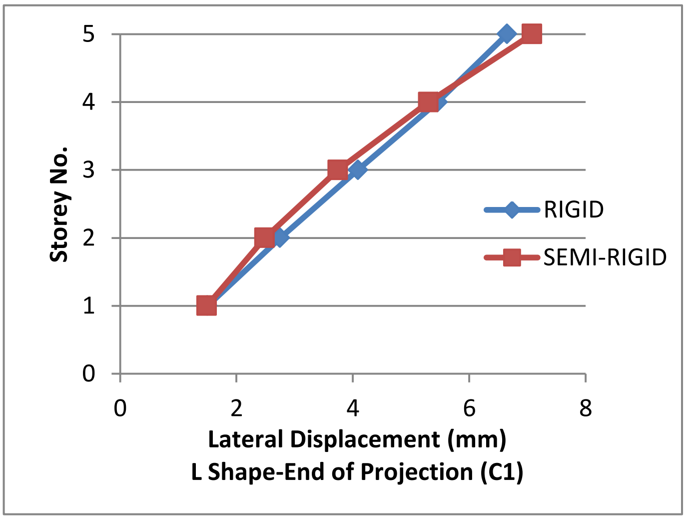


**Chart -3:** Variation of lateral displacement due to Push X (Y-direction)

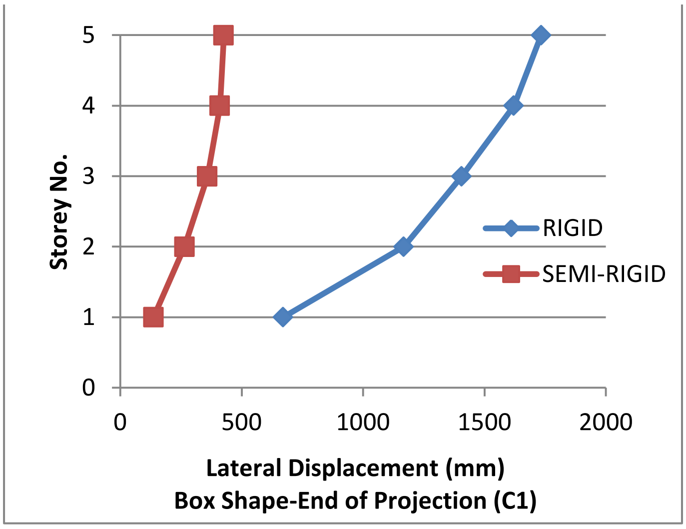


**Chart -4:** Variation of lateral displacement due to Push Y (Y-direction)

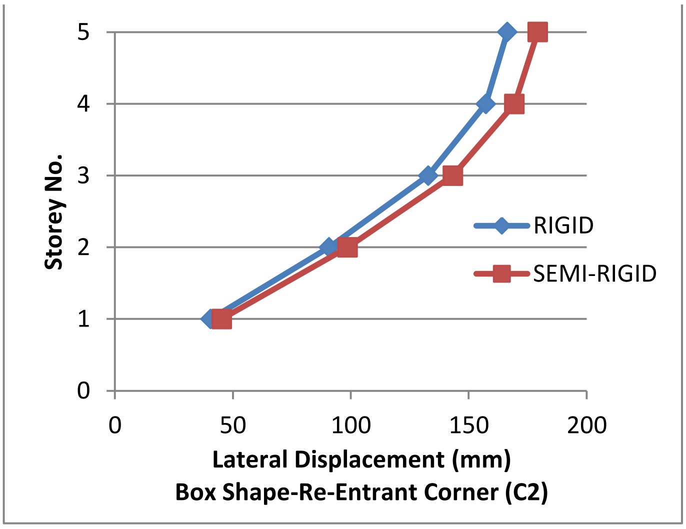


**Chart -7:** Variation of lateral displacement due to Push X (X-direction)

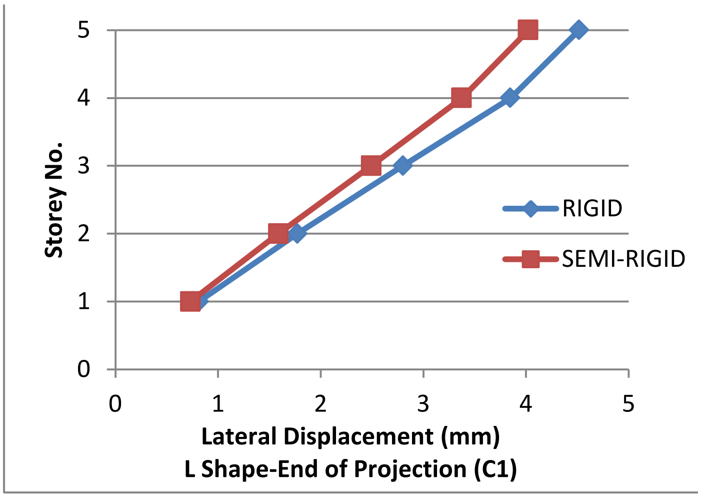


**Chart -5:** Variation of lateral displacement due to Push Y (X-direction)

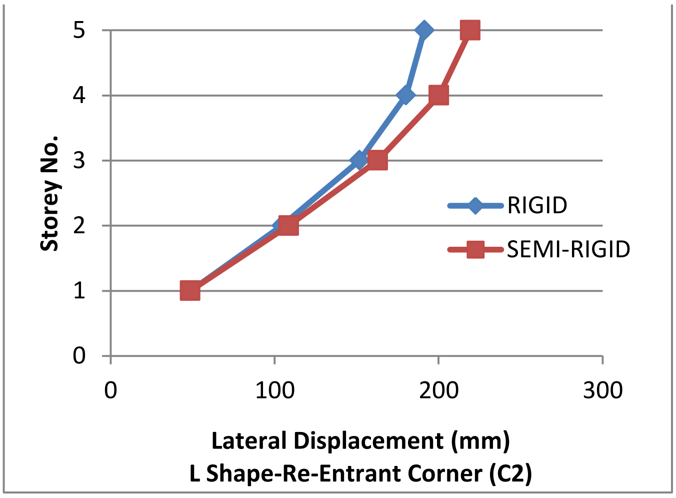


**Chart -8:** Variation of lateral displacement due to Push X (X-direction)

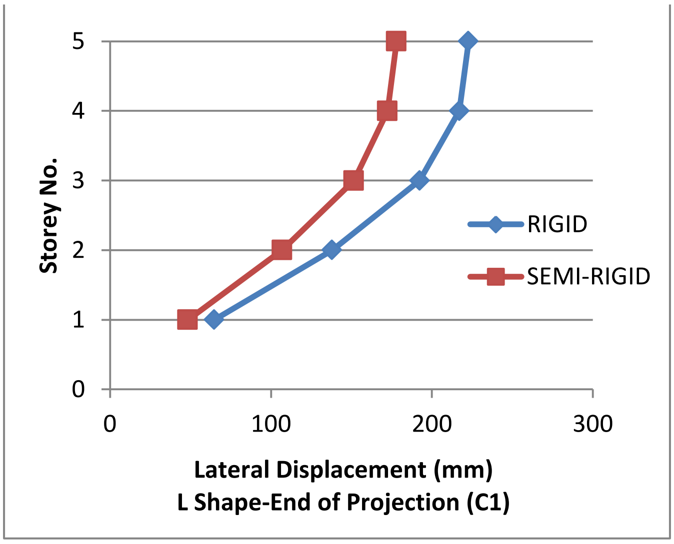


**Chart -6:** Variation of lateral displacement due to Push Y (Y-direction)

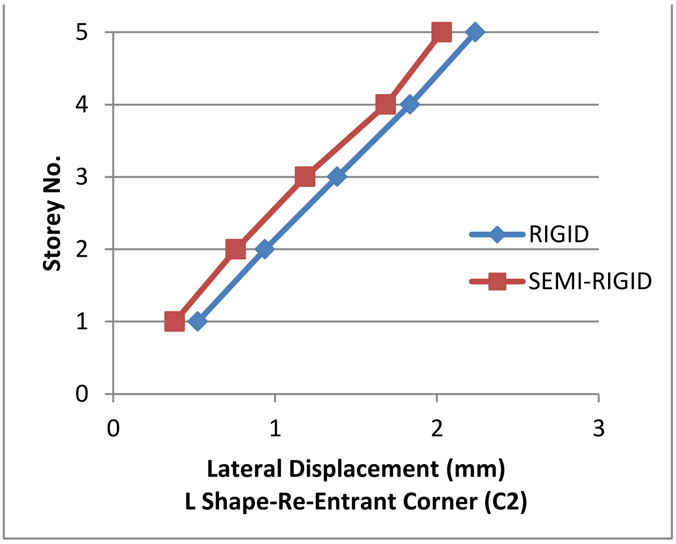


**Chart -9:** Variation of lateral displacement due to Push X (Y-direction)

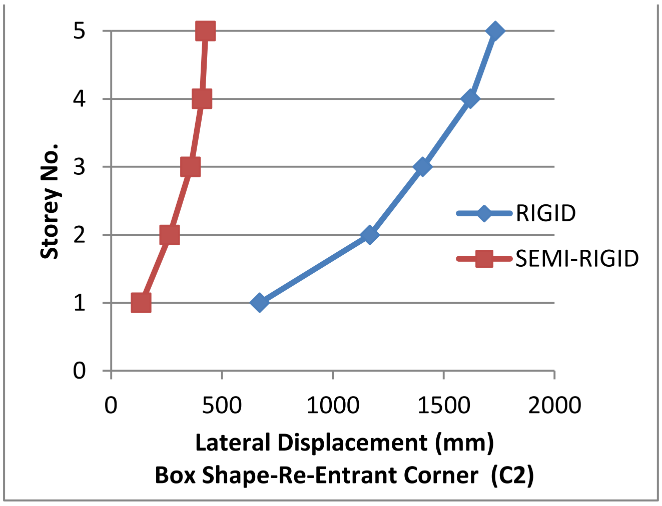


**Chart -10:** Variation of lateral displacement due to Push Y (Y-direction)

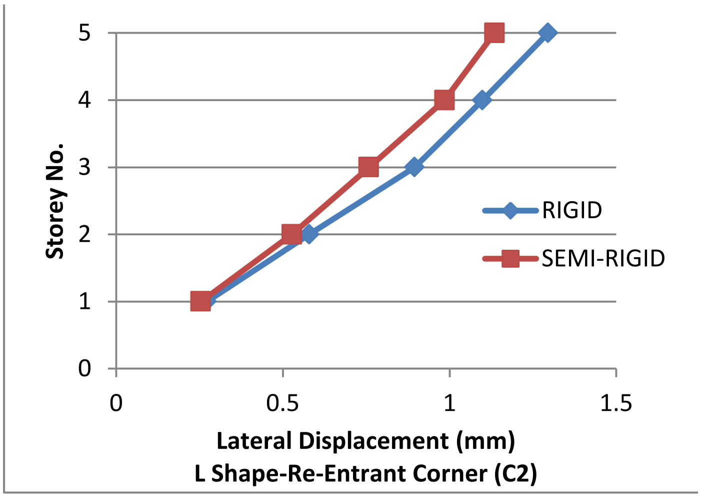


**Chart -11:** Variation of lateral displacement due to Push Y (X-direction)

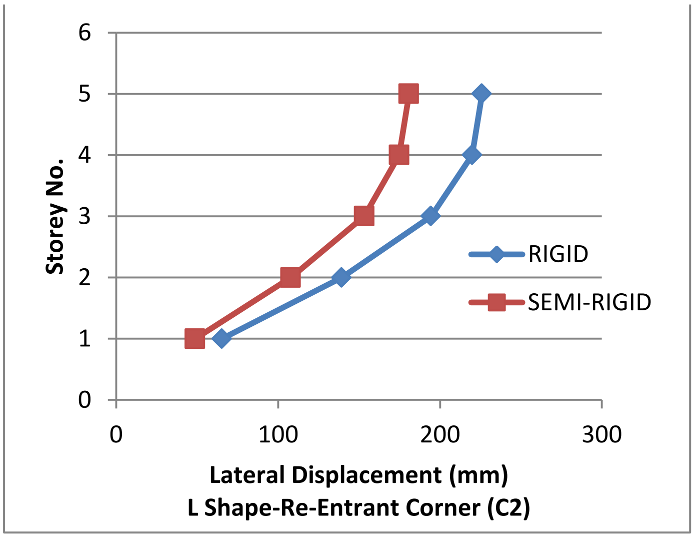


