SEISMIC ANALYSIS OF BUILDING WITH MASS AND STIFFNESS VARIATION

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Abstract: Earthquakes are a major problem all around the world as they cause catastrophic damage such as building failure and collapse and most importantly loss of human lives and homes. One of the most common causes of failure during earthquakes is irregular configuration, either in plan or in elevation. As a result, irregular structures, especially in seismic zones, becomes the main cause of concern. The present study deals with the performance analysis of a G+15 Storey building with Stiffness and Mass irregularity carried out by varying the positions of these irregularities in the building as per IS 1893 (Part 1): 2002 considering seismic zone 5. Equivalent static analysis has been adopted for analysing the effect of Stiffness and Mass irregularity using ETABS16 software. Parameters such as Storey displacement, Storey drift, Storey stiffness, Storey shear and overturning moment have been considered for its performance study. With the consideration of all the irregular models and their behavior in earthquake loading, it is evident that the MODEL-5 gives the most optimal results and is recommended to be constructed in the earthquake prone areas that includes least Displacement, least Drift and least Shear force among all the other models.

1. INTRODUCTION

An "earthquake" is defined as a change in the surface of Earth. Surface of the Earth is suddenly shaking. Earthquakes are undeniably terrible disasters. A combination of earthquake's magnitude & distance from its epicentre determines level of severity. The capacity of a tall building to withstand substantial shaking vibrations is affected by its vertical and horizontal mass distribution and stiffness. If building's stiffness or mass varies significantly across floors, we say that it is irregular. Worryingly, there is a vertically unequal frame that might collapse in the event of an earthquake. Points where structure's stiffness, mass, or strength suddenly changes are called weak or crucial points. Decay and ultimate collapse of the building are caused by this defect. Irregular building shapes, whether in plan or in height, are one of main causes of earthquake failure.

Disruptions may be categorized into two main kinds.

1. Vertical Irregularities
2. Plan Irregularities

Vertical Irregularities are mainly of five types.

Stiffness Irregularity: For a storey to be considered soft, its lateral stiffness must be lower than 70% of the storey above it or lower than 80% of average lateral stiffness of 3 storeys before.

Stiffness Irregularity: When lateral stiffness is lower than 70% of average stiffness of 3 storeys above or lower than 60% of lateral stiffness of the storey above, we say that storey is very soft.

Mass Irregularity: Any story with a seismic weight more than 200% of surrounding storeys is said to have mass irregularity. It is not necessary to take roof irregularities into account.

Vertical Geometric Irregularity: Lateral pressure resisting system in any given storey must have horizontal dimension more than 150 percent of that in next storey for the building to be deemed vertically geometrically uneven.

In-Plane Discontinuity in Vertical Elements Resisting Lateral Force: Length of elements resisting lateral force is higher than the in-plane offset of those elements.

Discontinuity in Capacity: Storey Weakness—A storey is considered weak if its lateral strength is lower than 80% of storey above it.

2. LITERATURE REVIEW

1.Muzammil Ahmed, et.al: Using seismic zone 4 as a reference, this research analyzes performance of a G+6 storey residential structure with stiffness and mass anomalies by modifying their placements inside the building, in accordance with IS 1893 (Part 1): 2002. Impact of stiffness & mass irregularity was examined using response spectrum analysis in the ETABS16 program. The performance analysis took into account parameters including overturning moment, Storey shear, Storey stiffness, Storey drift, and Storey displacement. After looking at how each of the non-standard models reacts to dynamic earthquake loading, it's clear that Model H11 produces best results and should be built in earthquake-prone regions because it has lowest levels of displacement, drift, and shear force.

2. Kaushal Basaraf et.al: Effect of earthquake lateral pressures on an unevenly-structured building's reaction is examined in this research by examining the effects on each floor of the building. Because of their status as industry standards for seismic analysis and design, research follows requirements laid forth in IS 1893:2016 (Part 1). Findings emphasize critical requirement of precise mass placement in reducing earthquake hazards by showing that an uneven distribution of mass produces significant sideways forces and structural instability. Report goes on to say that structures whose stiffness distribution isn't uniform are more likely to experience structural collapse due to torsional impacts during earthquakes. Buildings may be more effectively designed to resist lateral pressures and minimize damage by engineers adhering to standards outlined in IS 1893:2016 (Part 1). In order to guarantee stability and safety of structures in earthquake-prone regions, this study highlights the significance of seismic design that takes into account the distribution of both mass and stiffness. Taking this tack may lessen the financial toll of future earthquakes while also saving lives.

