EFFECT OF VERTICAL IRREGULARITIES IN R.C FRAME STRUCTURES ON ACCURACY OF EQUIVALENT NON-LINEAR STATIC SEISMIC ANALYSIS

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Abstract - *Pushover analysis is one of the most used nonlinear static methods to assess the seismic performance of regular buildings. Therefore, nowadays it is extensively used by practicing engineers for the seismic analysis of virtually every type of building and it has an advantage of simplicity when compared to other dynamic methods. The present study evaluates the accuracy of the non-linear pushover analysis(NPA) in estimating the seismic demands of vertically irregular frames in comparison with the exact results from non-linear time history analysis (NLTHA).In this paper fifteen vertically irregular frame models are analyzed with three different heights and five types of vertical irregularities. Vertical irregularities are introduced as per Indian standards IS 1893:2002 (part I) namely stiffness irregularity, mass irregularity, vertical geometry irregularity, in-plane discontinuity in vertical elements resisting lateral force and discontinuity in capacity. For each frame model, non-linear time history analysis and non-linear pushover analysis are performed using computer program SAP2000. For non-linear time history analysis, three ground motions recorded at different soil sites of India are used. Base shear forces and storey drifts are computed for all models. Comparison between the pushover analysis and time history analysis shows that pushover analysis reasonably estimated the seismic demands of the vertically irregular buildings and the estimated pushover results have good correlation with the selected ground motions.*

***Key Words*: nonlinear static analysis, vertical irregularity, base shear, Lateral displacement, R.C building, time history analysis...Etc**

1. INTRODUCTION

1.1 Seismic analysis

Seismic analysis is a major tool in earthquake engineering which is used to understand the response of buildings due to seismic excitations in a simpler manner. It is part of the process of structural design, earthquake engineering or structural assessment and retrofit in regions where earthquakes are prevalent. A building has the potential to 'wave' back and forth during an earthquake. This is called the 'fundamental mode', and is the lowest frequency of building response. Most buildings, however, have higher modes of response, which are uniquely activated during earthquakes. The earliest provisions for seismic resistance were the requirement to design for a lateral force equal to a proportion of the building weight applied at each floor level.

Current Indian codes do not address the evaluation of seismic resistance of existing building stock, which may not have been designed for earthquake forces. Further, adequate codal provisions are lacking for strengthening of the structural systems of seismically deficient buildings. The present guidelines are intended to provide a systematic procedure for the seismic evaluation of buildings which can be applied consistently to a rather wide range of buildings.

Seismic analysis methods can be divided into the following five categories.

> i) Equivalent Static Analysis
> ii) Response Spectrum Analysis
> iii) Linear Dynamic Analysis
> iv) Nonlinear Dynamic Analysis
> v) Nonlinear Static Analysis

From the five types of seismic analysis, Non-linear dynamic analysis and Non-linear static analysis is used in this paper.

2. OBJECTIVES AND SCOPES

The main objective of this work includes the following:

The main objective of this project is the study of effect of vertical irregularities in frames on accuracy of equivalent non-linear static seismic analysis. Now a days it is extensively used by practicing engineers for the seismic analysis of virtually every type of building and it has an advantage of simplicity when compared to other dynamic methods.

1) To obtain the response of G+4, G+7, G+11 storey RC frame structure i.e., base shear and lateral displacement and performance point by pushover analysis. Modeling and analysis are achieved using SAP 2000 software.

2) The combine effect of vertical irregularities i.e., mass, stiffness and vertical setbacks are studied.

3) Non linear static analysis method is conducted for zone-III according to IS 1893 2002 (Part 1) for medium soil type.

4)   All the five models are studied and analyzed using pushover analysis.

3. PUSHOVER ANALYSIS

Pushover analysis is a static non-linear analysis method where a structure is subjected to gravity loading and a monotonic displacement controlled lateral load pattern which continuously increases through elastic and inelastic behavior until an ultimate condition is reached. Lateral load may represent the range of base shear induced by earthquake loading, and its configuration may be proportional to the distribution of mass along building height, mode shapes, or another practical means.

