Seismic Analysis of Multi-Storeyed Building Having Vertical Irregularities Using Pushover Analysis

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Abstract - *Nowadays, as in the urban areas the space available for the construction of buildings is limited. So in limited space we have to construct such type of buildings which can be used for multiple purposes such as lobbies, car parking etc. To fulfill this demand, buildings with irregularities is the only option available. During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes. A performance based seismic analysis can be used for various purposes such as assessment of large structures, design verification of new construction, evaluation of an existing structure to identify damage states for various amplitudes of ground motions.*

In this work the building with vertical irregularities like mass irregularity and mass & stiffness irregularity are considered by modeling the roof diaphragm as rigid and semi rigid. The analysis of the building is done by using ETABS 2015 software by considering the static nonlinear analysis called pushover analysis. So from the results it can be concluded that when building becomes more and more vertically irregular (mass irregular and mass & stiffness irregular), the lateral displacement is lower at base and goes on increasing towards top. For mass regular and mass & stiffness regular building have less lateral displacement compared to mass irregular and mass & stiffness irregular building. From pushover curve it can be observed that the model with semi rigid diaphragm possesses lower monitored displacement and base shear compared to rigid diaphragm.

Keywords: Mass irregularity, Mass & stiffness irregularity, Roof diaphragm, Rigid, Semi rigid, Pushover analysis, ETABS 2015.

1. INTRODUCTION

Earthquakes have the potential for causing the greatest damages, among all the natural hazards. Since earthquake forces are random in nature & unpredictable. During an earthquake, the damage in a structure generally initiates at location of the structural weakness present in the building systems. These weaknesses trigger further structural deterioration which leads to the structural collapse which is due to geometry, mass discontinuity and stiffness of structure. The structures having this discontinuity are known as Irregular structures. These structures constitute a large portion of the modern urban infrastructure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes.

1.1 Vertical Irregularity

Vertical irregularity results from the uneven distribution of mass, strength or stiffness along the elevation of a building structure. Mass irregularity results from a sudden change in mass between adjacent floors, such as mechanical plant on the roof of a structure. Stiffness irregularity results from a sudden change in stiffness between adjacent floors, such as setbacks in the elevation of a building.

Types of Vertical Irregularities

- Stiffness Irregularity- Soft Storey-A soft storey is one in which the lateral stiffness is less than 70percent of the storey above or less than 80 percent of the average lateral stiffness of the three storey's above.
- Stiffness Irregularity-Extreme Soft Storey-An extreme soft storey is one in which the lateral stiffness is less than 60percent of that in the storey above or less than 70 percent of the average stiffness of the three storey's above. It is as shown in Fig.1.

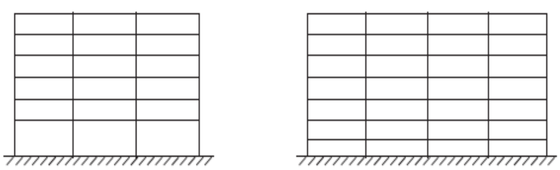

Fig-1: Stiffness irregularities

- Mass Irregularity-Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storey's. In case of roofs irregularity need not be considered. It is as shown in Fig.2.
- Vertical geometric irregularity: It should be considered to exist where the horizontal dimension of the lateral force resisting system in any storey is more than 150% of that in its adjacent storey.
- In-Plane discontinuity in the vertical elements resisting lateral force: A in -plane offset of the lateral force resisting element greater than the length of those elements.

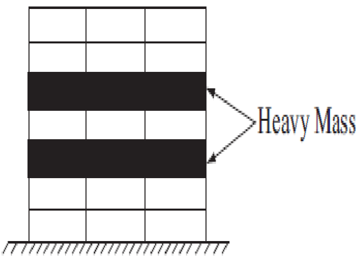

Fig- 2: Mass irregularity

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building structure to earthquakes. It is part of the process of structural design, earthquake engineering and retrofit in regions where earthquakes are prevalent. Structural analysis methods are classified into following five categories:

The pushover analysis of a structure is a static nonlinear analysis under permanent vertical loads and gradually increasing lateral loads as shown in fig.3. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base shear versus top displacement in a structure is obtained. By this analysis any permanent failure or weakness can be identified. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity on a building frame, plastic rotation is monitored and lateral inelastic forces versus displacement response for the complete structure is analytically computed. This type of analysis enables us to identify the weakness in the structure. The decision to retrofit can be taken in such studies.