3. More Amol R, Prof. Dr. Kale R.S: Impact of irregularities in column stiffness and mass on a structure's seismic response is the focus of this research. This project's overarching goal is to conduct RSA on RC building frames that are irregular in their vertical mass and column stiffness. There will be a comparison of the analysis findings for regular and irregular structures. Also included will be a comparison of mass irregular structures with varying column stiffness.

4. Saugat Tiwari, et.al: This article analyses and numerically models a ten-story RC structure in SAP 2000 with changing mass and stiffness parameters. To simulate the building, response spectrum analysis is used. Seismic zone V and medium soil type are used in four separate models that have various loadings and combinations of loads. Standards such as IS 456:2000 and IS 1893 (Part 1):2016 are used for building modeling. Each building is given a unique mix of dead load, live load, and seismic load based on the structure's applied loads. Deformation, base shear, storey drift, and reinforcing bar need are some of the structural characteristics that are computed using the SAP2000 building model. The axial forces in the columns and the building's base shear both rise when the stiffness of the columns is increased. Similarly, when the lateral force increases due to a building's mass concentration on the upper floor, the displacement of that floor is greater. According to the results, buildings with same floor height are less important than those with uneven floors and higher floor heights. Stiffness and mass variation closer to the structure's base, as opposed to its top, reduces rebar required and building displacement.

5.Shirin vaghasia, et.al: Nowadays, just as in cities, there isn't a lot of room to develop on. Therefore, we need to design multi-use buildings with numerous functions, including lobbies and parking garages, to make the most of the space we have. Only alternative that can meet this need are buildings with anomalies. Irregular structures are those that have discontinuities. A significant amount of urban infrastructure consists of irregularly shaped buildings. When an earthquake strikes, weak spots in a building are the first to give way. A structural discontinuity in mass, stiffness, or geometry causes this weakness. When earthquakes strike, buildings with vertical abnormalities are more likely to collapse. Models were examined in ETABS 2013 to evaluate the behavior of buildings with mass, stiffness, and vertical abnormalities at various levels. All models in seismic zone III are being considered for this building behavior research. This analysis should take into account the following parameters: base shear, storey drift, lateral displacement, time period in different mode forms, force in beam and column.

6.Avantika H. Dahikar et.al: A seismic resistant structural study is an important part of this research as it will allow us to compare buildings with various floor plans. Here, the behavior of structures shaped like G + 5 H is studied. The dimensions of the planned H-shaped building are 29 by 35 meters, and its structural attributes have been specified. The building model is made using the STAAD Pro program. In accordance with IS 1893: 2002 part1, the characteristics are specified. The model takes into account a seismic zone of IV and a soil type of medium. Indian seismic zone IV, IS1893–2002, is used for construction modeling. The imposed loads on a specific structure comprise live load, seismic zone load, and dead load in that order. Our load consumption data is likewise based on the standards set by IS1893 (part 1):2002.The maximum node, displacement, and base shear stiffness are determined by the study. Graphs representing the outcomes of the investigation are then examined in order to derive conclusions.

7.P.Vignesh, et.al: Seismic resistance of structures with unusual vertical orientation has been investigated. Examining the effects of earthquakes on G+6RC L-shaped buildings with regular and uneven stiffness is the primary goal of this research. The ETABS 2017 program is used for the building's modeling and analysis, and Nonlinear Static Analysis is taken into account for evaluation. It is possible to get several seismic reactions, such as lateral displacement for the column at the projection end (C1) and the re-entrant corner (C2), as well as storey shear force. A comparison among vertical regular & irregular structures has been done utilizing these replies. Findings indicate that, when subjected to seismic force, a structure having stiffness irregularities becomes unstable. Consequently, RC construction benefits from a corresponding level of stiffness to limit instability.

8.Syed Abubakar et.al: In this research, we try to figure out how 15-story reinforced concrete frame buildings affected by soft storeys react to seismic stress according to IS-1893: 2002 (Part-I). To mitigate the effects of buckling due to thinness, appropriate building layouts and configurations were selected with regard to the height-to-width ratio and element size. By altering the characteristics of the storey members in question, and in particular by raising the storey height by 46.87%, irregularities are introduced. Next, the response parameters of the idealized 15-story model were evaluated under different combinations of tit soft storey locations using the software ETABS, and the results were compared with those obtained manually using the Seismic Coefficient Method. From a building without any soft storeys at all to one with four, the research included five distinct scenarios, each with its own unique mix of soft storeys. Five, ten, twelve, and fifteen stories of the building were proposed. In this report's findings section, you may see a series of reaction charts that were used to measure stiffness, displacement, and inter-story drift.