Output generates a static-pushover curve which plots a strength-based parameter against deflection. For example, performance may relate the strength level achieved in certain members to the lateral displacement at the top of the structure, or bending moment may be plotted against plastic rotation. Results provide insight into the ductile capacity of the structural system, and indicate the mechanism, load level, and deflection at which failure occurs.

Non-linear static pushover analysis procedure was formulated by two agencies namely, federal emergency management agency (FEMA 356) and applied technical council (ATC 40), under their seismic rehabilitation program and guidelines.

3.1 Pushover curve

A Pushover analysis is performed by subjecting a structure to a monotonically increasing pattern of lateral loads, representing the inertial forces which would be experienced by the structure when subjected to ground shaking. Under incrementally increasing loads various structural elements may 26 yields sequentially. Consequently, at each event, the structure experiences a loss in stiffness. The main output of a pushover analysis is in terms of response demand versus capacity. If the demand curve intersects the capacity envelope near the elastic range then the structure has a good resistance.

If the demand curve intersects the capacity curve with little reserve of strength and deformation capacity then it can be concluded that the structure will behave poorly during the imposed seismic excitation and need to be retrofitted to avoid future major damage or collapse.

4.2 Demand Curve

Demand spectrum can be obtained from the conversions of ATC, which is obtained between spectral acceleration and spectral displacement. Both the demand spectrum and capacity curve are converted into same units

as they have to be superimposed in one graph to obtain the performance point of the structure.

4. NUMERICAL MODELLING

A Reinforced concrete three structures representing low (G+4), medium (G+7) and high (G+11) rise reinforced buildings are considered in this study. Using equivalent static lateral force method for zone-III for soil type-II (Medium soil) as per IS 1893(part 1):2002, five type of irregularities (Stiffness irregularity, mass irregularity, vertical geometry irregularity, in-plane discontinuity in vertical elements resisting lateral force and discontinuity in capacity) are introduced to the buildings. Five types of irregular models with regular frame model and three different storey structures makes a total numbers of sixteen frame models.

All models are designed as per Indian codes IS 456-2007 and IS 1893-2002.Basic dimensions and loadings are taken from the previous works by Kard (2007) and Kadid (2008). As per codal provisions loading combinations are taken as 1.5(DL+LL).Models are created and analyzed by the Structural analysis Program SAP2000.

5. PRELIMINARY ASSUMED DATA:

Descriptions of Building
Structure type: Special Moment Resisting Frame [SMRF]
Plan dimension: 4 x 4m
Slab thickness: 150 mm
Storey height: All models have a uniform height of 3m except SI4, SI7 and SI11 model's bottom storeys.SI4, SI7 and SI11 have a bottom storey height of 5m. [Soft storey frame-SI]
Height of building: G+4, G+7, G+11 = 5, 8,12storeys.
Grade of concrete: M25.
Grade of steel: Fe415.
Column size: bottom storey columns - 600x600 mm and other columns - 500 x 500 mm.
Beam size: 230 x 600 mm.
Density of Brick wall: $18Kn/m^3$
Live load: $3.0Kn/m^3$
Floor finish: $1.0Kn/m^3$
Commercial loading for Mass irregularity: $5.0Kn/m^2$
Seismic zone: Zone III
Zone factor: 0.16
Soil type: Type 2(Medium soil)
Importance factor: 1
Response reduction factor: 5.0(SMRF)

