SEISMIC DESIGN OF R.C.C BUILDING WITH IRREGULATIES BY USING REVISED IS 1893:2016

Submitted in partial fulfillment of the requirements of the degree of

Bachelor of Engineering (B.E)

By

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CERTIFICATE

This is to certify that the project entitled **"Seismic Design of RCC Building with Irregularities using Revised IS 1893:2016"** is a bonafide work of **Mohammad Shahnawaz (15DCES77), Shaikh Abdur Rehman (15DCES83), Shaikh Abrar Ahmad (15DCES84)** and **Shaikh Mohammad Anas (15DCES87)** submitted to the University of Mumbai in partial fulfilment of the requirement for the award of the degree of "Bachelor of Engineering" in Department of Civil Engineering.

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DECLARATION

We declare that this written submission represents my ideas in our own words and where others ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that, we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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ABSTRACT

India is a developing country with a variety of building practices and social and economic structure, which needs to evolve its own strategies for seismic hazard evaluation. The last decade has pointed to our shortcoming in risk reduction programmers, during the few damaging earthquakes. Due to this earthquake alone in India there was immense loss of life and property. After this painful loss attention is now being given to the evaluation of the adequacy of strength in structures to resist strong ground motions. After Bhuj earthquake IS 1893 was revised and published in the year 2002 and now in the year 2016, before this incident it was revised in 1984. The code was first published in 1962 as “Recommendations for Earthquake Resistant Design of Structure”. The main reason for the loss of life and property was inadequacy of knowledge of behaviour of structures during ground motions. The vulnerability of the structures against seismic activity must be essentially studied. In this study we are analysing different irregular structures and their behaviour during seismic excitations with and without irregularities by Response Spectrum method using ETABS.

Keywords— *Irregularities; Response Spectrum; IS 1893:2016: IS 1893:2016; ETABS 2016*

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Chapter 1

INTRODUCTION

1.1 General

During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having this discontinuity are termed as Irregular structures. In these modern days, the structures are involved with architectural importance and it is highly difficult to plan with regular shapes. This leads to planning with irregularity in the structure. According to IS 1893 (Part 1) : 2016 buildings with simple regular geometry and uniformly distributed mass and stiffness in plan and in elevation, suffer much less damage, than buildings with irregular configurations. There are various types of irregularities in the buildings depending upon their location and scope, but mainly, they are divided into two groups which are discussed in next chapter.

1.2 Recent Earthquakes in India

The table 1.1 gives an overview of recent earthquakes in India along with magnitude and loss of life and property

Table 1.1. Recent Earthquakes in India

Date	Time	Location	Epicentre	Death	Magnitude
03 January, 2017	2:39 IST	India, Bangladesh	24.015°N, 92.018°E	8	5.7
4 January, 2016	04:35 IST	North East, India	24.8°N, 93.6°E	11 dead, 200 injured in Manipur & Assam	6.7
26 October, 2015	14:39 IST	Northern India, Pakistan, Afghanistan	36.524°"N, 70.368°"E	280 in Pakistan, 115 in Afghanistan and 4 in India	7.5
12 May, 2015	12:35 IST	Northern & North East India	27.794°N, 85.974°E	218	7.3

25 April, 2015	12:19 IST	Northern India	28.230°N, 84.731°E	8857	7.8
1 May, 2013	06:57 IST	Kashmir	33.1°N, 75.84°E	3 dead, 100 injured	5.7
5 March, 2012	13:10 IST	New Delhi	28.6°N, 77.4°E	1	5.2
18 September, 2011	18:10 IST	Gangtok, Sikkim	27.723°N, 88.064°E	118	6.9
10 August, 2009	01:21 IST	Andaman Islands	14.1°N, 92.8°E	26	7.5
6 February, 2008	11:39 IST	West Bengal	23.468°N, 87.116°E	50	4.3
6 November, 2007	05:58 IST	Gujrat	21.28°N, 70.7°E	5	5.1
8 October, 2005	08:50 IST	Kashmir	34.493°N, 73.629°E	130,000	7.6
26 December, 2004	09:28 IST	India Maldives	3.30°N, 95.87°E	283,106	9.1
26 January, 2001	08:50 IST	Gujarat	23.6°N, 69.8°E	20,000	7.7
29 March, 1999	00:35 IST	Chamoli district, Uttarakhand	30.408°N, 79.416°E	103 Approx.	6.8
22 May, 1997	13:41 IST	Jabalpur, Madhya Pradesh	23.18°N, 80.02°E	39	6.0
30 September, 1993	09:20 IST	Latur	18.08°N, 76.52°E	9,748	6.2
20 October, 1991	02:53 IST	Uttarkashi, Uttarakhand	30.73°N, 78.45°E	>2,000	7.0

21 August, 1988	04:40 IST	Udaipur, Nepal	26.755°N, 86.616°E	1,000	6.7
19 January, 1975	13:32 IST	Himachal Pradesh	32.46°N, 78.43°E	47	6.8

1.3 Need of the Project

In modern days construction of Irregular structure are in the trend and for that lot of investment of money, time both are required. After construction of those structure that area get crowded because of the importance of those building. If proper care is not taken during planning, designing and construction during emergencies like earthquakes, the buildings will collapse and it will result in painful loss lots of life, time and money. Hence it is very important to study the behavior of the irregular buildings and understand, explain the intentions behind the changes in the recent revision of the seismic design code.

1.4 How the Ground Shakes During Earthquake?

Seismic Waves

Large strain energy released during an earthquake travels as seismic waves in all directions through the Earth's layers, reflecting and refracting at each interface. These waves are of two types – *body waves* and *surface waves*; the latter are restricted to near the Earth's surface (Figure 1). Body waves consist of *Primary Waves (P-waves)* and *Secondary Waves (S-waves)*, and surface waves consist of *Love waves* and *Rayleigh waves*. Under P-waves, material particles undergo extensional and compressional strains along direction of energy transmission, but under S-waves, oscillate at right angles to it (Figure 2). Love waves cause surface motions similar to that by S-waves, but with no vertical component. Rayleigh wave makes a material particle oscillate in an elliptic path in the vertical plane (with horizontal motion along direction of energy transmission).

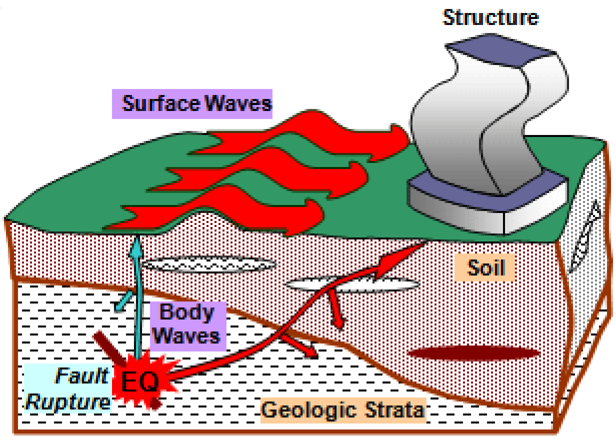


Figure 1.1. Arrival of Seismic Waves at a Site [2]