9.Brahim Benaied, et.al: This research looks at the inelastic behavior of reinforced concrete structures that have mass and stiffness defects when hit by an earthquake. This leads us to use the adaptive pushover approach that is based on displacement. The latter is driven by the use of a lateral displacement pattern that is updated progressively at each analysis step and is created by mixing distinct mode shapes. In order to evaluate and quantify the reactions of important factors, a ten-story regular frame structure is selected and then changed by adding vertical irregularities in different shapes. Base shear forces, roof displacement, inter-story drift, and story-shear distribution are the headings used to describe the acquired data. In terms of vertical mass and stiffness abnormalities, it was seen that stiffness irregularities had a more substantial influence on the seismic response than mass irregularities that were determined to have a little effect on the building's seismic behavior. Furthermore, it is shown that the straightforward method permits a more reasonable assessment of design forces and displacements, in line with the present understanding and contemporary trends in construction standards. But the findings show that the asymmetrical building can't handle seismic loads and has to be built differently.

3. OBJECTIVES AND SCOPE OF WORK

3.1 Objectives: Following are primary aims of conducted research.

1. With the goal of eliciting the behavior of a normally constructed structure.
2. In order to learn how stiff and mass-irregular RC constructions behave and function, we need to compare and contrast the two.
3. For the purpose of comparing and analyzing its reactions, such as overturning moment, storey displacement, storey drift, storey shear force, and storey stiffness, optimal design should be considered.
4. To do an equivalent static analysis with medium soil conditions, taking seismic zone-V into account.

3.2 Scope of work:

1. RC building (both regular and irregular) was the subject of the modeling.
2. The brick wall's weight was taken into account.
3. A seismic zone factor was applied to all models and the results of base shear, time period, displacement, and tale drift were compared.
4. This research shows that in seismic zone V, mass and stiffness vary in various places.

4. METHODOLOGY

While the study just considers gravity loads at slab level, the swimming pool introduces mass irregularities to the structure. All swimming pools must be filled to the same level with water. Methodology encompasses the following:

1. A literature review was conducted to comprehend the topic's core notion by referring to books and research papers.
2. Recognition of the need for investigation and formulation of a problem statement.
3. Choosing a course of study, It is necessary to use software in order to do analytical modeling work.
4. Examining each model with the help of the ETABS software.
5. Results and their interpretation and conclusion.

4.1 Description of Models: For the purpose of seismic analysis, nine models of standard RC buildings were created.

1. Model-1: Regular Model with no irregularities.
2. Model-2: Stiffness irregularities in Ground floor and Mass irregularities in First floor.
3. Model-3: Stiffness irregularities in Ground floor and Mass irregularities in Sixth floor.

4. Model-4: Stiffness irregularities in Ground floor and Mass irregularities in Eleventh floor.
5. Model-5: Stiffness irregularities in Ground floor and Mass irregularities in sixteen floor.
6. Model-6: Stiffness irregularities in 8th floor and Mass irregularities in First floor.
7. Model-7: Stiffness irregularities in 8th floor and Mass irregularities in Sixth floor.
8. Model-8: Stiffness irregularities in 8th floor and Mass irregularities in Eleventh floor.
9. Model-9: Stiffness irregularities in 8th floor and Mass irregularities in sixteen floor.

4.2 Modelling different types of model using Etabs

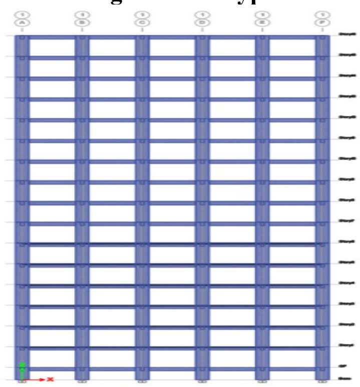


Figure-1: Elevation of regular model with no irregularities

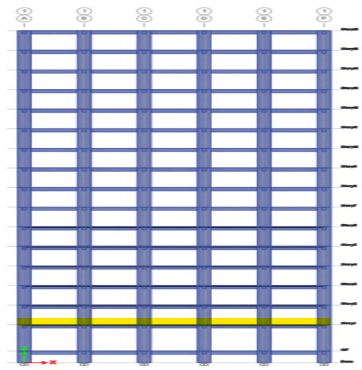


Figure 2: Elevation of model-2 with stiffness irregularities in GF and Mass irregularities at First floor

