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SESMIC ANALYSIS OF VERTICALLY REGULAR AND IRREGULAR BUILDING

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Abstract

Earthquake damage results from several key factors, including irregularities in building design, soft stories, inadequate lateral strength, and structural interactions between the building and the ground. Within contemporary urban infrastructure, tall irregular structures play a significant role, representing a prominent feature that significantly impacts a building's response to seismic activity. Irregular structures are characterized by variations in geometry, mass distribution, and stiffness, making them susceptible to earthquake-induced damage.

This study focuses on the analytical examination of vertical irregularities, encompassing stiffness irregularities, mass irregularities, and vertical geometry irregularities. The study comprises a total of 10 models, including an 11-story moment-resisting frame (MRF) building, along with additional models derived from the initial one to investigate stiffness, mass, and vertical geometry irregularities. Response spectrum analysis considering the design response spectrum provided by NBC 105:2020 is performed in each model and various responses of building are compared.

From the study, it is concluded that there is significant variation in the responses of tall building with introduction of different vertical irregularities. Among the different kinds, the vertical geometry irregularity has comparatively more effect in responses in comparison to mass and stiffness irregularity in a particular storey.

CHAPTER 1 INTRODUCTION

1.1 General

Many buildings in the present scenario have different configurations both in plan and elevation, which in future may subject to devastating earthquakes hence it is necessary to identify the performance of the structures to withstand against disaster primarily due to earthquake. Vertical irregularity are not avoidable in construction of buildings; however, the behavior of structures with or without these vertical irregularity during earthquake needs to be studied so that adequate precautions can be taken. A detailed study of structural behavior of the buildings with vertical irregularity is essential for design and behavior in earthquake.

To perform well in an earth quake a building should possess four main attributes namely simple and regular configuration and adequate lateral Strength, stiffness and ductility. Buildings having simple regular geometry and uniformly distributed mass and stiffness in plan as well as elevation, suffer much less damage than buildings with irregular configuration.

1.2 Objectives of the study

The main objective of this study is to analyze tall RC buildings with vertical regularity and vertical irregularity of same plan using new building code of Nepal (NBC:105:2020). The following are the objectives of the study:

i. To find out the effect of stiffness irregularities on seismic response of tall buildings.
ii. To find out the effect of mass irregularities on seismic response of tall buildings.
iii. To find out the effect of mass irregularities on seismic response of tall buildings.

1.3 Scope and the limitation of the study

Following are the scope and limitation of the study of this thesis:

i. The study is limited to analytical models only.
ii. Size of beams and column size are kept constant throughout the study.
iii. The study is done only for 11 storey building.
iv. The study area is limited to Birendranagar, Surkhet for soil type C only.

CHAPTER 2 LITERATURE REVIEW

2.1 General

A brief review of previous studies on the seismic analysis of multi storey RCC framed building with vertical regularity and vertical irregularity are presented in this section and past effort most closely related to the needs of the present work.

2.2 Literature review about similar topic by previous authors

In the study conducted by Pardeshi Sameer and colleagues (2016), four different structural models, namely Regular, L-Shape, T-Shape, and Plus Shape, were examined through Time History Analysis. The findings indicated that the Plan configuration exhibited a strong response in seismic analysis. Maximum shear force was observed at the first storey, while T-Shape structures showed significant displacement.

In the research by Prof. Vedantee Prasad Shukla and colleagues (2018), the focus was on the design of irregular and regular buildings in various earthquake zones with slopes greater than 3 degrees. The analysis was carried out using the Response Spectrum Method and included parameters such as storey displacement, storey drift, base shear, and time period. Notably, regular buildings had a longer time period than irregular ones, and they employed the Pushover Analysis method, showing higher base shear for regular structures.

Mr. S. Mahesh and colleagues (2014) compared the analysis and design of regular and irregular multi-story buildings in different seismic zones using STAAD PRO and Time History Analysis. In Zone IV, they found that drift was weaker in regular buildings.

Dr. S. K. Dubey and P. D. Sangamnerkar (2015) conducted a study on the seismic behavior of asymmetric R.C. buildings, modeling a five-storey commercial complex with a 'T' shape using STAAD PRO in Zone IV.

Abhay Guleria (2016) analyzed multi-story RCC buildings of various plan configurations under earthquake loads, using ETABS. Their study suggested that L-Shape and I-Shape structures had similar responses in terms of overturning moment, story drift, and story displacement.