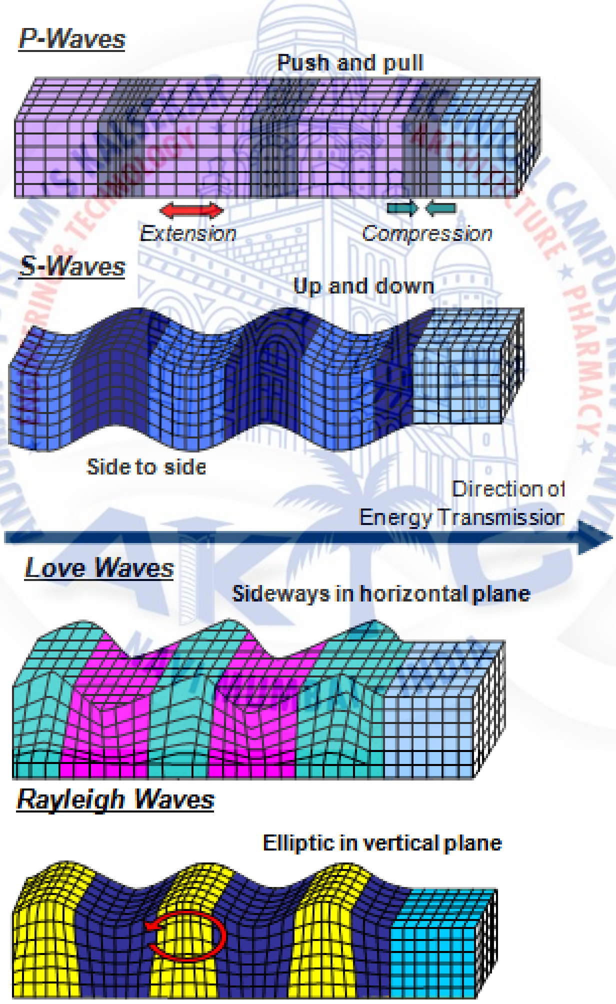


Figure 1.2. Motions caused by Body and Surface Waves [2]

P-waves are fastest, followed in sequence by S-, Love and Rayleigh waves. For example, in granites, P- and S-waves have speeds ~4.8 km/sec and ~3.0km/sec, respectively. S-waves do not travel through liquids. S-waves in association with effects of Love waves cause maximum damage to structures by their racking motion on the surface in both vertical and horizontal directions. When P- and S-waves reach the Earth's surface, most of their energy is reflected back. Some of this energy is returned back to the surface by reflections at different layers of soil and rock. Shaking is more severe (about twice as much) at the Earth's surface than at substantial depths. This is often the basis for designing structures buried underground for smaller levels of acceleration than those above the ground.

Measuring Instruments

The instrument that measures earthquake shaking, a *seismograph*, has three components – the *sensor*, the *recorder* and the *timer*. The principle on which it works is simple and is explicitly reflected in the early seismograph (Figure 3) – a pen attached at the tip of an oscillating simple pendulum (a mass hung by a string from a support) marks on a chart paper that is held on a drum rotating at a constant speed. A magnet around the string provides required damping to control the amplitude of oscillations. The pendulum mass, string, magnet and support together constitute the *sensor*; the drum, pen and chart paper constitute the *recorder*; and the motor that rotates the drum at constant speed forms the *timer*.

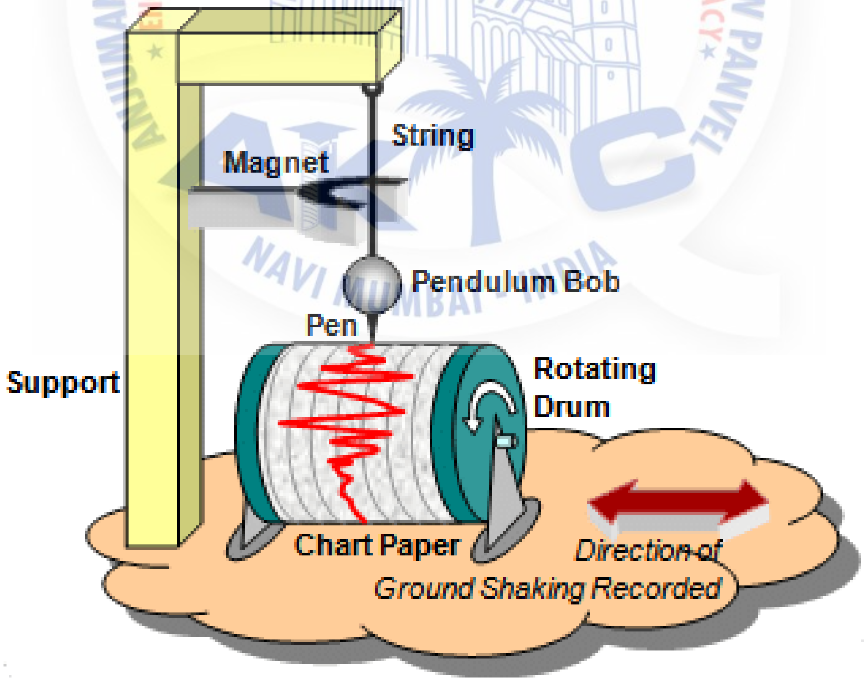


Figure 1.3. Schematic of Early Seismograph [2]

One such instrument is required in each of the two orthogonal horizontal directions. Of course, for measuring vertical oscillations, the *string* pendulum (Figure 3) is replaced with a *spring* pendulum oscillating about a fulcrum. Some instruments do not have a timer device (*i.e.*, the drum holding the chart paper does not rotate). Such instruments provide only the maximum extent (or scope) of motion during the earthquake; for this reason they are called **Seismoscopes**.

The analogy instruments have evolved over time, but today, *digital instruments* using modern computer technology are more commonly used. The digital instrument records the ground motion on the memory of the microprocessor that is in-built in the instrument.

Strong Ground Motions

Shaking of ground on the Earth's surface is a net consequence of motions caused by seismic waves generated by energy release at each material point within the three-dimensional volume that ruptures at the fault. These waves arrive at various instants of time, have different amplitudes and carry different levels of energy. Thus, the motion at any site on ground is random in nature with its amplitude and direction varying randomly with time.

Large earthquakes at great distances can produce weak motions that may not damage structures or even be felt by humans. But, sensitive instruments can record these. This makes it possible to locate distant earthquakes. However, from engineering viewpoint, strong motions that can possibly damage structures are of interest. This can happen with earthquakes in the vicinity or even with large earthquakes at reasonable medium to large distances.

Characteristics of Strong Ground Motions

The motion of the ground can be described in terms of displacement, velocity or acceleration. The variation of ground acceleration with time recorded at a point on ground during an earthquake is called an **Accelerogram**. The nature of accelerograms may vary (Figure 4) depending on energy released at source, type of slip at fault rupture, geology along the travel path from fault rupture to the Earth's surface, and local soil (Figure 1). They carry distinct information regarding ground shaking; *peak amplitude*, *duration of strong shaking*, *frequency content* (*e.g.*, amplitude of shaking associated with each frequency) and *energy content* (*i.e.*, energy carried by ground shaking at each frequency) are often used to distinguish them.

Peak amplitude (*peak ground acceleration, PGA*) is physically intuitive. For instance, a horizontal PGA value of *0.6g* (= *0.6* times the acceleration due to gravity) suggests that the movement of the ground can cause a maximum horizontal force on a rigid structure equal to *60%* of its weight. In a rigid structure, all points in it move with the ground by the same amount, and hence experience the same maximum acceleration of PGA. Horizontal PGA values greater than *1.0g* were recorded during the 1994 Northridge Earthquake in USA. Usually, strong ground motions carry significant energy associated with shaking of frequencies in the range *0.03-30Hz (i.e., cycles per sec)*.