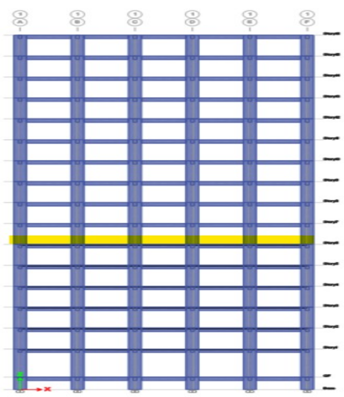


Figure 3: Elevation of model-3 with stiffness irregularities in GF and Mass irregularities at sixth floor

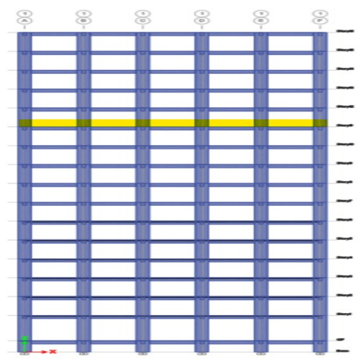


Figure 4: Elevation of model-4 with stiffness irregularities in GF and Mass irregularities at 11th floor

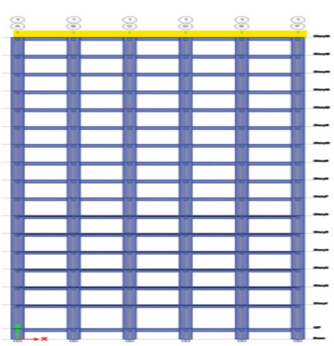


Figure 5: Elevation of model-5 with stiffness irregularities in GF and Mass irregularities at sixteen floor

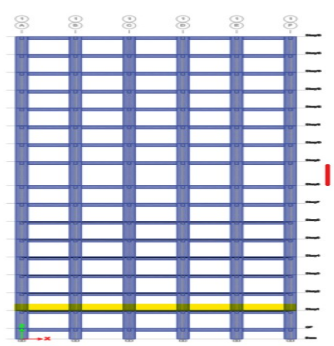


Figure 6: Elevation of model-6 with stiffness irregularities in 8-floor and Mass irregularities at first floor

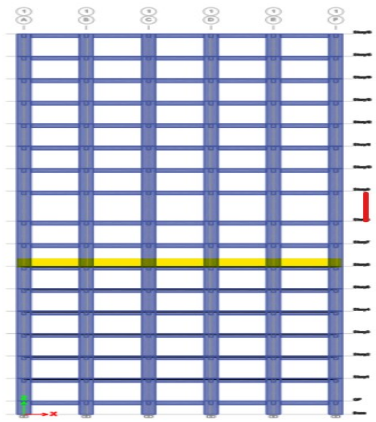


Figure 7: Elevation of model-7 with stiffness irregu larities in 8-floor and Mass irregularities at sixth floor

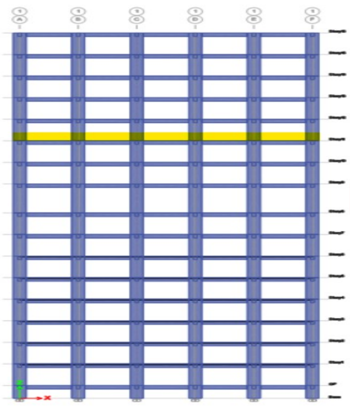


Figure 8: Elevation of model-8 with stiffness irregularities in 8-floor and Mass irregularities at Eleventh floor

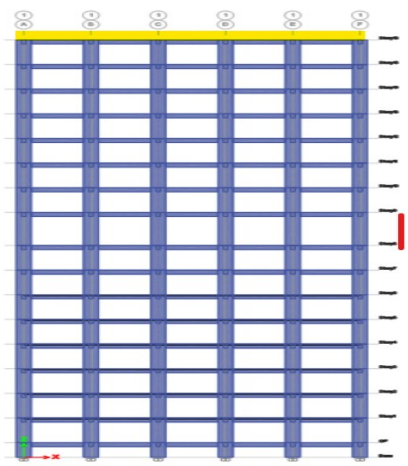


Figure 9: Elevation of model-9 with stiffness irregularities in 8-floor and Mass irregularities at sixteen floor