Sanhik Kar Majumder and Priyabrata Guha (2015) presented a comparison between wind and seismic loads on different structures, concluding that buildings with irregularities were more susceptible to earthquake damage, with torsion being a critical factor leading to significant damage or complete collapse.

Magliulo, Maddaloni, and Petrone (2017) investigated the influence of earthquake direction on the seismic response of irregular plan R.C. frame buildings. They analyzed three multi-story R.C. buildings, including Rectangular Plan Shape, L-Plan Shape, and Rectangular Plan Shape with a courtyard, using STAAD Pro.

CHAPTER 3 THEORY

3.1 Introduction

Earthquakes are perhaps the most unpredictable and devastating of all-natural disasters. They not only cause great destruction in terms of human casualties, but also have a tremendous economic impact on the affected area. The concern about seismic hazards has led to an increasing awareness and demand for structural design to withstand seismic forces. In such a scenario, the onus of making buildings and structures safe in the earthquake prone areas lies on the designers, architects and engineers who conceptualized these structures.

Factors that should be considered in the designing of an earthquake resistant structure includes understanding of the physics of earthquake, the properties and configuration of the structure, study of the behavior of structures in past earthquakes and also recommendations and codes provided by relevant authorities.

3.1.1 The earthquake

Rocks are made of elastic material, and so elastic strain energy is stored in them during the deformations that occur due to the gigantic tectonic plate actions that occur in the Earth. But, the material contained in rocks is also very brittle. Thus, when the rocks along a weak region in the Earth's Crust reach their strength, a sudden movement takes place there ; opposite sides of the fault (a crack in the rocks where movement has taken place) suddenly slip and release the large elastic strain energy stored in the interface rocks. For example, the energy released during the 2001 Bhuj (India) earthquake is about 400 times (or more) that released by the 1945 Atom Bomb dropped on Hiroshima.

Most earthquakes in the world occur along the boundaries of the tectonic plates and are called Inter-plate Earthquakes (e.g., 1897 Assam (India) earthquake). A number of earthquakes also occur within the plate itself but away from the plate boundaries (e.g., 1993 Latur (India) earthquake); these are called Intra-plate Earthquakes. Here, a tectonic plate breaks in between. In both types of earthquakes, the slip generated at the fault during earthquakes is along both vertical and horizontal directions (called Dip Slip) and lateral directions (called Strike Slip), with one of them dominating sometimes.

3.1.2 Earthquake resistant design of buildings

Buildings should be designed like the ductile chain. For example, consider the common urban residential apartment construction the multi-storey building made of reinforced concrete. It consists of horizontal and vertical members, namely beams and columns. The seismic inertia forces generated at its floor levels are transferred through the various beams and columns to the ground. The correct building components need to be made ductile. The failure of a column can affect the stability of the whole building, but the failure of a beam causes localized effect. Therefore, it is better to make beams to be the ductile weak links than columns. This method of designing RC buildings is called the strong-column weak-beam design method. By using the routine design codes (meant for design against non-earthquake effects), designers may not be able to achieve a ductile structure. Special design provisions are required to help designers improve the ductility of the structure. Such provisions are usually put together in the form of a special seismic design code, e.g., IS: 13920-1993 for RC structures. These codes also ensure that adequate ductility is provided in the members where damage is expected.

3.1.3 Earthquake resistant buildings

The engineers do not attempt to make earthquake proof buildings that will not get damaged even during the rare but strong earthquake; such buildings will be too robust and also too expensive. Instead, the engineering intention is to make buildings earthquake resistant; such buildings resist the effects of ground shaking, although they may get damaged severely but would not collapse during the strong earthquake. Thus, safety of people and contents is assured in earthquake-resistant buildings, and thereby a disaster is avoided. This is a major objective of seismic design codes throughout the world.

3.1.4 Earthquake design philosophy

The earthquake design philosophy may be summarized as follows:

i. Under minor but frequent shaking, the main members of the building that carry vertical and horizontal forces should not be damaged; however building parts that do not carry load may sustain repairable damage.
ii. Under moderate but occasional shaking, the main members may sustain repairable damage, while the other parts of the building may be damaged such that they may even have to be replaced after the earthquake; and
iii. Under strong but rare shaking, the main members may sustain severe (even irreparable) damage, but the building should not collapse.