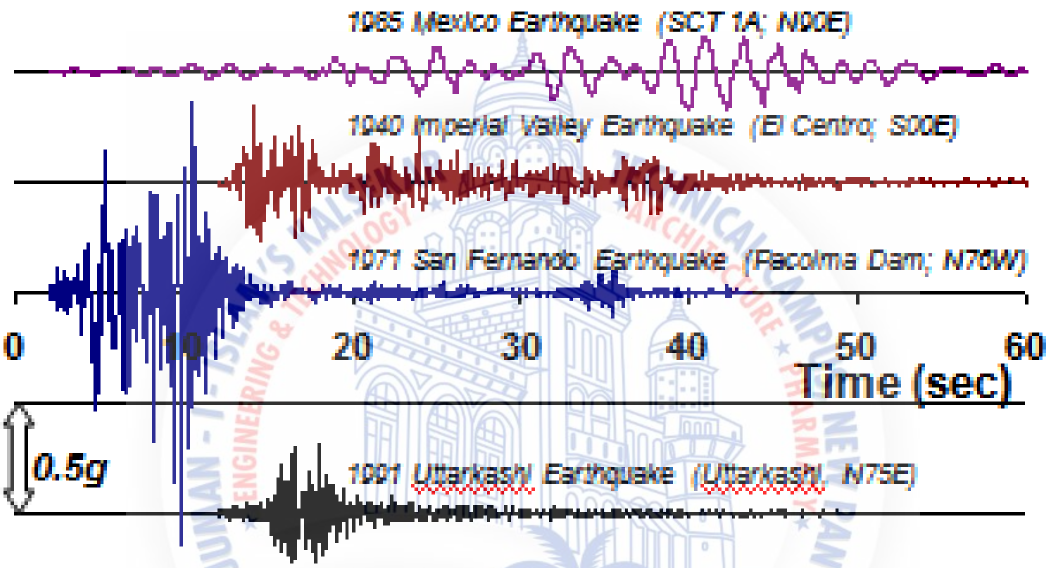


Figure 1.4. Some Typical Recorded Accelerograms [2]

Generally, the maximum amplitudes of horizontal motions in the two orthogonal directions are about the same. However, the maximum amplitude in the vertical direction is usually less than that in the horizontal direction. In design codes, the vertical design acceleration is taken as ½ to ⅔ of the horizontal design acceleration. In contrast, the maximum horizontal and vertical ground accelerations *in the vicinity* of the fault rupture do not seem to have such a correlation.

1.5 Virtues of Earthquake-Resistant Buildings

1. Good *seismic configuration*, with no choices of architectural form of the building that is detrimental to good earthquake performance and that does not introduce newer complexities in the building behaviour than what the earthquake is already imposing;

2. At least a minimum *lateral stiffness* in each of its plan directions (uniformly distributed in both plan directions of the building), so that there is no discomfort to occupants of the building and no damage to contents of the building;
3. At least a minimum *lateral strength* in each of its plan directions (uniformly distributed in both plan directions of the building), to resist low intensity ground shaking with no damage, and not too strong to keep the cost of construction in check, along with a minimum *vertical strength* to be able to continue to support the gravity load and thereby prevent collapse under strong earthquake shaking.
4. Good overall *ductility* in it to accommodate the imposed lateral deformation between the base and the roof of the building, along with the desired mechanism of behaviour at ultimate stage.

Behaviour of buildings during earthquakes depend critically on these four virtues. Even if any one of these is not ensured, the performance of the building is expected to be poor.

Chapter 2

LITERATURE REVIEW

2.1 General

Due to the recent earthquakes there was a tremendous loss of life and property. The previous IS 1893 recently revised in 2016 and it gives importance to irregularities this chapter presents review of literature pertaining to different types of irregularities, their behavior and design process. Both codes of seismic design, i.e. 1893-2002 and 1893-2016 are also compared to understand the difference in the codes.

2.2 Introduction to Irregular Structure

2.2.1 Plan Irregularities

a. **Torsional Irregularity**: It is the ratio of maximum horizontal displacement at one end and the minimum horizontal displacement at the other end.

b. **Re-entrant Corners**: A building is said to have a re-entrant corner in any plan direction, when its structural configuration in plan has a projection of size greater than 15 percent of its overall plan dimension in that direction

c. **Cut-Outs**: Opening in the slab are termed as Cut-Outs.

d. **Out-of-Plane Offset in Vertical Element**

e. **Non-Parallel Lateral Force System**: A building is said to have non-parallel system when the vertically oriented structural systems resisting lateral forces are not oriented along the two principal orthogonal axes in plan.

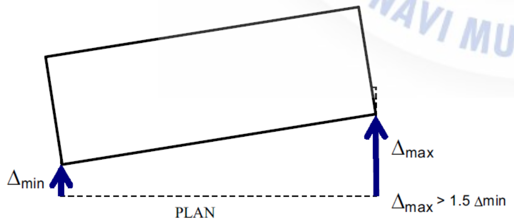


Figure 2.1. Re-Entrant Corner

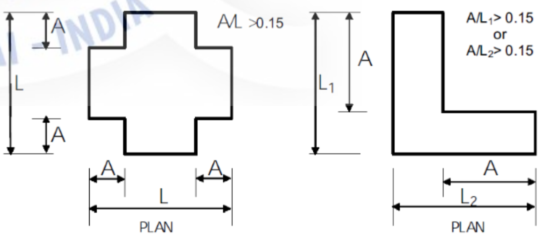


Figure 2.2. Torsional Irregularity

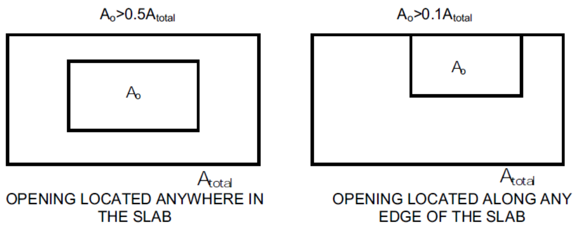


Figure 2.3. Cut-Outs Irregularity

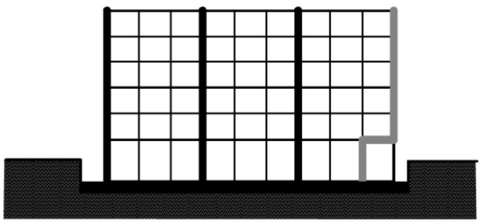


Figure 2.4. Out-of-Plane Offset

2.2.2 Vertical Irregularities

a. **Stiffness Irregularity (Soft Storey)**: A soft storey is a storey whose lateral stiffness is less than that of the storey above.

b. **Mass Irregularity**: Mass irregularity shall be considered to exist, when the seismic weight (as per 7.7) of any floor is more than 150 percent of that of the floors below.

c. **Vertical Geometric Irregularity**: It shall be considered to exist, when the horizontal dimension of the lateral force resisting system in any storey is more than 125 percent of the storey below.

d. **In-plane Discontinuity in Vertical Elements Resisting Lateral Force**: It shall be considered to exist, when in-plane offset of the lateral force resisting elements is greater than 20 percent of the plan length of those elements.

e. **Strength Irregularity (Weak Storey)**: A weak storey is a storey whose lateral strength is less than that of the storey above.