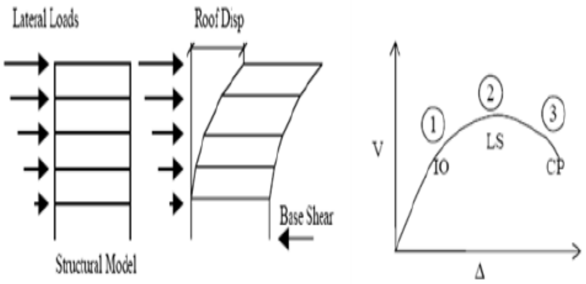

Fig-3: Building model and pushover curve.

2. METHODOLOGY

The software 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 present study include buildings with mass irregularity and mass & stiffness irregularity. The shape of the model considered is a box shaped model (fig. 4). Both mass regularity and mass irregularity, mass & stiffness regularity and mass & stiffness irregularity models consist of 5 floors each (G+4), with the floor heights being 3.5 m each. The dimension of the columns being fixed at 230 mm x 450 mm and that of the beams at 230 mm x 450 mm for the models as shown in table 1. The column positions have so been fixed. The spans of all the beams in both X and Y directions are kept same and equal to 5 m. For mass regular, mass irregular, mass & stiffness regular and mass & stiffness irregular, the loading conditions are same except an additional mass has been added to the third storey of mass irregular building to maintain the vertical irregularity. But for mass & stiffness irregular, the column size is 230 mm x 600 mm is adopted from base to fourth floor to maintain the vertical irregularity. Also both models have been analyzed for rigid and semi rigid Diaphragm condition. In this study the results are considered for the column C1 (End of the projection) and Column C2 (Re – entrant corner) as shown in fig. 4.

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 building
Foundation type	Isolated footing
Seismic zone	V
Soil type	Medium
Material properties	
Grade of concrete	M_{20}
Young's modulus of concrete, E_c	$25x10^6$ kN /m^2
Grade of steel	Fe415
Density of concrete	25 kN /m^3
Poisson's ratio of concrete	0.20
Member properties	
Slab thickness	0.125m
Beam size	0.23m x 0.45 m
Column size	0.23m x 0.45m
Wall size	0.23m
Dead load intensities	
Roof finishes	2 kN/m^2
Floor finishes	1 kN/m^2
Partition wall load	1 kN/m^2
Live load intensities	

Roof	2.5 kN/m^2
Floor	3.5 kN/m^2
Earthquake live load on slab as per clause 7.3.1 and 7.3.2 of IS: 1893(Part-1) 2002	
Roof	Nil
Floor	0.5 x 3kN/m^2

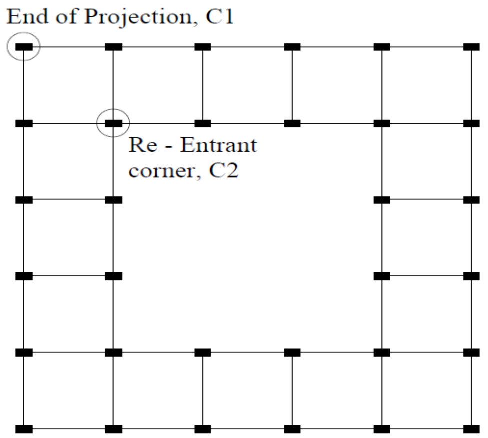

Fig-4: Beam and column layout of model.

3. RESULTS AND DISCUSSION

The following section discusses the results obtained from the analysis of a box shaped building with regards to lateral displacement with respective to storey number.The roof modeling is considered as rigid diaphragm and semi rigid diaphragm respectively. The pushover curves are shown below.

Analysis results of mass regular, mass & stiffness regular, mass irregular and mass & stiffness irregular models are as shown below.