Thus, after minor shaking, the building will be fully operational within a short time and the repair costs will be small. And, after moderate shaking, the building will be operational once the repair and strengthening of the damaged main members is completed. But, after a strong earthquake, the building may become dysfunctional for further use, but will stand so that people can be evacuated and property recovered. The consequences of damage have to be kept in view in the design philosophy. For example, important buildings, like hospitals and fire stations, play a critical role in post-earthquake activities and must remain functional immediately after the earthquake. These structures must sustain very little damage and should be designed for a higher level of earthquake protection. Collapse of dams during earthquakes can cause flooding in the downstream reaches, which itself can be a secondary disaster. Therefore, dams (and similarly, nuclear power plants) should be designed for still higher level of earthquake motion.

3.2 Importance of seismic design codes

Ground vibrations during earthquakes cause forces and deformations in structures. Structures need to be designed to withstand such forces and deformations. Seismic codes help to improve the behavior of structures so that they may withstand the earthquake effects without significant loss of life and property. Countries around the world have procedures outlined in seismic codes to help design engineers in the planning, designing, detailing and constructing of structures. An earthquake-resistant building has four virtues in it, namely:

i. Good Structural Configuration: Its size, shape and structural system carrying loads are such that they ensure a direct and smooth flow of inertia forces to the ground.
ii. Lateral Strength: The maximum lateral (horizontal) force that it can resist is such that the damage induced in it does not result in collapse.
iii. Adequate Stiffness: Its lateral load resisting system is such that the earthquake-induced deformations in it do not damage its contents under low-to moderate shaking.
iv. Good Ductility: Its capacity to undergo large deformations under severe earthquake shaking even after yielding is improved by favorable design and detailing strategies. Seismic codes coverall these aspects.

3.3 Concept of regular and irregular plan

A. Plan Irregularity Asymmetric or plan irregular structures are those in which seismic response is not only translational but also tensional, and is a result of stiffness and/or mass eccentricity in the structure. Asymmetry may in fact exist in a nominally symmetric structure because of uncertainty in the evaluation of center of mass and stiffness, inaccuracy in the measurement of the dimensions of structural elements.

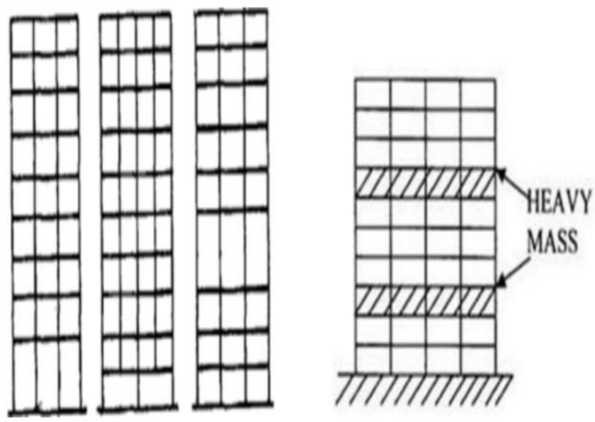


Figure 3.1 Mass irregularity and stiffness irregularity

B. Torsion Irregularity: To be considered when floor diaphragms are rigid in their own plan in relation to the vertical structural elements that resist the lateral forces. Tensional irregularity to be considered to exist when the maximum storey drift, computed with design eccentricity, at one end of the structures transverse to an axis is more than 1.2 times the average of the storey drifts at the two ends of the structure

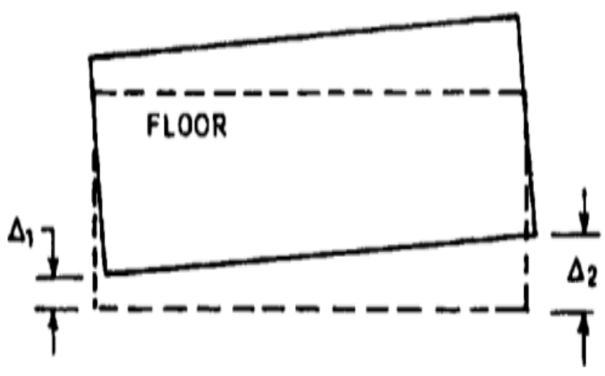


Figure 3.2 Torsion irregularity

C. Re-entrant Corners Plan configurations of a structure and its lateral force resisting system contain re-entrant corners, where both projections of the structure beyond the re-entrant corner are greater than 15 % of its plan dimension in the given direction.