4.3 Details of Structure:

Building type	**Commercial Building**
Frame type	Special moment resisting frame
Size of Building	25m x 25m
Total storeys	17 (G+16)
Each storey height	3.35m
Bottom storey height	2.0m
Full height of building	56.75 m
Wall thickness	230mm
LL (live load)	3KN/m^2
FF(floor finish)	1.0 KN/m^2
Concrete grade	M40
Steel grade	500 N/mm^2
Density of Brick masonry	18 KN/m^3
Size of column	700mm x 1100 mm
Size of Beam	300mm x 550mmm
Thickness of slab	150mm
Seismic zone	V
Response Reduction Factor	5.0
Type of soil	Medium

4.4 Following loads are considered for analysis:
4.4.1 Dead load
4.4.2 Live load
4.4.3 Seismic load

5. METHODS OF SEISMIC ANALYSIS

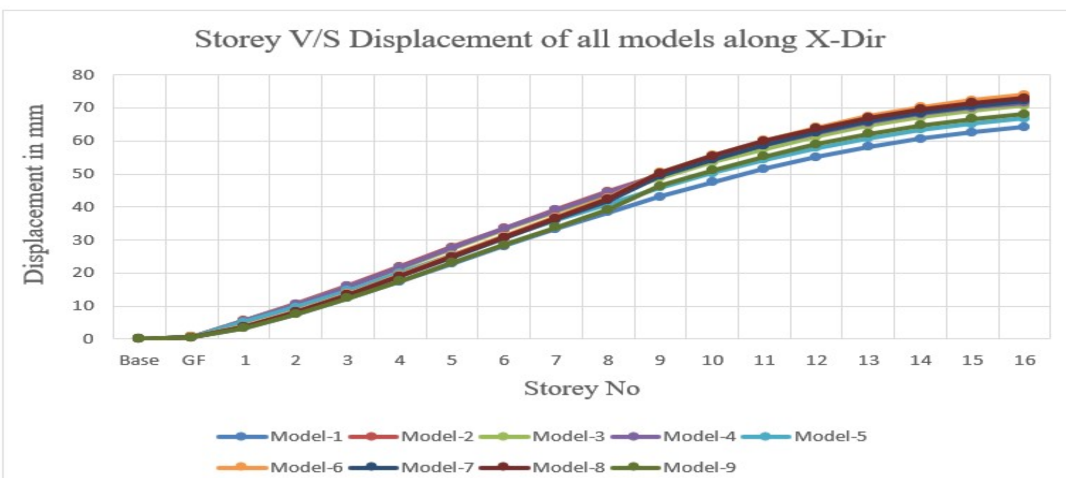
Aim of carrying out the seismic analysis is to make the structure resistant having tremor forces. Earthquake is a natural calamity. If all of a sudden earthquake occurs and the building is designed considering the earthquake loads, the building may get damaged due to lateral loads but it will not collapse. Thus it provides sufficient time for the resident to escape from the disaster.
Seismic analysis is the process of calculating of overburden forces. These forces are incorporated and the design is carried out. The capability of building to resist the lateral force increases & damaging due to seismic action can be minimized. Because of seismic analysis, the structure becomes more stable to seismic forces and prevents life loss that occurs due to earthquake.
It is possible to classify certain approaches to seismic analysis as either linear or non-linear. There are a variety of linear approaches, such as linear dynamic and RSA methods, as well as linear static and equivalent velocity methods. Some instances are as follows:

a. Equivalent static analysis
b. Response spectrum analysis
c. Pushover analysis
d. Time history analysis