6. PUSHOVER ANALYSIS RESULTS

6.1 Hinge results

After the analysis, SAP2000 shows the pushover results for each step. Results shows the five points labeled A, B, C, D, and E are used to define the force deflection behavior of the

hinge and three points labeled IO, LS and CP are used to define the acceptance criteria for the hinge. (IO, LS and CP stand for Immediate Occupancy, Life Safety and Collapse Prevention respectively.)The values assigned to each of these points vary depending on the type of member as well as many other parameters defined in the ATC-40 and FEMA-273 documents. The typical regular G+7 model Pushover analysis Hinge results are shown in Fig 1.
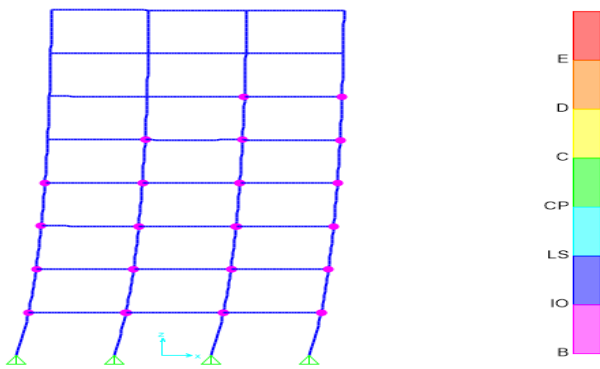

Fig -1: Failure Pattern of RF7 (regular frame) Model

7. PUSHOVER CURVE RESULTS

In SAP2000 pushover curves are obtain in the form of capacity curves and capacity demand curves.

7.1 Capacity Curve

Figure 2 shows the failure pattern (Capacity curve) of RF7 Model at the performance point of the buildings. Performance point is the junction of demand created by the earthquake and resistance provided by the building (capacity).It is determined by the ATC 40 Capacity spectrum curve
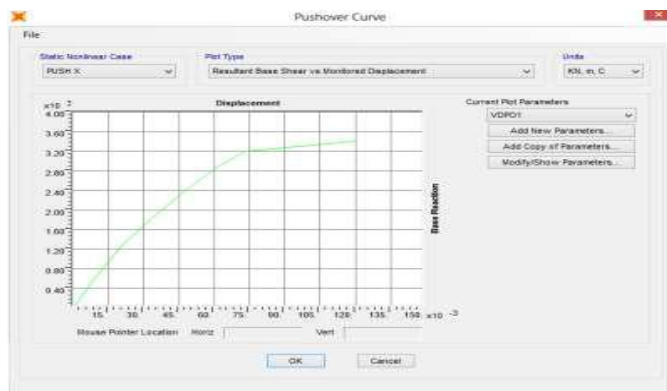
Fig -2: Capacity Curve

7.2 Demand Curve

Figure 3 shows that the demand curve and it lies near the yield region and it means structure safe during an earthquake and the figure 3 also shows the performance of the building frame.
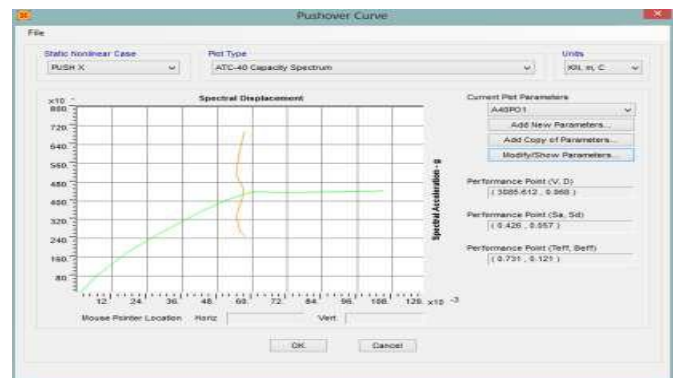
Fig -3: Demand Curve

7.3 BASESHEAR RESULTS

Base shear results shows the maximum base shear utilized by the buildings to the corresponding roof displacements. Figure 4 shows the base results of RF4, RF7 and RF11 models.
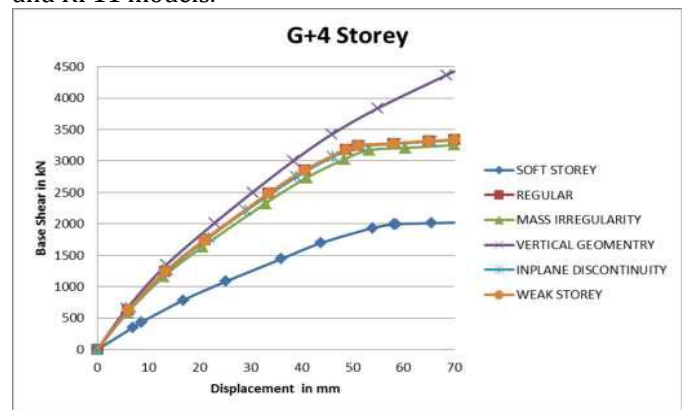
Fig -4: Base shear Results of G+4 Models

Figure 4,5 and 6 shows the base shear results of G+4,G+7 and G+11 models.