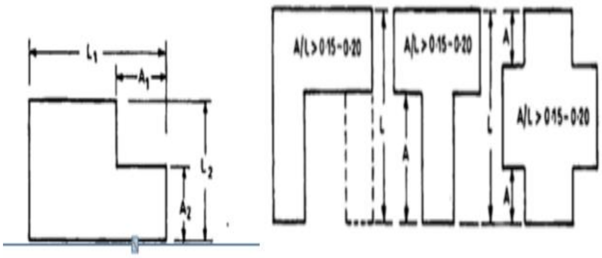


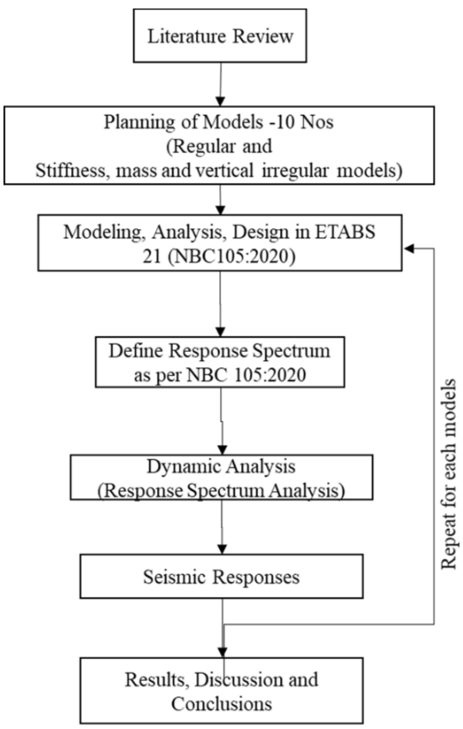
Figure No-1.3: Re-entrant corner irregularity [IS 1893:2002]

The response spectrum technique is really a simplified special case of modal analysis. The modes of vibration are determined in period and shape in the usual way and the maximum response magnitudes corresponding to each mode are found by reference to a response spectrum. The response spectrum method has the great virtues of speed and cheapness.

CHAPTER 4 METHODOLOGY

4.1 Methodology

The methodology for the study is shown in the following flowchart.



CHAPTER 5 RESULTS AND DISCUSSIONS

In the present study the various vertical irregular buildings are analysis using NBC 105:2020 to study the responses with irregularity and discussed in this section.

Displacement

The variation of displacement of different stories for all models when a response spectrum is along longitudinal direction is show in the Table.

Table 1 Comparison of Top Displacement of Stiffness Irregular Buildings

Model No	Displacement RSx (mm)
Model 1	122.213
Model 2	123.58
Model 3	126.82
Model 4	122.664

Table 2 Comparison of Top Displacement of Mass Irregular Buildings

Model No	Displacement RSx (mm)
Model 1	122.213
Model 5	122.296
Model 6	122.842
Model 7	131.108

Table 3 Comparison of Top Displacement of Vertical Geometry Irregular Buildings

Model No	Displacement RSx (mm)
Model 1	122.213
Model 5	107.134
Model 6	94.785
Model 7	96.796

The results from the response spectrum analysis indicate that the introduction of discontinuity of

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columns in lower storeys causes significant change in displacement of the tall building which the introduction of same in upper storeys has lesser effects which is inferred by the results presented in table. In the case of mass irregular building, it is observed that heavier the mass in the upper storeys, more with be the top displacement. Further, the lesser the number of bays in upper storeys, lesser will be the top deformation in the case of vertical geometry irregular buildings.

Time Period

The time period for each model are compared below:

Table 4 Comparison of Time Period for Stiffness Irregular Building

Model No	Time Period
MODEL 1	1.30
MODEL 2	1.31
MODEL 3	1.33
MODEL 4	1.30

The comparison of time period in stiffness irregular building indicates that more the number of vertical elements, more will be the time period of the building. Also, discontinuity in lower storey has slightly more increment in time period than that in upper storey.

Table 5 Comparison of Time Period for Mass Irregular Building

Model No	Time Period
MODEL 1	1.300
MODEL 5	1.328
MODEL 6	1.333
MODEL 7	1.355

In the case of mass irregular building, it is observed that mass irregularities in upper storey has larger incremental effect in the time period than that in lower storeys.

Table 6 Comparison of Time Period for Vertical Geometry Irregular Building

Model No	Time Period
MODEL 1	1.300
MODEL 8	1.210
MODEL 9	1.133
MODEL 10	1.130

For the vertical geometry irregular building, it is observed that lesser the number of bays in upper storeys, lesser will be the time period of the building.