**Chart -12:** Variation of lateral displacement due to Push Y (Y-direction)

## 4. CONCLUSIONS

From the past earthquakes it has been noticed that the plan asymmetric buildings have performed very poorly. Hence to understand the behavior of the structure performance based analysis like pushover analysis is very useful.

Also it is observed that the lateral displacement values for rigid and semi rigid diaphragm roof modelling conditions are almost same for the Push-X load case for both box-shaped and L-shaped buildings. Whereas for Push-Y load case a huge reduction in lateral displacement may be noticed in the case of models with semi rigid roof modelling as compared to the lateral displacement values of the models with rigid roof modelling for both box shaped and L-shaped buildings. Thus from this, it may concluded that the buildings with semi rigid roof modelling/diaphragm condition are more stable than those with rigid roof modelling/ diaphragm condition

It is also observed that the L shaped building experiences a slight lateral displacement in Y direction even though the Push-X load is applied in X direction.This may be attributed to the fact that the longer direction of the columns is oriented along the X-X direction. When the longer dimension of the column is oriented along the direction of the applied load, the lateral displacement is less as when compared to that in the case when the shorter dimension of the column is oriented along the direction of applied load; from which it can be concluded that the orientation of the columns plays a major role in the stability of the structure.This also shows that the behaviour of the plan-asymmetric buildings is different than that of the plan symmetric buildings.

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Mr. N Punith was born in Mysore, India, on 21st Oct 1987. He did his B.E. in Civil Engineering from Dr.AIT, Bangalore and M.Tech. in SJCE, Mysore. Currently pursuing the Ph.D. under VTU. He has more than 6 years of teaching experience and is presently working as assistant professor in MIT-Mysore.

Dr. Naresh Kumar B G was born in Mandya, India on 21st May 1958. He did his M.E. (Structures) from University of Roorkee (1987) and obtained his Ph.D. from IIT - Roorkee(1996). He has more than 36 years of teaching experience and is presently working as professor and principal in MIT-Mysore.

Dr. Prakash T M was born in Thagahalli , Karnataka, India on 23rd Jan 1964. He did his M.Tech in Building Science and Construction Management from IIT-Delhi (1998), and obtained his Ph.D. from VTU-Belgaum(2013). He has more than 28 years of teaching experience and is presently working as associate professor in PESCE-Mandya.