Fig -5: Base shear Results of G+7 Models

7.4 Storey drift results

The Storey drift can be defined as the ratio of roof displacement to the height of the story measured from the top of the RC footing to the center line of the RC beam. Figure 7, 8 and 9 shows the storey drift results G+4, G+7and G+11 models respectively.
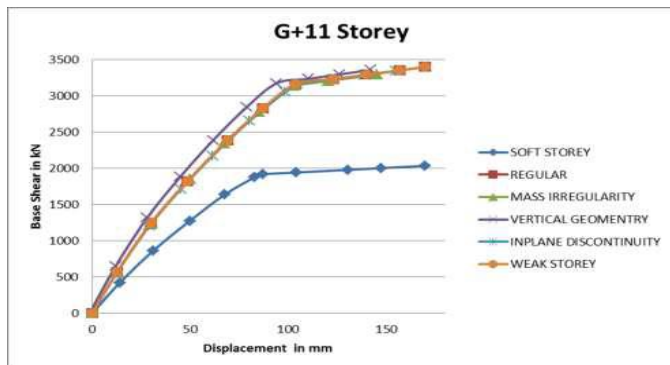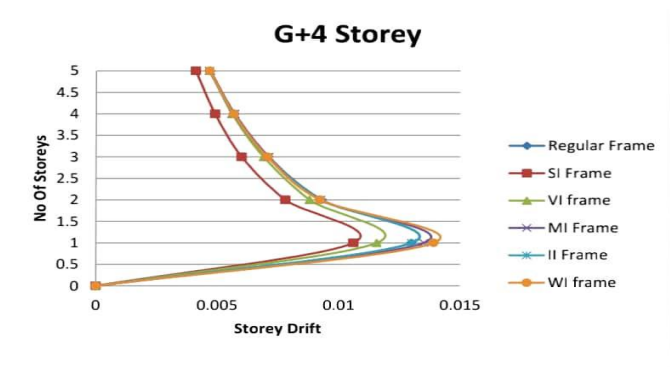
Fig -6: Base shear Results of G+11 Models

Fig -7: Storey Drifts of G+ 4 Models
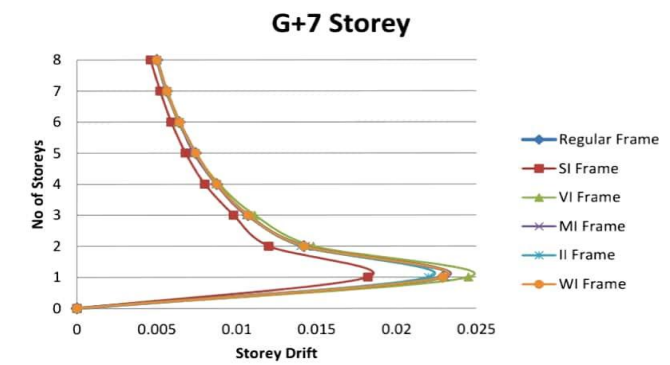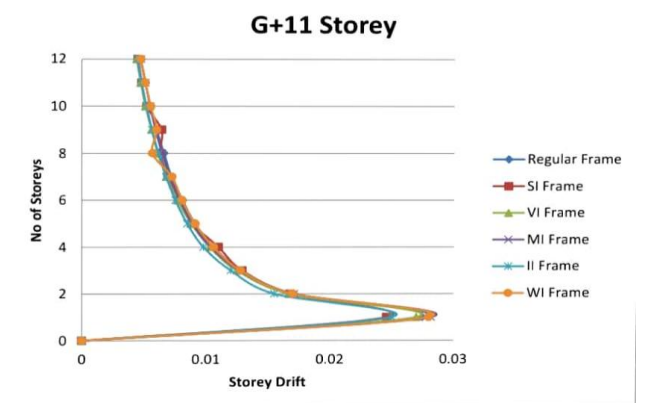