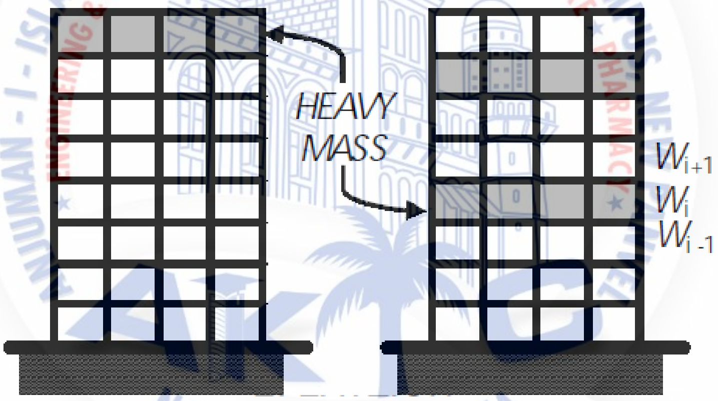


Figure 2.5. Stiffness Irregularity

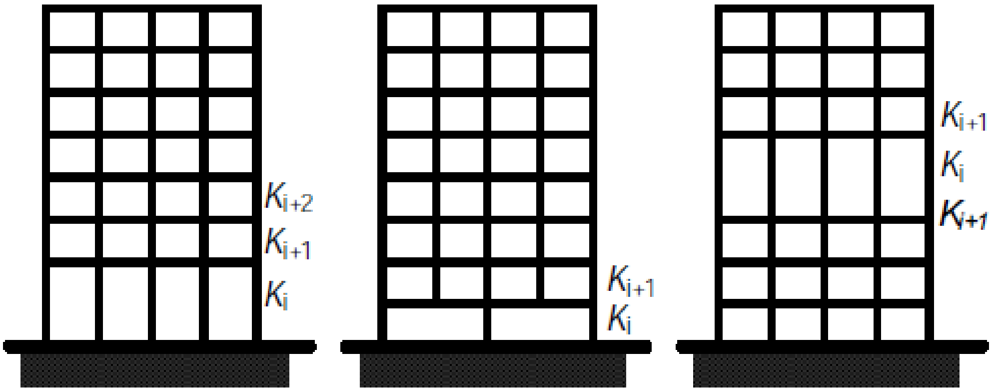


Figure 2.6. Mass Irregularity

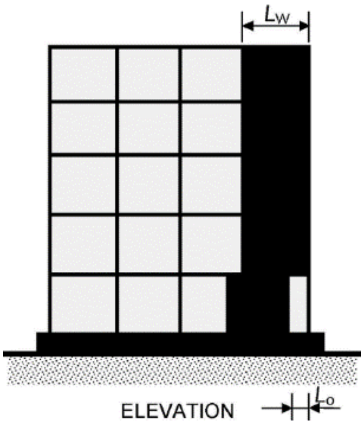


Figure 2.7. In-plane Discontinuity

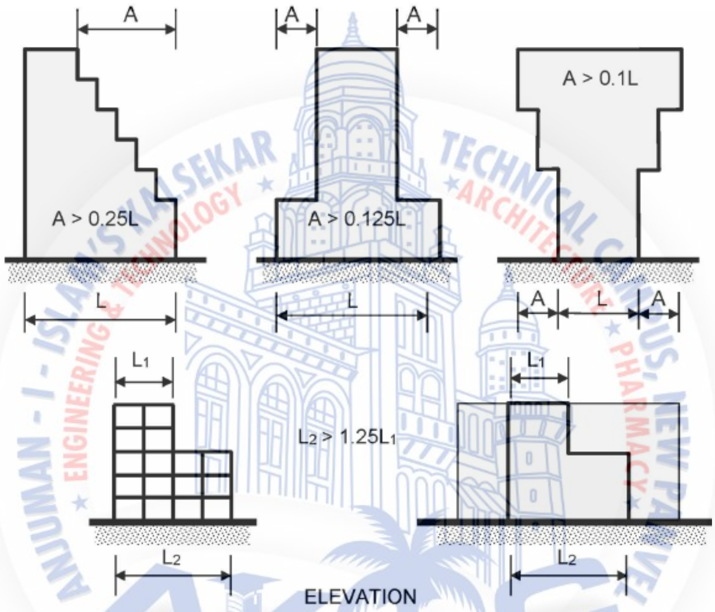


Figure 2.8. Geometric Irregularity

2.3 Review of Literature

Himanshu Bansal, Gagandeep ***(2012)*** carried out Response spectrum analysis (RSA) and Time history Analysis (THA) of vertically irregular RC building frames and to carry out the ductility based design using IS 13920 corresponding to Equivalent static analysis and Time history analysis. Three types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered. According to our observation, the storey shear force was found to be maximum for the first storey and it decreases to minimum in the top storey in all cases. The mass irregular structures were observed to experience larger base shear than similar regular structures. The stiffness irregular structure experienced lesser base shear and has larger inter-storey drifts.

Shaikh Abdul Aijaj *et.al. (2013)* made attempts to investigate the proportional distribution of lateral forces evolved through seismic action in each storey level due to changes in stiffness of frame on vertically irregular frame.

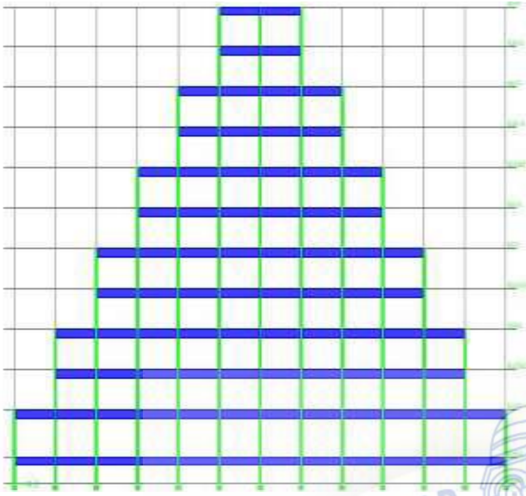


Figure 2.9. Regular Frame [20]

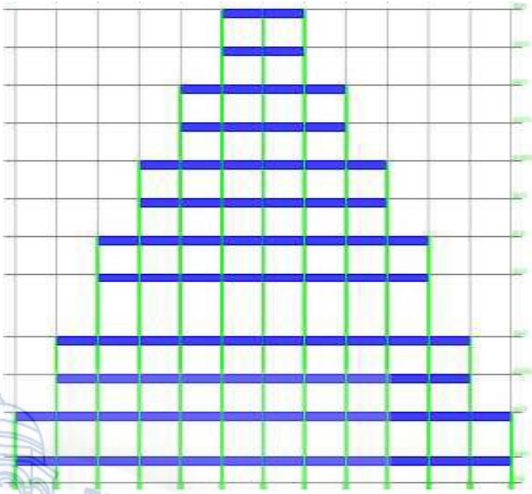


Figure 2.10. Irregular Frame [20]

As per the IS 1893 (part1):2002 a G+10 vertically irregular building was modelled as a simplified lump mass model for the analysis with stiffness irregularity at Fourth floor.

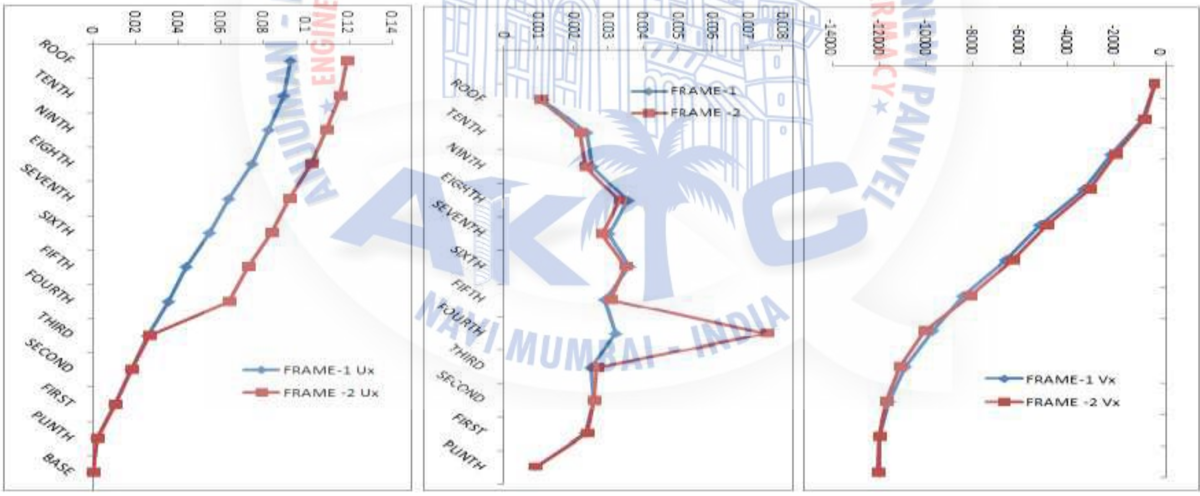


Figure 2.11. Response of various frames with irregularities [20]

To response parameters like story drift, story deflection and story shear of structure under seismic force under the linear static & dynamic analysis was studied. This analysis showed focus on the base shear carrying capacity of a structure and performance level of structure under severe zone of India. The result remarks the conclusion that, a building structure with stiffness irregularity provides instability and attracts huge storey shear. A proportionate amount of stiffness is advantageous to control over the storey and base shear.

Gayathri H. *et.al. (2014)* analyse RC irregular high-rise structures and to observe the behaviour of structures by introducing SMRF, SMRF with Shear Wall and Flat Slab with Shear Wall system by equivalent static analysis and pushover analysis and study the various responses such as base shear, storey drift, lateral displacement for the structure also compare the results of SMRF, dual system and flat slab system for different patterns with same data.