6. RESULT AND DISCUSSION

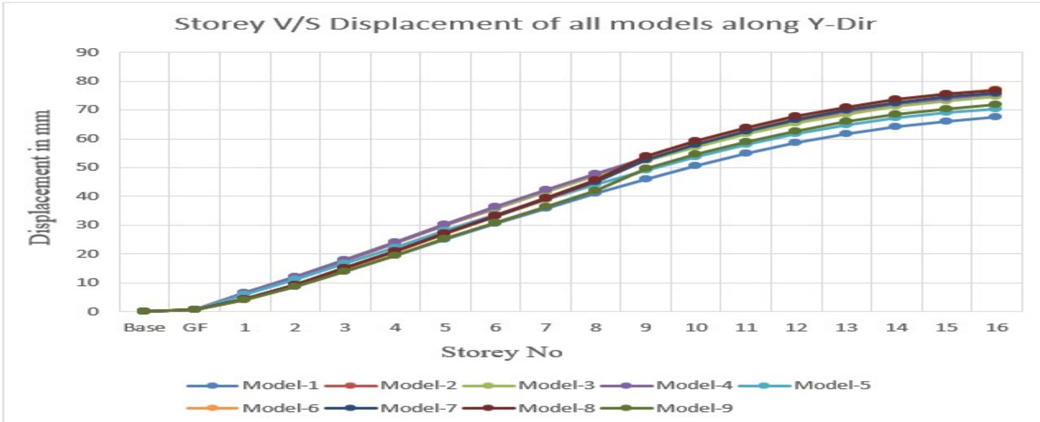
6.1 GENERAL:
Seismic load equivalent static technique was used to construct nine RC building models for the purpose of assessment. Using the ETAB 2020 program, we were able to finish analyzing all of the distinct building models. We compare results for one standard building and eight variational structures with respect to mass along with stiffness as a function of displacements, storey drifting, time periods, and foundation shear.

6.2 DISPLACEMENT: When a building's foundation is moved relative to the ground, the displacement of a floor is said to be one storey.
As Per paragraph 7.11.1.2 of IS 1893 Part 1, the maximum permissible displacement in a multi-storey building is hs/500, where hs is the height of the structure.. Allowable deflection is 56.75/500 = 0.1135m=113.5mm



Graph 6.1: Displacement in mm of all models due to seismic load along X-direction.

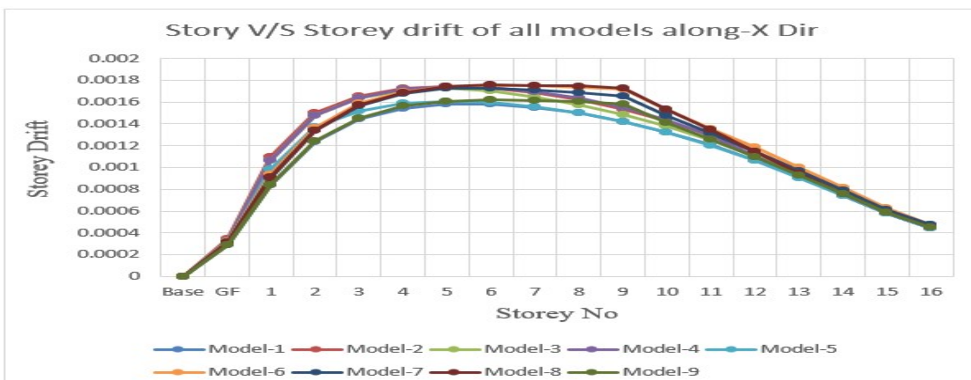
With graph it's seen as displacement is minimum for regular building. As the stiffness irregularities at ground floor kept constant and mass irregularities are changed at different floor the displacement gets increases in model-2 to model-4. But it is noticed that when the mass irregularities are taken at top floor (sixteen storey) the displacement gets decreases compare to model-2 to model-4.
Hence now stiffness irregularities are changed to 8th floor and mass irregularities are taken successively at 1st floor, 6th floor, and 11th floor there is not that much variation in displacement.



Graph 6.2: Displacement in mm of all models due to seismic load along Y-direction.

With graph its observed as least displacement was observed in model-1 compared to all other models. When we go with model-2 there is an increase in displacement of about 10.52%. When we switch to model-3 there is increase in displacement of about 9.48%. When we go with model-4 there is increase in displacement of about 10.52%, when we go with model-5 there is increase in displacement of about 4.15%. Similarly when we go till model-9 there is increase in displacement in same range as above.