Fig -8: Storey Drifts of G+ 7 Models

Fig -9: Storey Drifts of G+ 11 Models

8. TIME HISTORY ANALYSIS

In Time history analysis, past Earthquakes Acceleration vs. time data's are used for Analysis. SAP2000 is the software tool used for time history analysis. In this study three ground motion records are used for analysis. The earthquake records are downloaded from IIT Roorkee website (http://pesmos.in/2011). Time history data is selected between peak ground acceleration of 0.3-0.4 g and magnitude of 4-5.1. All three records are taken from three different earthquake zones of India and same soil type.

8.1 Time history accelerogram

Accelerograms are directly input to the SAP2000 Program by the time history function option. Accelerogram data's are drawn between acceleration in m/s2 in vertical axis and time in seconds in horizontal axis. Noida earthquake accelerogram contains 6000 records in the interval of 0.005 seconds.
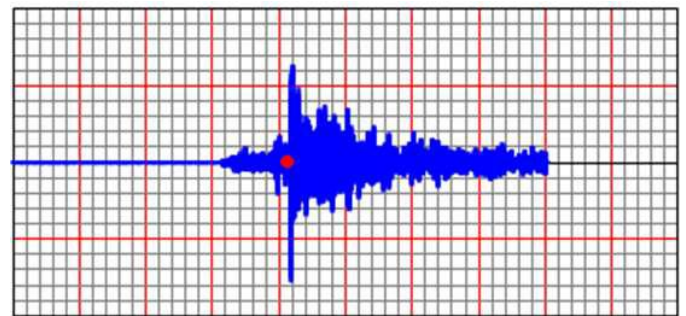

Fig -10: Input Accelerogram for Noida Earthquake

Uttrakashi earthquake accelerogram contains 13000 records in the interval of 0.005 seconds and Assam earthquake accelerogram contains 13100 records in the interval of 0.005 seconds.
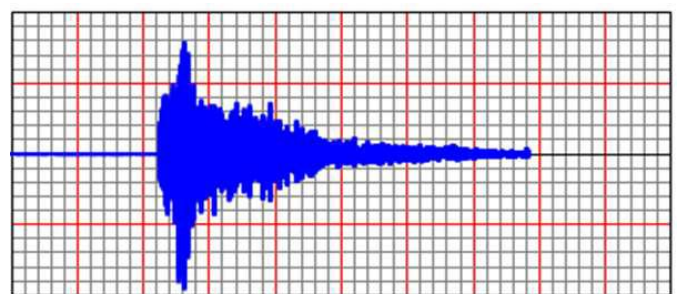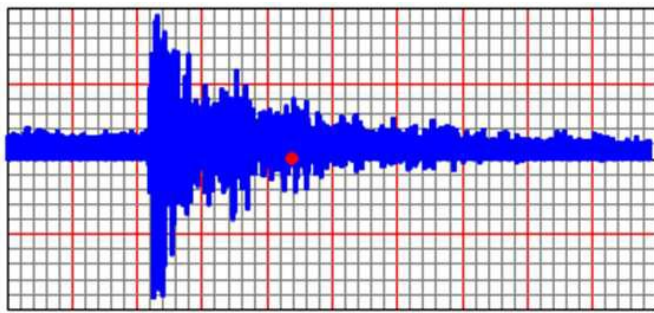

Fig -11: Input Accelerogram for Uttrakashi Earthquake

Fig -12: Input Accelerogram for Assam Earthquake

8.2 Base shear results

Time history analysis results are obtained by selecting base shear in vertical side and time data in horizontal side in the output results. From the 48 base shears vs. time results, RF4, RF7 and RF11 frame results are shown in the following figures. For storey drift results, envelope curve is used for obtaining results of respected strong ground motions. Graph drawn between base shear in kN in vertical axis and time in seconds in horizontal axis.