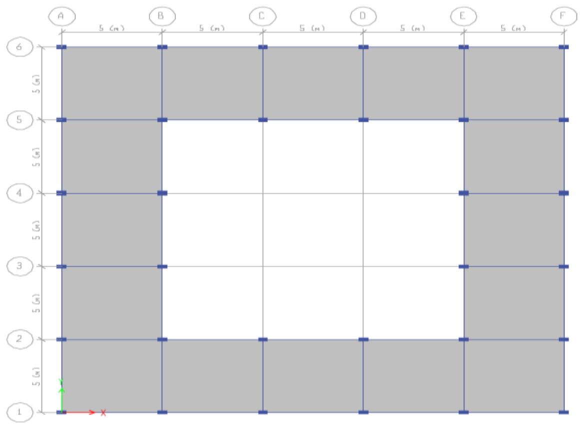

Fig-6: Plan of the model.

3.1. Mass Regular and Mass Irregular Building

3.1.1 Lateral Displacement

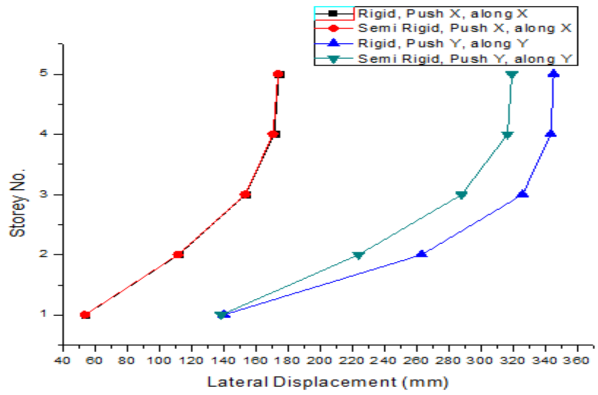

Chart-1: Variation of lateral displacement- mass regular, at the re-entrant corner and at the end of the projection

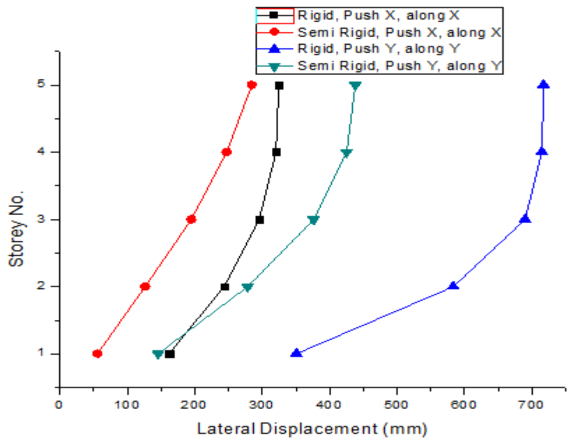

Chart-2: Variation of lateral displacement- mass irregular, at the re-entrant corner and at the end of the projection

Chart 1 and chart 2 shows the variation of lateral displacement at different storey for a mass regular and mass irregular building due to the application of push X force in X-direction and push Y force in Y- direction for both rigid and semi rigid diaphragm. From the chart it can be observed that the lateral displacement goes on increases from base storey to top storey. This clearly suggests that the lateral displacement will be more near the top storey and it goes on decreasing towards the bottom storey. The lateral displacement is same at the re-entrant corner (C2) and at the end of the projection (C1) for mass regularity and mass irregularity models. When the building is subjected to push X and push Y load, the lateral displacement is lower for semi rigid diaphragm than compared to the rigid diaphragm for mass regularity and mass irregularity.