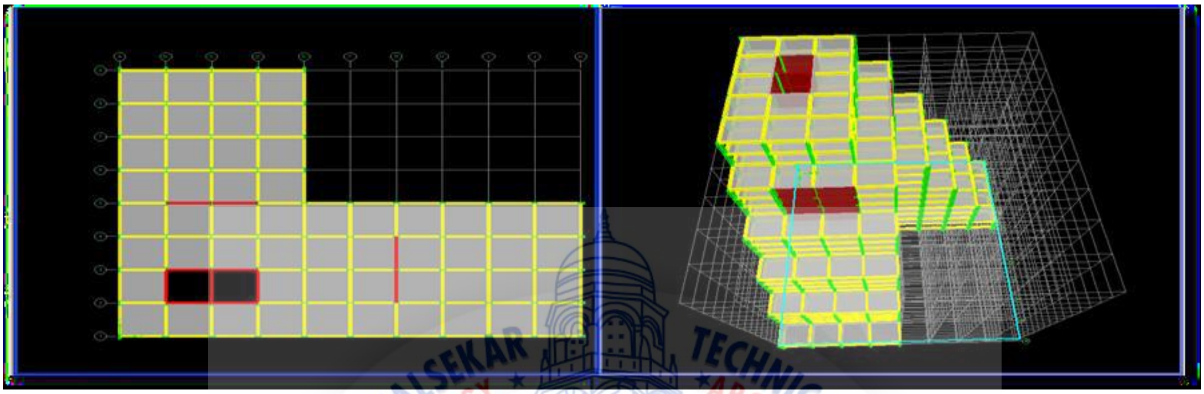


Figure 2.12. 3D View of Special Moment Resisting Frame with Shear Wall Building [4]

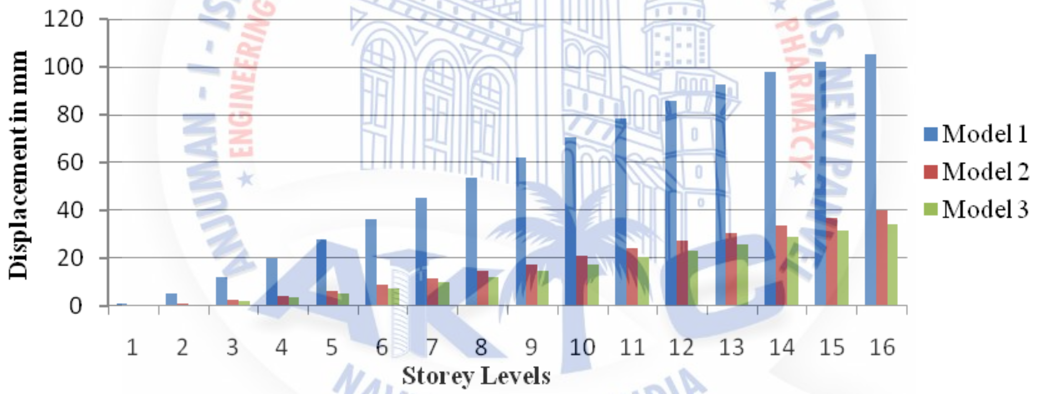


Figure 2.13. Displacement for SMRF, SMRF with Shear Wall, Flat Slab with Shear Wall [4]

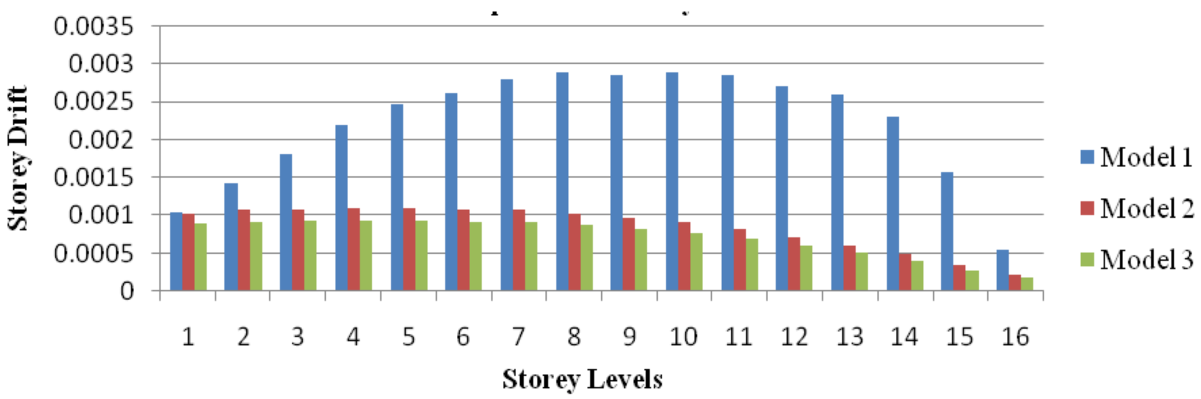


Figure 2.14. Story Drift for SMRF, SMRF with Shear Wall, Flat Slab with Shear Wall[4]

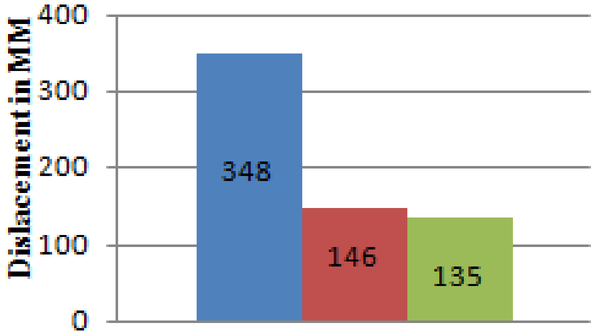


Figure 2.15. Displacement at Performance [4]

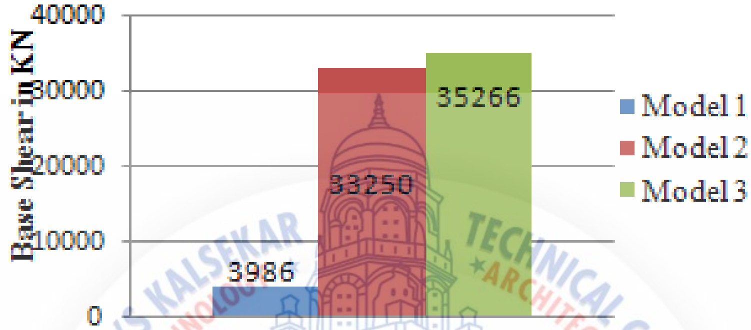


Figure 2.16. Base Shear at Performance [4]

Hence to conclude that the provision of shear wall is more important in structural point of view and in particular serviceability point of view, since lateral displacement has reduced to 61.90% and 67.48% as compared to SMRF without shear walls.

Rajkuwar Dube ***et.al. (2014)*** aimed at controlling the structural damage based on precise estimations of proper response parameters. PBSD method evaluates the performance of a building frame for any seismic hazard, the building may experience. Use of this method for vertical irregular buildings is verified with comparison of conventional method. Soft storey is subjected to failures due to stiffness and strength reduction. This paper deals with application of Performance based seismic design method for soft storey RC building frames (10 storeys). Push over analysis results show significance of PBSD method in frames having soft story at lower floor level compared to higher ones.

Ramesh Konakalla ***(2014)*** analysed four different 20 story building for effect of vertical irregularity under Dynamic Loads Using Linear Static Analysis. Response of all cases is compared and concluded that in regular structure there is no torsional effect in the frame because of symmetry.