Storey Shear

The comparison of storey shear is done in the following figure. Large change in storey and base shear, with respect to initial model, is observed in the buildings with vertical geometry irregular buildings. No significant change in storey shear is observed for building with stiffness and mass irregular buildings.

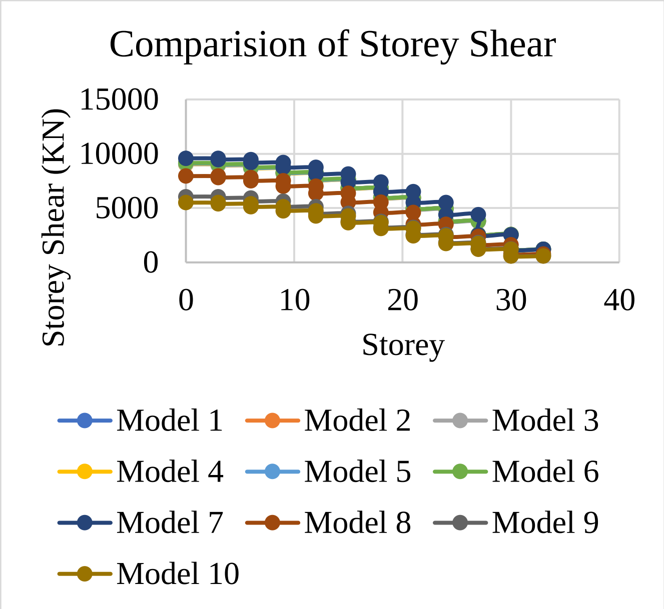

Figure 1 Comparison of Storey Shear for Vertically Regular and Irregular Buildings

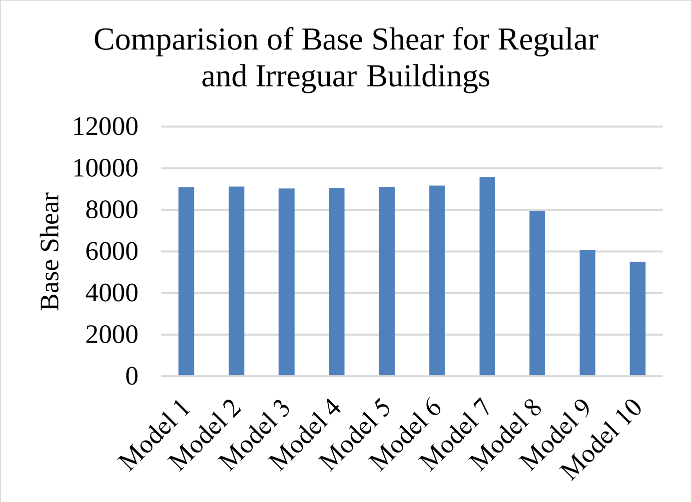

Figure 2 Comparison of Base Shear for Regular and Irregular Buildings

Drift

The comparison of drift for each model is done in the following figures. The result shows that the drift in the storey with discontinuity of vertical element significantly increases. For instance, there is significant increase in drift value in storey 2 and 3 where the column is discontinued. Further, there is also increase in drift at 8th storey where the column is discontinued in the case of model 4. It is also seen that, the increment in drift in lower storey will be comparatively more than that in upper storey where the column is discontinued.

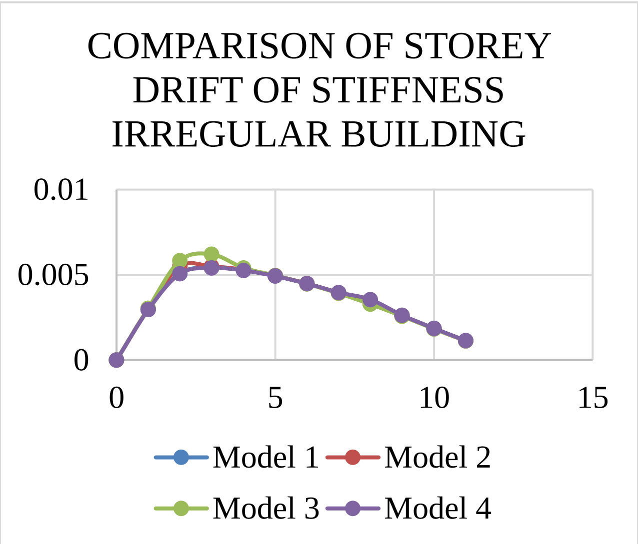

Figure 3 Comparison of storey drift for stiffness irregular building

In the case of mass irregular building, there is no significant change in storey drift due to mass irregularity in particular storey which can be seen in the figure. In the case of vertical geometry irregular building, there is significant change in storey drift due to vertical geometry irregularity which is shown in figure. It is observed that , lesser the number of bays in upper storeys lesser will be the storey drifts.