3.1.2 Pushover Curve

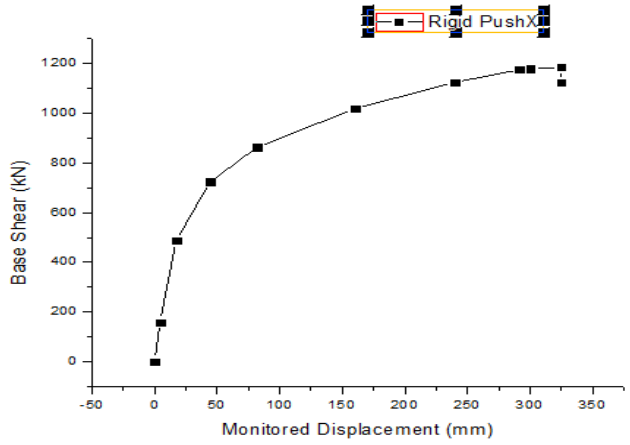

Chart-3: Pushover curve - mass regular (rigid), push X

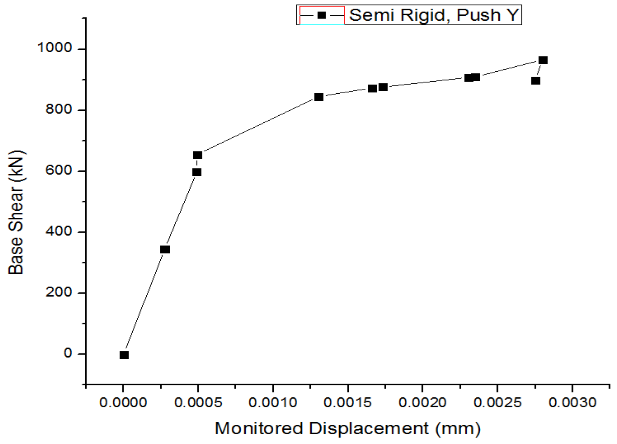

Chart-6: Pushover curve - mass regular (semi rigid), push Y

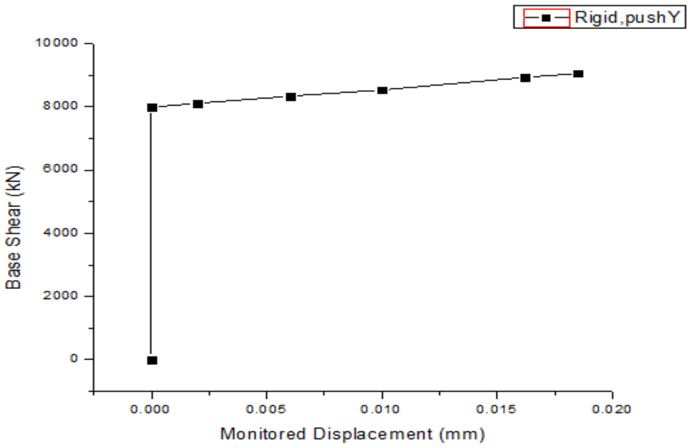

Chart-4: Pushover curve - mass regular (rigid), push Y

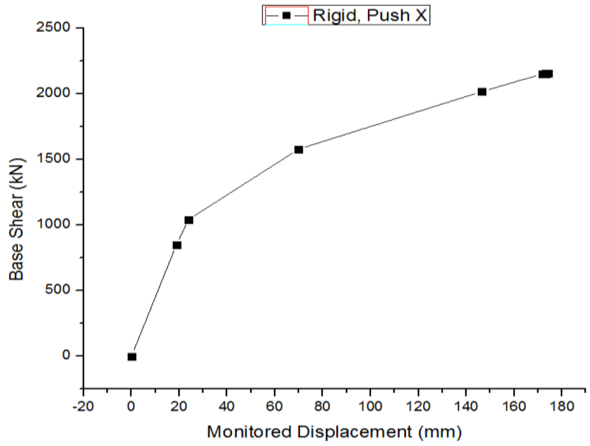

Chart-7: Pushover curve - mass irregular (rigid), push X

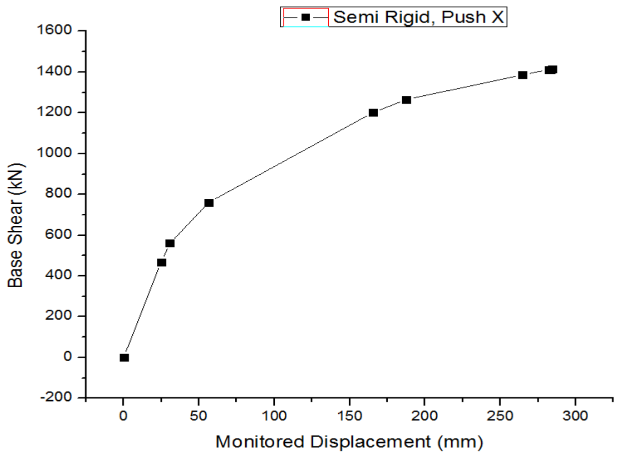

Chart-5: Pushover curve - mass regular (semi rigid), push X

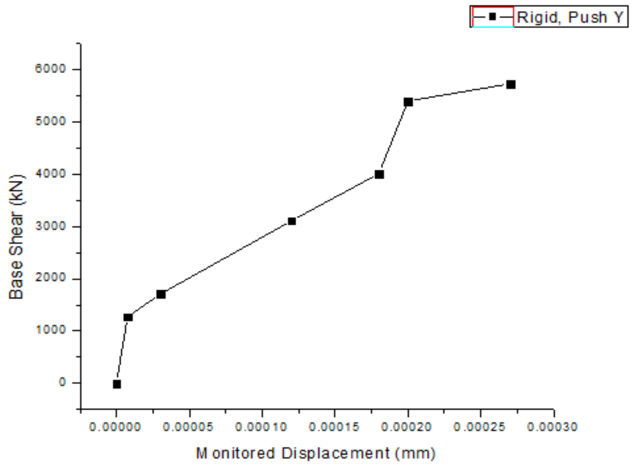

Chart-8: Pushover curve - mass irregular (rigid), push Y

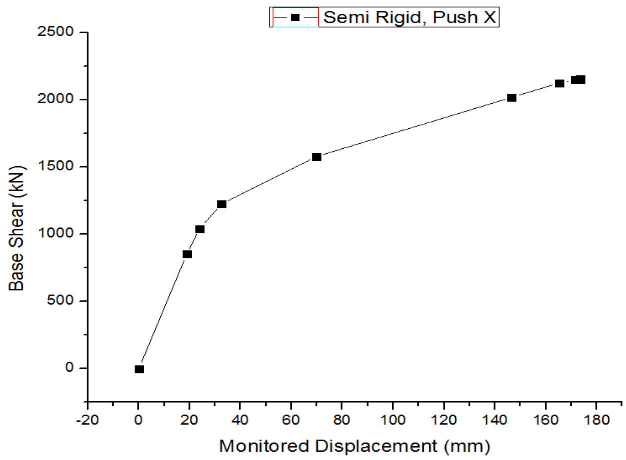

Chart-9: Pushover curve - mass irregular (semi rigid), push X

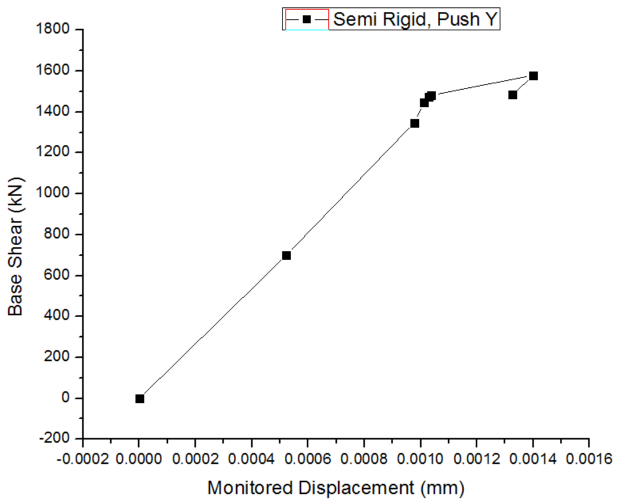

Chart-10: Pushover curve - mass irregular (semi rigid), push Y

From chart 3 to chart 10 shows the variation of monitored displacement and base shear for a mass regular and mass irregular models subjected to push X and push Y force for rigid and semi rigid diaphragm. Charts shows as the monitored displacement increases the base shear also increase. It can be seen that the model with semi rigid diaphragm possesses lower monitored displacement and base shear compared to rigid diaphragm. As for as possible we need to avoid vertical irregularities in the building. If vertical irregularity is introduced for an architectural appearance proper mechanism should be applied to restrict such inelastic behavior (for e.g. cross bracing, energy dissipating devices etc.).