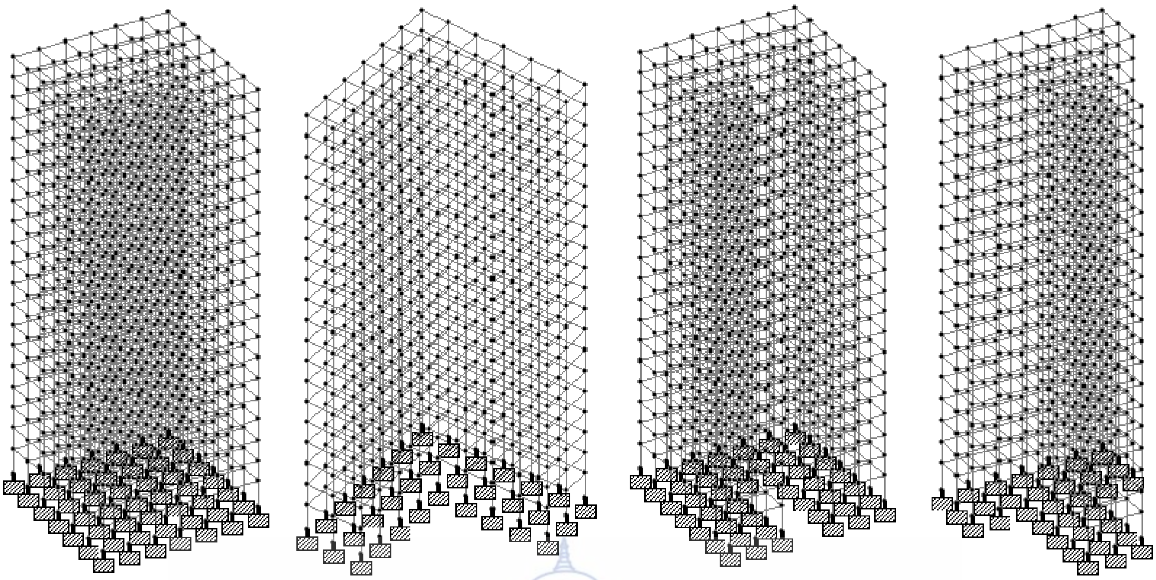


Figure 2.17. Selected Frames with Shapes, Supports, Nodes and Framing [15]

The response for vertically irregular buildings is different for the columns which are located in the plane perpendicular to the action of force. This is due to the torsional rotation in the structure.

Gururaj B. Katti, Basavraj S. Balapgol ***(2014)*** analyse a multistoried RC building (G+10 Storey) for earthquake intensity III, by using different methods such as IS method, response spectrum analysis and Time history analysis (Bhuj and Koyna) and study the effects of different Seismic zones on performance of multi-storey building in terms of seismic responses such as base shear, storey displacement to know the relationship between different methods of seismic analysis and their seismic responses.

Table 2.1. Different Time Histories Considered for study [5]

Sr. No.	EQ	Date	Magnitude Richter Scale	P.G.A. (g)
1	Bhuj	Jan 26, 2001	6.9	0.11
2	Koyna	Dec 11, 1964	6.5	0.489

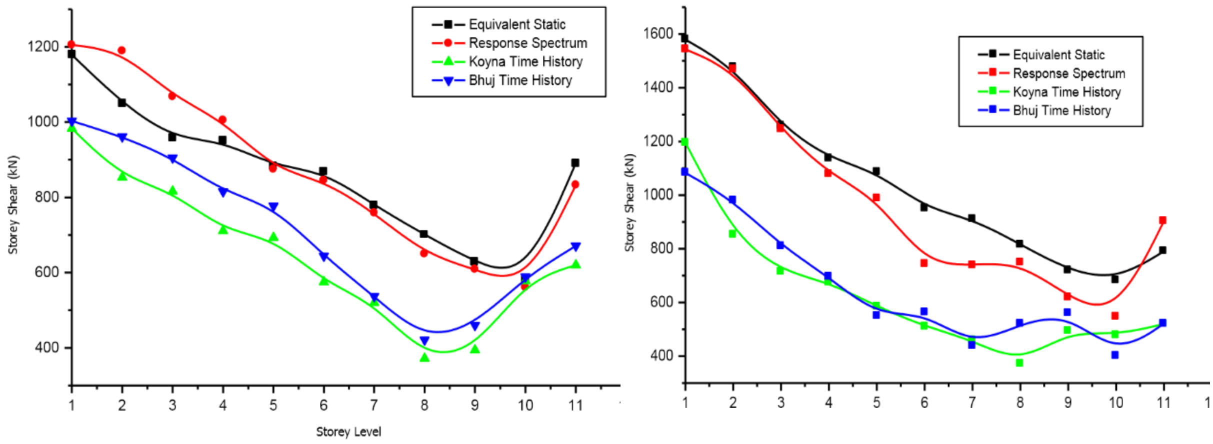


Figure 2.18. Variations in Storey Shear (kN) for X and Y Direction [5]

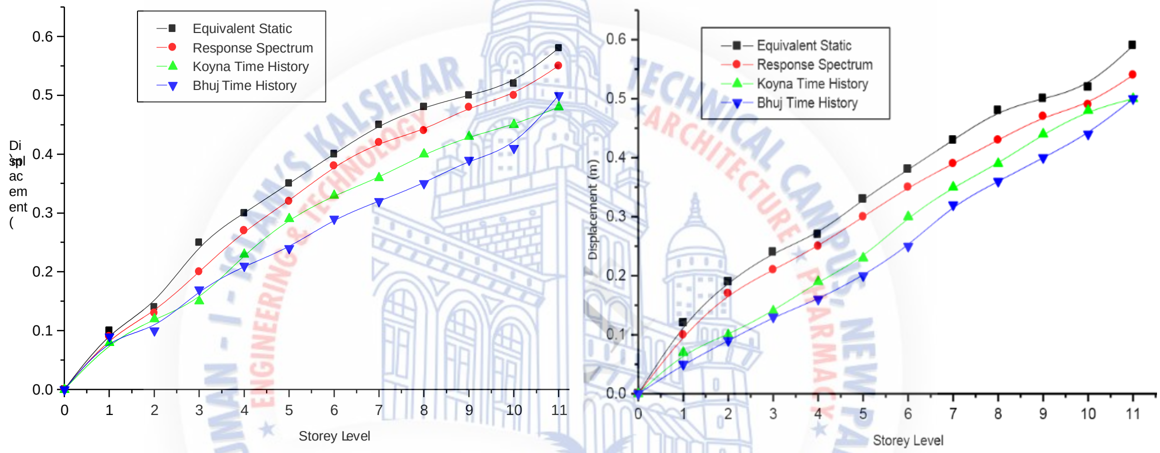


Figure 2.19. Variations in Storey Displacement for X and Y Direction [5]

It concluded that Time History is realistic method used for seismic analysis, it provides a better check to the safety of structures analysed and designed as compared to Equivalent static analysis and Response spectrum methods.

Neha P. Modakwar *et.al.(2014)* main objective of study is to understand different irregularity and torsional response due to plan (Re-entrant corner) and vertical (Mass) irregularity and to analyse cross shape and L shape building while earthquake forces acts and to calculate additional shear due to torsion in the columns. It concluded that the Re-entrant corner columns are needed to be stiffened for shear force in the horizontal direction perpendicular to it as significant variation is seen in these forces.

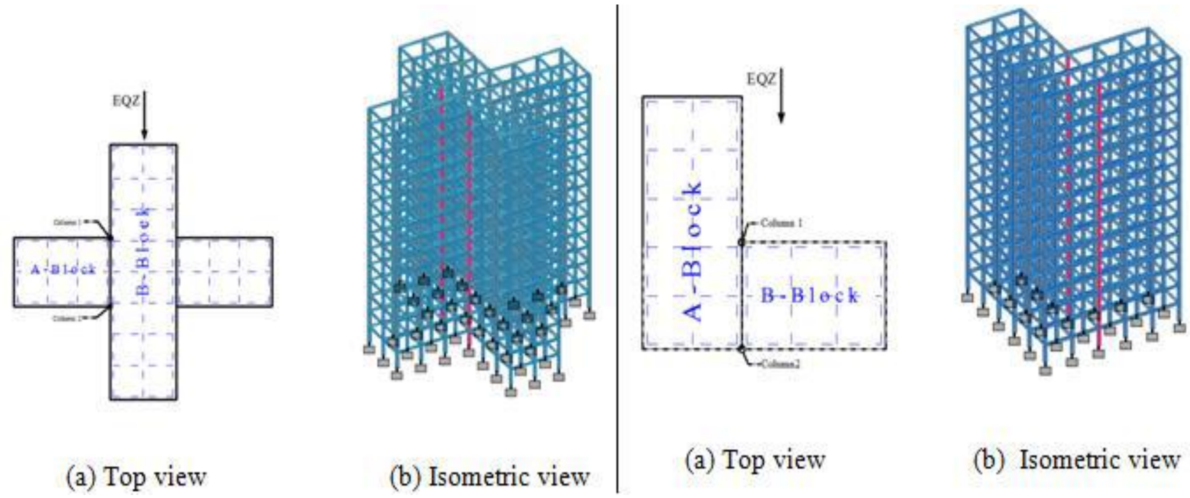


Figure 2.20. Model Of Cross Shape and L Shape Building [11]