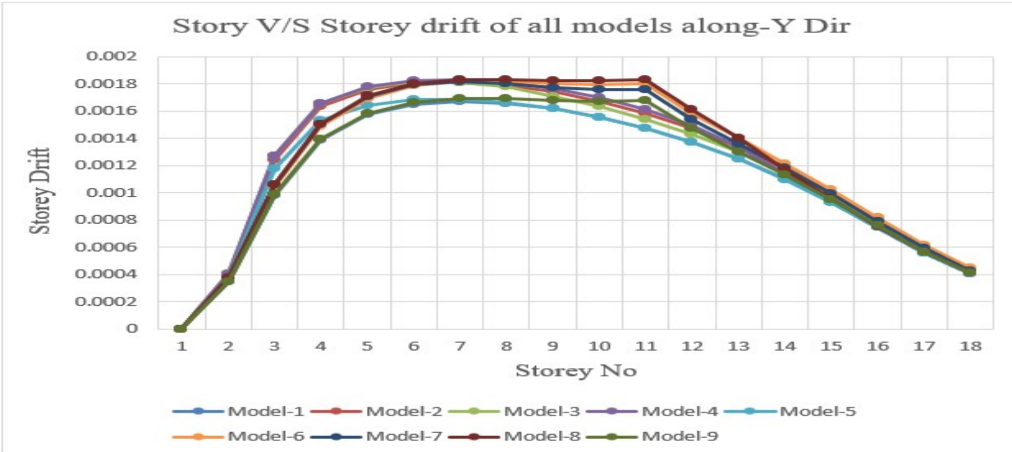
6.3 STOREY DRIFT: Term "storey drift" refers to horizontal displacement of one floor in relation to another, & "storey drift ratio" is calculated by dividing this displacement by height of a storey.



Graph 6.3: Storey Drift in mm of all models because of seismic load along X-direction.

With graph its seen as storey drift is minimum for model-1 at storey-1. As we introduce stiffness irregularities at ground floor and mass irregularities at 1st floor in model-2 there is an increase in drift value of about 23.72%. As we go with model-3 there is increase in drift of about 21.42%, when we switch to model-4 there is increase in drift of about 21.50%, when we go with model-5 there is increase in drift of about 15.29% compared to model-1.

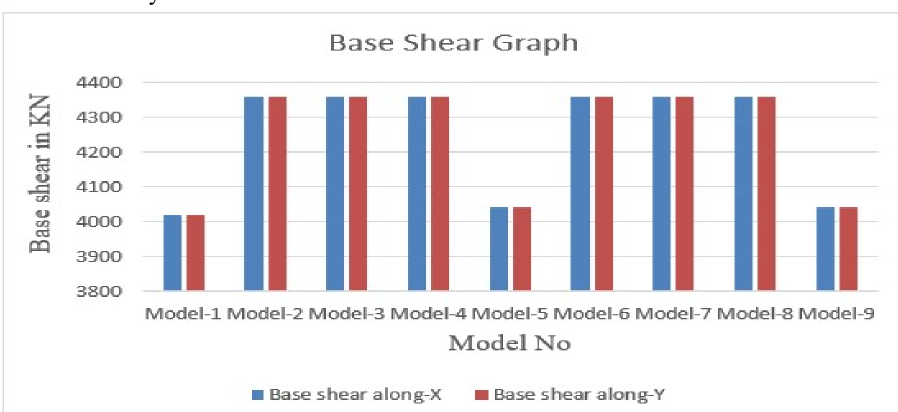
When we go to model-6 where stiffness irregularities at 8th storey and mass irregularities at first floor the drift values get increases of about 10.30%. When we switch to model-7 the drift value gets increases of about 7.82%, and when we go to model-8 the storey drift goes on increases of about 7.82%. When we switch to model-9 the storey drift gets increases of only 0.594% compared to model-1.



Graph 6.4: Storey Drift in mm of all models because of seismic load along Y-direction.

With graph its observed as storey drift is minimum for model-1 which is regular building. As we go with model-2 where we have stiffness irregularities at ground floor and mass irregularities successively at 1st floor, 6th floor, 11th floor and 16th floor the storey drift increases by 21.15%, 22.71%, 22.77% and 16.66% respectively.
Now stiffness irregularities are changed to 8th story and mass irregularities are kept successively at 1st floor, 6th floor, 11th floor and 16th floor the storey drift gets increases by 6.13%, 7.8%, 7.89% and 0.6% compared to model-1.