3.2. Mass & Stiffness Regular and Mass & Stiffness Irregular Building

3.2.1 Lateral Displacement

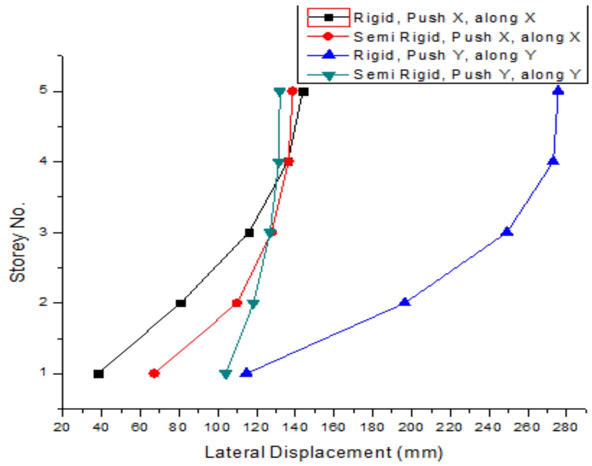

Chart-11: Variation of lateral displacement – mass & stiffness regular (at the re-entrant of corner and at the end of projection

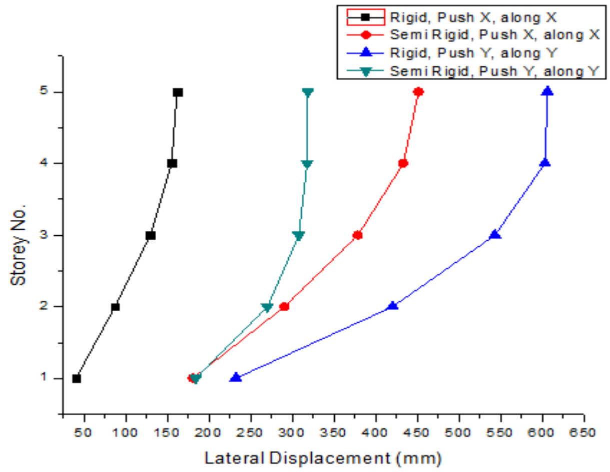

Chart-12: Variation of lateral displacement – mass & stiffness irregular (at the re-entrant of corner and at the end of projection

Chart 11 and chart 12 shows the variation of lateral displacement at different storey for a mass & stiffness regular and mass & stiffness irregular building due to the application of push X force in X- direction and push Y force in Y- direction for both rigid and semi rigid diaphragm. From the chart it can be observed that the lateral displacement goes on increases from base storey to top storey. This clearly suggests that the lateral displacement will be more near the top storey and it goes on decreasing towards the bottom storey. The lateral displacement is same at the re-entrant corner (C2) and at the end of the projection (C1) for mass & stiffness regularity and mass & stiffness irregularity models. When the building is subjected to push X and push Y load, the lateral displacement is lower for semi rigid diaphragm than compared to the rigid diaphragm for mass & stiffness regularity and mass & stiffness irregularity.