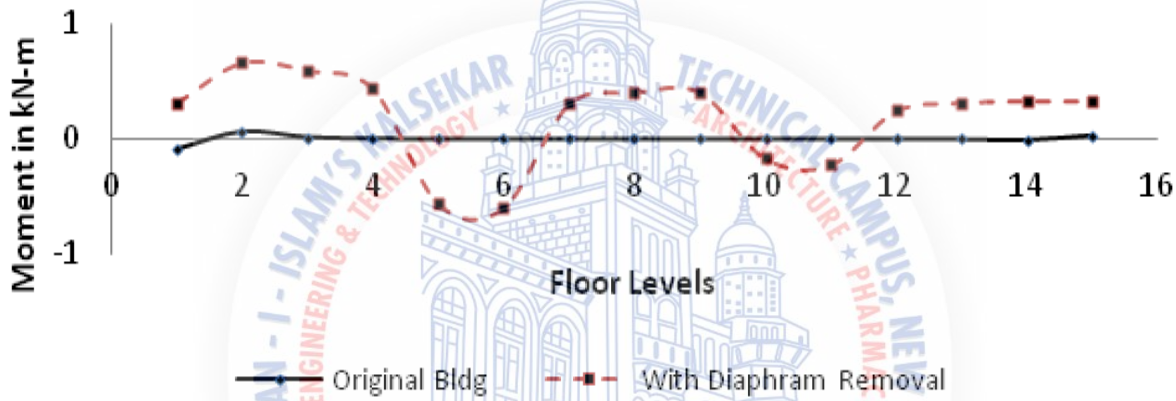


Figure 2.21. Effect of Torsion on Due to Removal of Diaphragm [11]

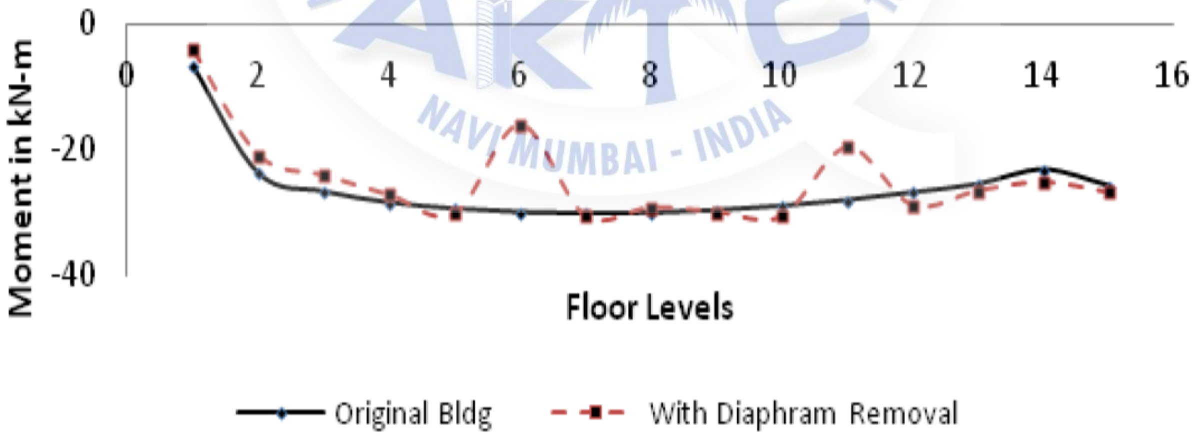


Figure 2.22. Effect of Moment in z-direction due to Removal of Diaphragm [11]

G.V. Sai Himaja *et.al.(2015)* aims to evaluating and comparing the response of thirty reinforced concrete buildings, systems with different with and without infill materials by the use of methodology namely the ones described by the FEMA-273 using nonlinear static procedures, with described acceptance criteria. The methodology is applied to a G+3 and G+9 RCC frames with and without vertical irregularity, both designed as per the IS 456-2000 and IS 1893-2002 (Part I) in the context of Performance Based Seismic Design procedures.

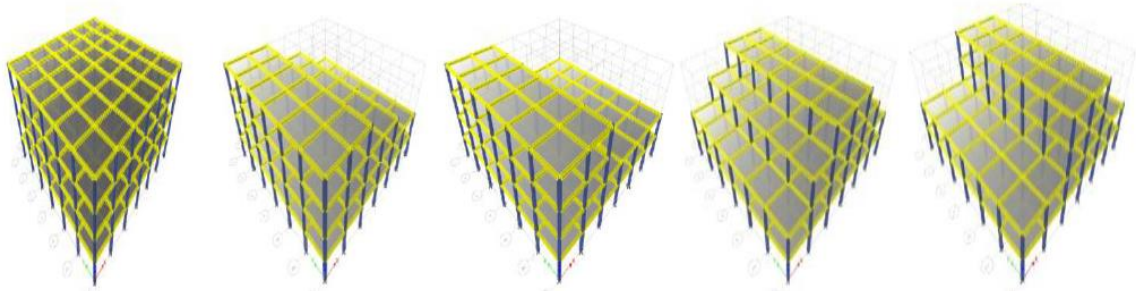


Figure 2.23. G+3 Bare Frames 3D view [3]

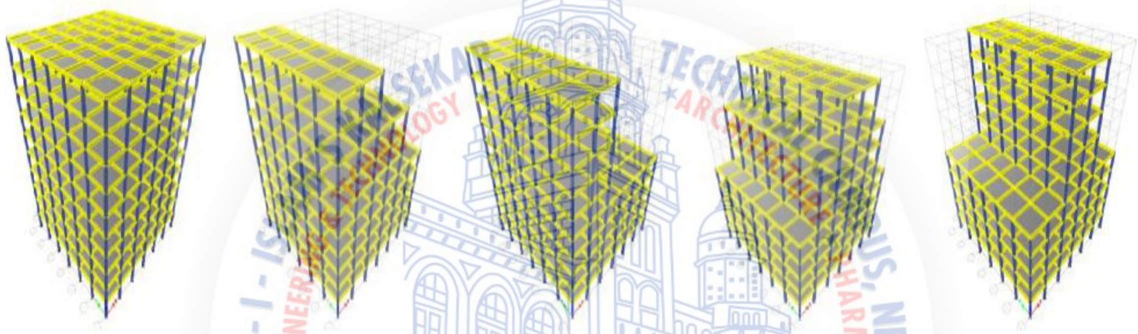


Figure 2.24. G+9 Bare Frames 3D view [3]

Figure 2.25. G+3 Infilled Frames 3D view [3]

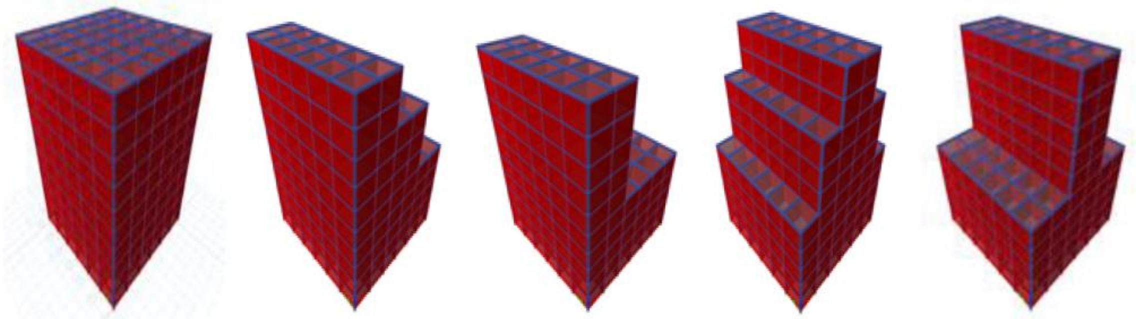


Figure 2.26. G+9 Infilled Frames 3D view [3]