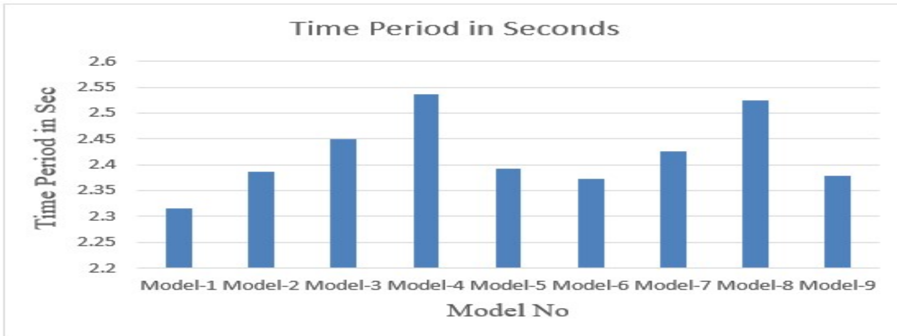
6.4 BASE SHEAR: It's a prediction of the greatest lateral forces that might occur at a building's foundation as a result of seismic activity.



Graph 6.5: Base Shear in KN of all models because of seismic load along X and Y-direction.

With graph its seen as base shear is minimum for model-1 (Regular building). As we introduce mass irregularities at first floor and stiffness irregularities at ground floor then there is small increase in base shear of 7.7% in model-2. As we change position of mass irregularities in other floors but stiffness irregularities kept at ground floor only i.e in model-3, model-4 the base shear remains same. But when we change position of mass at top floor (Roof) then base shear decreases with respect to model-2, 3, 4.
Next we change the position of stiffness irregularities at 8th floor and mass irregularities at first floor then base shear remains same as model-2. Then mass irregularities are change to 6th floor, next 11th floor the base shear remains same as model-2.

6.5 TIME PERIOD: It is the amount of time it takes for a single vibration cycle to pass through a certain place.



Graph 6.6: Time Period in Seconds of all models due to seismic load

With graph its seen as time period is minimum for regular building. As the stiffness irregularities at ground floor and mass irregularities at first floor taken the time period gets increases in small amount i.e 2.97%.
Next stiffness irregularities at ground floor and mass irregularities at sixth floor is taken then again time period gets increases by an amount equal to 5.43%.
Again when we move towards model-4 where time period gets increases by an amount equal to 8.67% compared to model-1. When we see other models from model-6 to model-9 there is not that much increase in time period as compared to model-1.Hence someone can go with stiffness irregularities and mass irregularities at a time.

7. OBSERVATION AND CONCLUSION

1. As seen time period is maximal in model-4 and model-8, this is due to Stiffness irregularities in Ground floor and Mass irregularities in Eleventh floor and Stiffness irregularities in 8th floor and Mass irregularities in Eleventh floor.
2. The least time period is observed in model-1 which is regular building.
3. The least base shear is observed in model-1 which is regular building.
4. As the stiffness irregularities in **ground floor** and mass irregularities in first floor, then mass irregularities in sixth floor, the mass irregularities in eleventh floor considered in successive models the base shear remains same from model-2 to model-4.
5. As the stiffness irregularities in **eight floor** and mass irregularities in first floor, then mass irregularities in sixth floor, the mass irregularities in eleventh floor considered in successive models the base shear remains same from model-6 to model-8.
6. It is observed that the least displacement observed in regular building.
7. It is seen that as the stiffness irregularities in **ground floor** and mass irregularities in first floor i.e heavy mass in first floor (model-2) then there is increase in displacement of about 11.15% compared to model-1.
8. It is observed that as the stiffness irregularities in **ground floor** and mass irregularities in sixth floor i.e heavy mass in sixth floor (model-3) then there is increase in displacement of about 9.2 % compared to model-1.
9. It is observed that as the stiffness irregularities in **ground floor** and mass irregularities in eleventh floor i.e heavy mass in eleventh floor (model-4) then there is increase in displacement of about 10.28 % compared to model-1.
10. It is observed that as the stiffness irregularities in **ground floor** and mass irregularities in sixteen floor i.e heavy mass in sixteen floor (model-5) then there is increase in displacement of about 3.91 % compared to model-1.
11. It is observed that model-5 giving best result compared to all models.

7.1 Scope for further study:

1. Present study deal with RC building of 16 storey. Further work may extend for higher storey.
2. Present work done on RC building, further work may extend for Steel building.

3. Present work is done by considering seismic force, further work may extend on wind force.
4. Present work deal with only mass irregularities on one floor, further work may extend for mass irregularities on two or three floor.

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