3.2.2 Pushover Curve

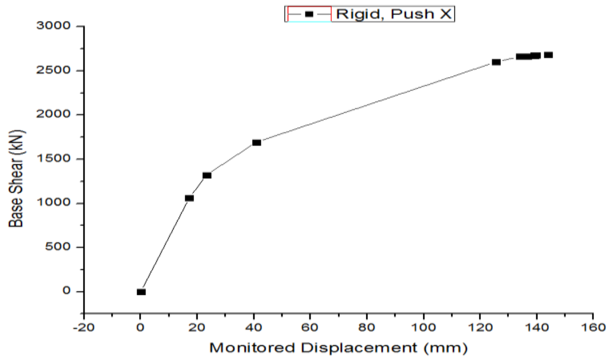

Chart-13: Pushover curve - mass & stiffness regular (rigid), push X

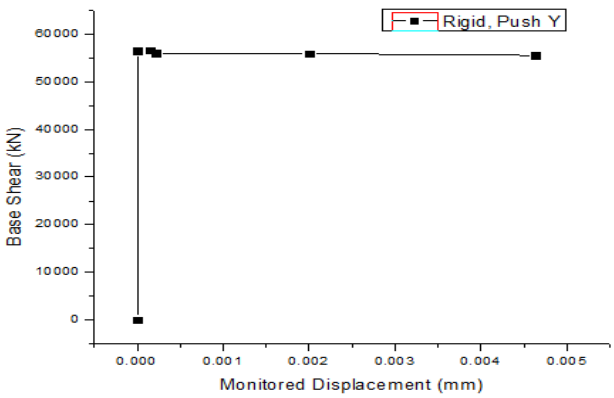

Chart-14: Pushover curve - mass & stiffness regular (rigid), push Y

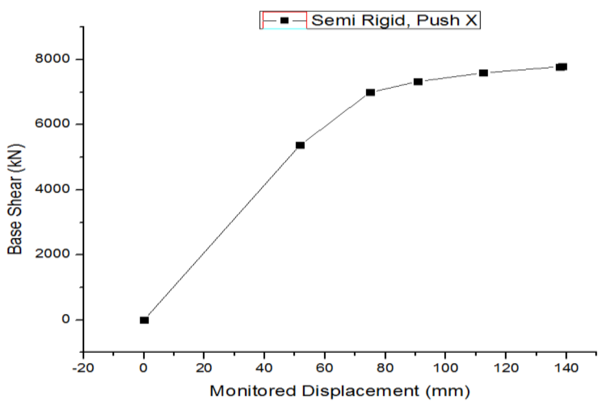

Chart-15: Pushover curve - mass & stiffness regular (semi rigid), push X

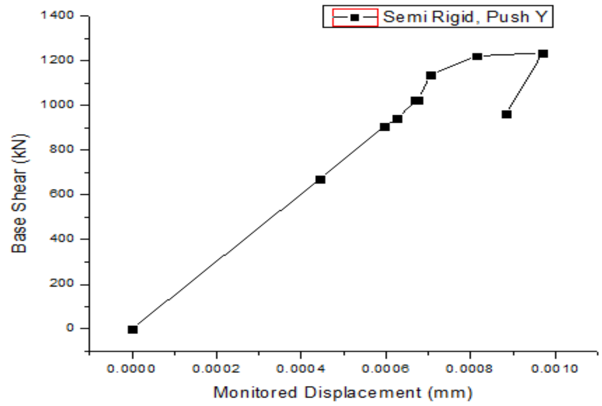

Chart-16: Pushover curve - mass & stiffness regular (semi rigid), push Y

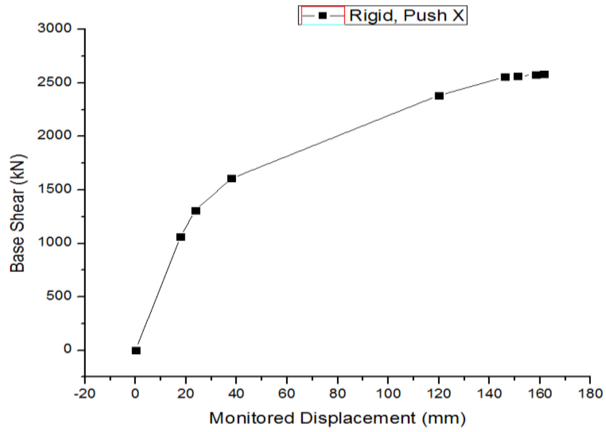

Chart-17: Pushover curve - mass & stiffness irregular (rigid), push X

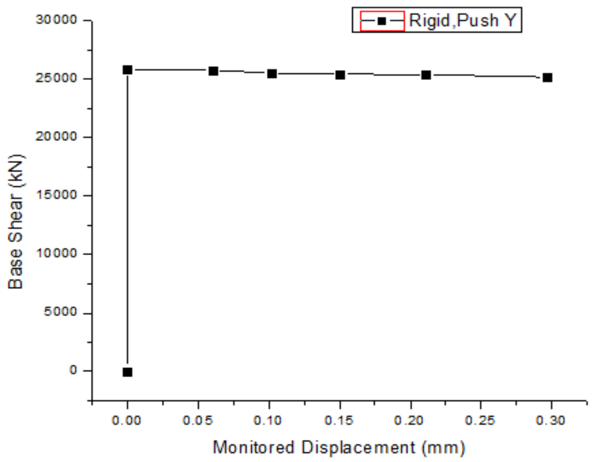

Chart-18: Pushover curve - mass & stiffness irregular (rigid), push Y

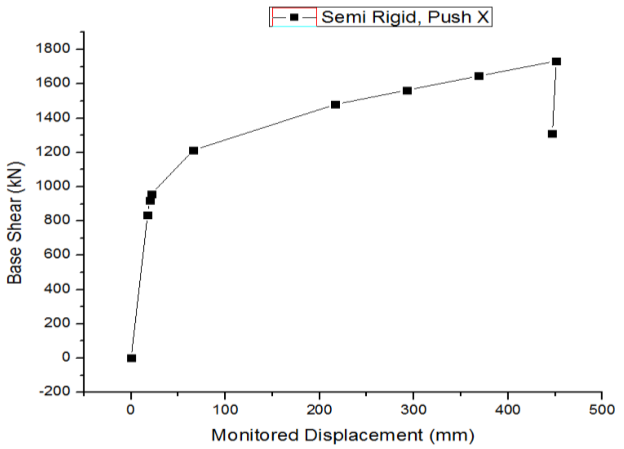

Chart-18: Pushover curve - mass & stiffness irregular (semi rigid), push X

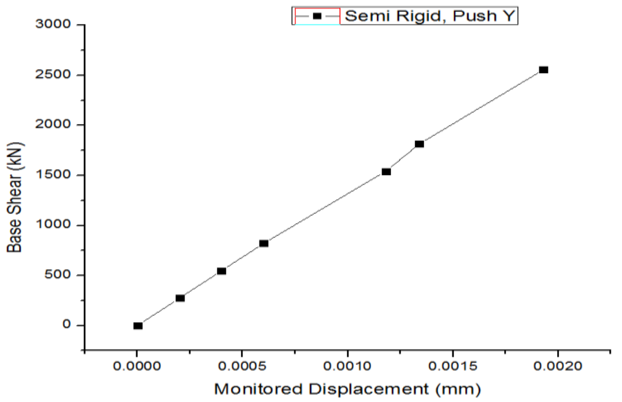

Chart-19: Pushover curve - mass & stiffness irregular (semi rigid), push Y

From chart 13 to chart 19 shows the variation of monitored displacement and base shear for a mass & stiffness regular and mass & stiffness irregular models subjected to push X and push Y force for rigid and semi rigid diaphragm. Charts shows that as the monitored displacement increases the base shear also increase. It can be seen that the model with semi rigid diaphragm possesses lower monitored displacement and base shear compared to rigid diaphragm.

4. CONCLUSION

In the present study, the pushover analysis of G+4 multi storied building with vertical irregularities like mass irregularity and mass & stiffness irregularity was carried out using ETABS 2015 software. From this analysis following conclusions are drawn.

1. The analysis results shows that the Re- Entrant corner and end of projections are the critical part of the building.
2. The lateral displacement values for at the re-entrant corner and at the end of projection are almost same.
3. The lateral displacement will be more near the top storey and it goes on decreasing towards the bottom storey for multi storeyed building having mass regularity, mass irregularity, mass & stiffness regularity and mass & stiffness irregularity subjected to push X and push Y force with rigid and semi rigid diaphragm.
4. From pushover curve it can be observed that the model with semi rigid diaphragm possesses lower monitored displacement and base shear compared to rigid diaphragm.
5. The structure with semi rigid diaphragm shows better performance under seismic excitation compared to rigid diaphragm.
6. The vertical irregularity structures (mass irregularity and mass & stiffness irregularity) are most vulnerable to seismic excitation compared to regular structures. As the structure becomes irregular, there will be reduction in the base shear carrying capacity, reduction in ductility demand. It results in collapse of the structure.

5. REFERENCES

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