Fig -12: Base shear Results for Noida Earthquake

Fig -13: Base shear Results for Uttrakashi Earthquake

8.3 STOREY DRIFT RESULTS

The Storey drift can be defined as the ratio of roof displacement to the height of the story measured from the

top of the RC footing to the center line of the RC beam. For time history analysis results, envelop curve is used for storey drift calculations. From the eighteen models, six G+4 storey drift results are graphically represented by Figures15 to 20.
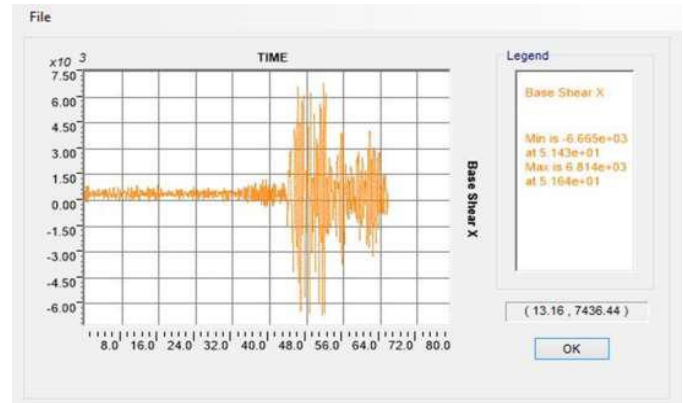

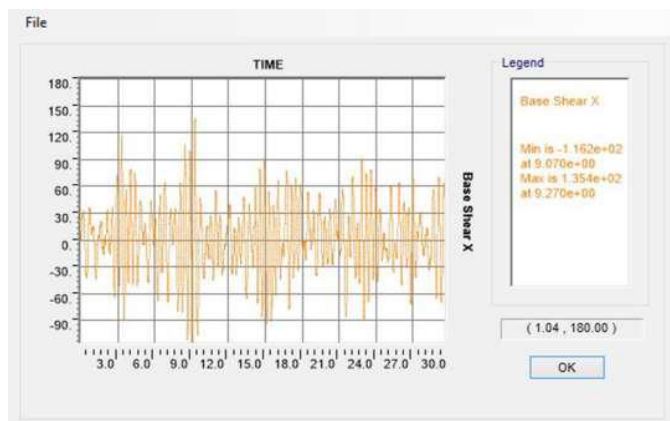
Fig -14: Base shear Results for Assam Earthquake

Fig -15: Regular Frame Model Storey Drift

Fig -16: Mass Irregular Model Storey Drift

Fig -17: In plane irregular frame Storey Drift

Fig -18: Vertical Geometry Irregular frame Storey Drift
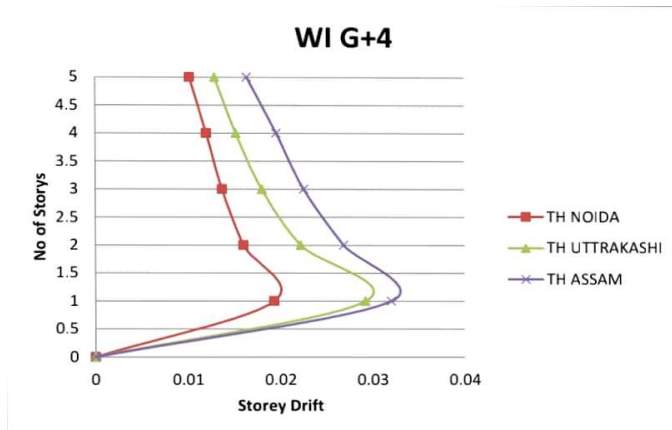
Fig -19: Weak storey Irregular frame Storey Drift