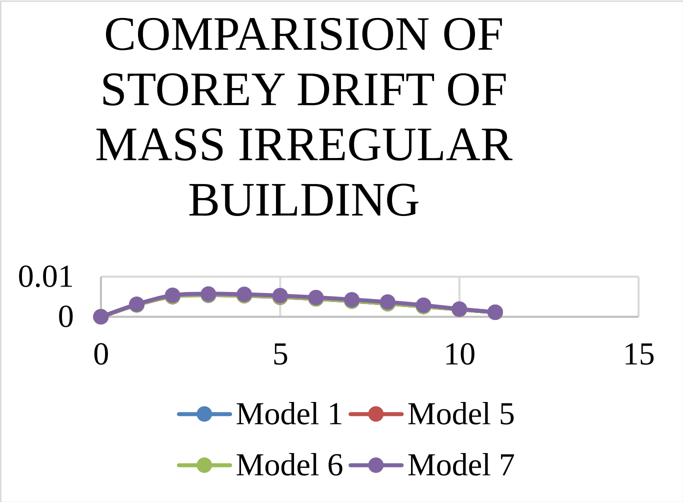

Figure 4 Comparison of storey drift for mass irregular building

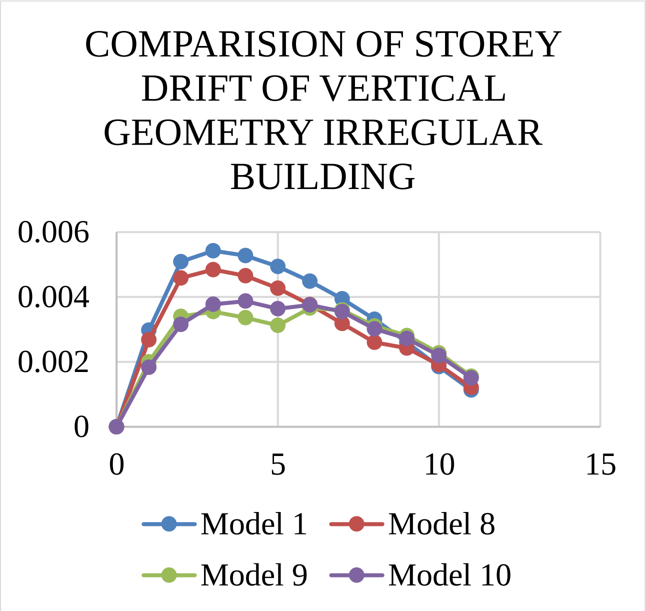

Figure 5 Comparison of storey drift for vertical geometry irregular buildings

CHAPTER 6
CONCLUSIONS AND RECOMMENDATIONS

Tem models of 11-storey building are anlysed using ETABS software. From analysis results, the parameters like storey displacements, storey drift, storey shear time period and base shear are determined for comparative study. From the analysis, the following conclusions are drawn:

i. The results from the response spectrum analysis indicate that the introduction of discontinuity of columns in lower storeys causes significant change in displacement of the tall building which the introduction of same in upper storeys has lesser effects.
ii. In the case of mass irregular building, it is observed that heavier the mass in the upper storeys, more with be the top displacement.
iii. The lesser the number of bays in upper storeys, lesser will be the top deformation in the case of vertical geometry irregular buildings.
iv. The drift of storey with discontinuity of vertical element increases significantly.
v. The base shear of model does not significantly vary with stillness and mass irregularity in particular storey however there is significant variation in the case of vertical geometry irregular tall buildings.
vi. Similarly, time period increases significantly when there is mass and stiffness irregularity in upper storeys of tall buildings. Further, lesser the number of bays in upper storeys, there will be significant decrement in time period of tall building.

1. SCOPE FOR FURTHER STUDY

The following are the area for further research:

1. The study can be done with introduction of soft and weak storey as stipulate in sub clause 5.5.1 of NBC 105:2020.

In addition to force method, performance-based design and study can be done for vertical irregularities.

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