Fig -20: Soft storey Irregular frame Storey Drift

9. RESULTS AND DISCUSSIONS

Main objective of the thesis is to check the accuracy of the pushover analysis for vertically irregular frames. Time history analysis results show the actual response of selected earthquake accelerograms. Pushover analysis results show the pre estimated seismic analysis results. So the comparison between these methods gives the clear idea about the accuracy of pushover analysis. In this chapter comparison should be done by the store drift results. For the comparison, average curves of time history storey drift results are used in this study. Figures 21-23 shows the comparison between pushover and time history storey drift results of G+4, G+7 and G+11 models.
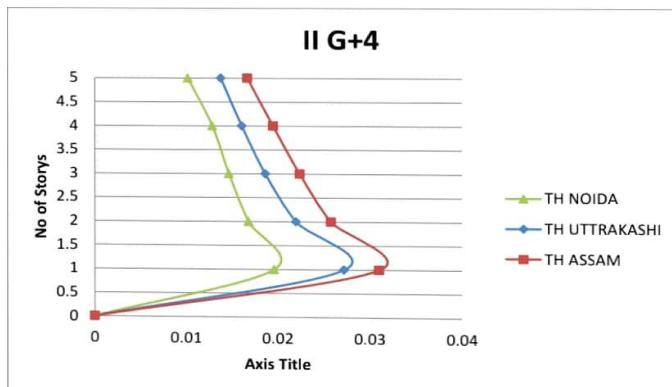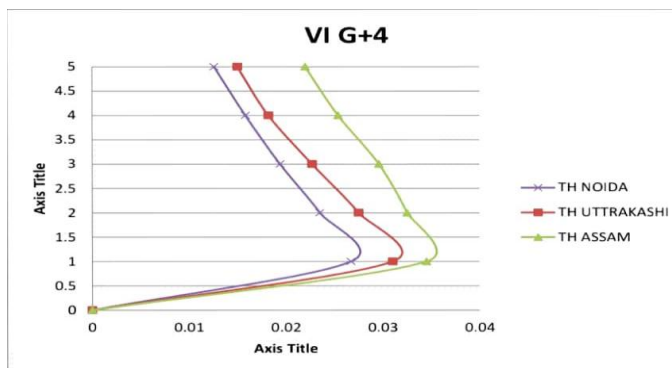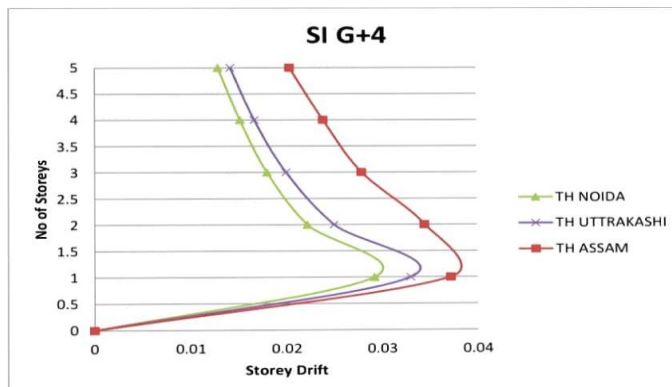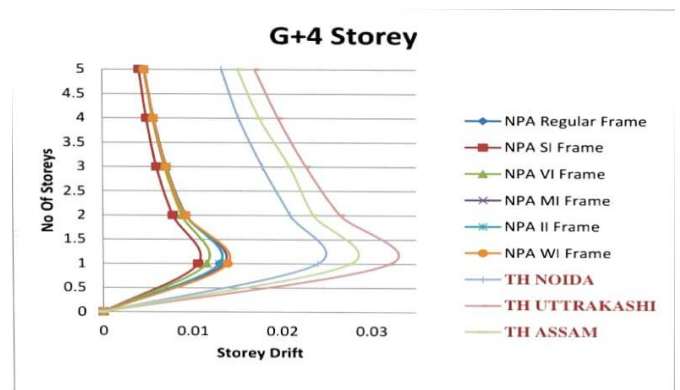

Fig -21: Comparison of Storey Drift Results of G+4 Models
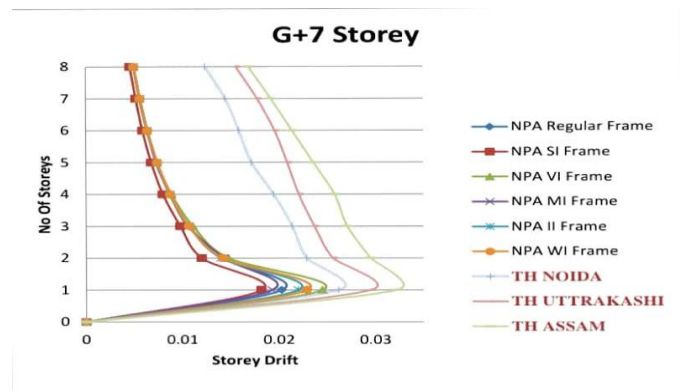

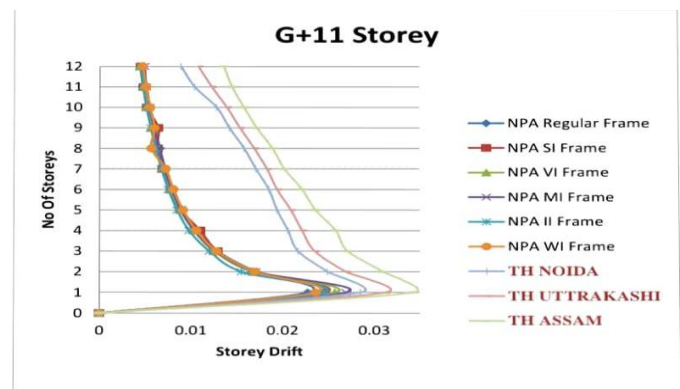**Fig -22**: Comparison of Storey Drift Results of G+7 Models

Fig -22: Comparison of Storey Drift Results of G+11 Models

10. CONCLUSION

The main objective of this thesis work is to estimate the effects of vertical irregularities in RC frames by the non-linear static analysis (pushover analysis) and the accuracy of the pushover analysis is verified by the non-linear time history analysis. As per IS 1893-2002 part I five types of vertical irregularities are used in this study namely the Stiffness irregularity, mass irregularity, vertical geometry irregularity, in-plane discontinuity in vertical elements resisting lateral force and discontinuity in capacity. Three different storey frames (G+4, G+7 and G+11) and three different ground motion records are used for time history analysis. Both the analyses are done using the SAP2000 program. Base shear forces and Storey drift results are obtained from the analysis. Results of this study give the following conclusions

10.1 BASESHEAR RESULTS

1)   From base shear results, it is found that the vertical geometry irregular frames give the maximum base shear and soft storey irregular frames give the minimum base shear.

2)   When compared to regular frame vertical geometry Irregular frames gives the 45 % increase in base shear and soft storey irregular frames gives the 57 % decrease in base shear.

3)   From the total base shear results, increase in number of storey increases the displacement demand of the models that means G+ 4 storeys give the minimum base shear force and G+ 11 storeys give maximum base shear at roof level.

10.2 Storey drift results

1)   From the storey drift results, it is found that soft storey Irregular frame gives maximum storey drifts and weak storey Irregular frame gives minimum storey drifts.

2)   When compared to regular frame soft storey Irregular frames gives the maximum 55 % increase in storey drift and weak storey irregular frames gives the maximum 17 % decrease in storey drift.

3)   When compared to all models G+4 models gives the maximum drift for all irregularities

10.3 General conclusion and recommendations

Comparison between the pushover analysis and time history analysis storey drift results gives the following conclusions:

1)   Pushover results are close up to 32 % for lower storeys and 57 % deviation in the upper storeys.

2)   Pushover results are more accurate in G+ 11 models and less accurate in G+ 4 models. So higher number of storeys increases the accuracy of pushover analysis.

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