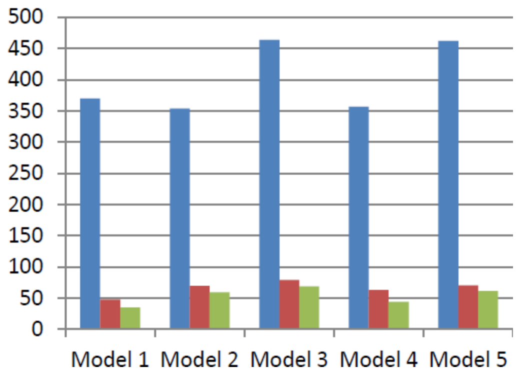


Figure 2.27. Displacement Graph G+3 [3]

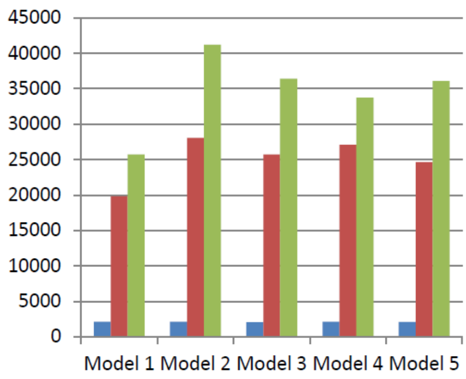


Figure 2.28. Bade Share Graph G+3 [3]

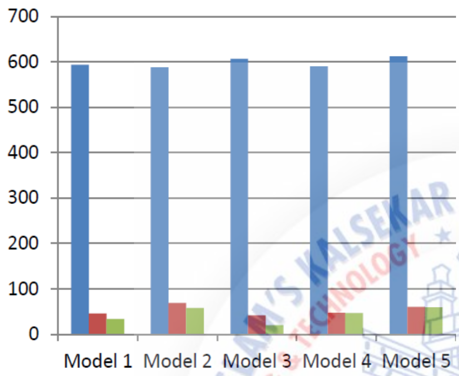


Figure 2.29. Displacement Graph G+9 [3]

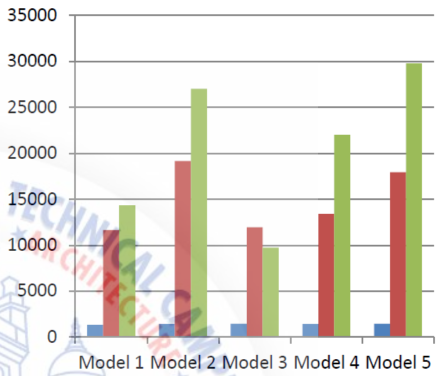


Figure 2.30. Bade Share Graph G+9 [3]

It was found that Ferro cement infilled irregular model 4 (300%) high rises building decrease in deformation or displacement of the building as it's stiffer than other buildings.

Ashvin G. Soni ***et.al.(2015)*** consider G+9 building frame with two different irregularity (Mass irregularity and Stiffness irregularity) as taken from IS 1893(part I): 2002 and analysed all the frame using equivalent static method of the same code after analysing all the frame.

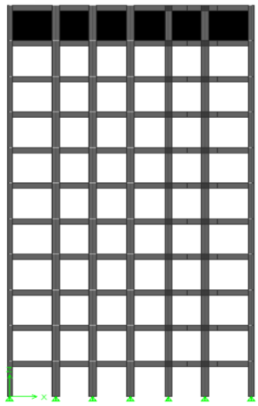


Figure 2.31. Top Level Heavy Load[1]

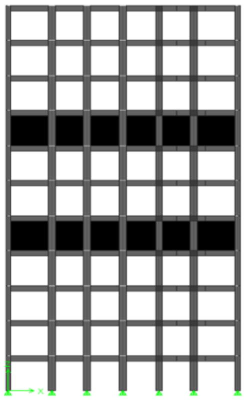
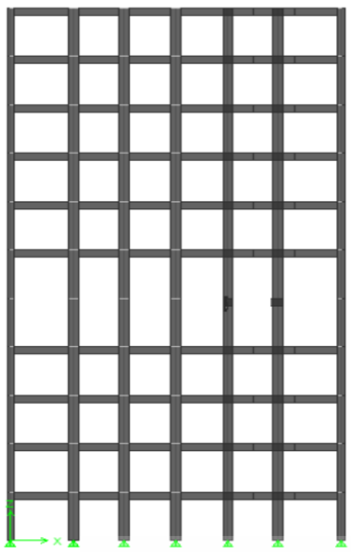


Figure 2.32. 4th & 7th Storey Heavy Load



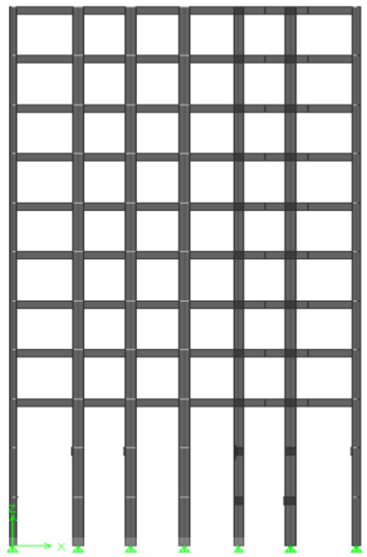


Figure 2.33. 1st and 2nd Storey Soft[1] **Figure 2.34.** 4th and 5th Storey Soft[1]

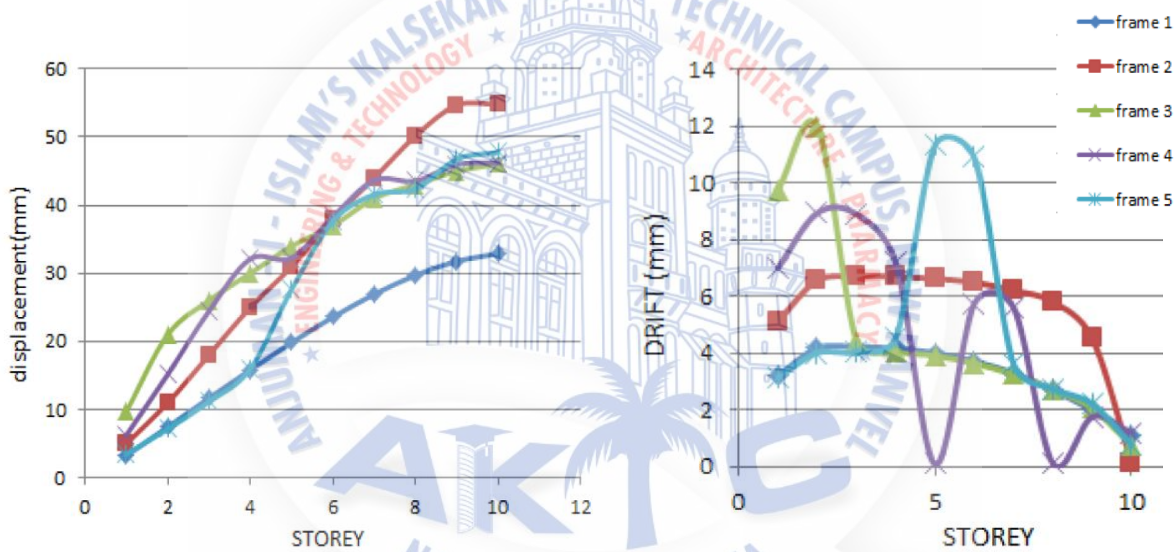


Figure 2.35. Response of Various Frames with Irregularities [1]

It concluded that regular structure having less storey displacement and storey drift as compare both the irregular frame hence irregularities in building are harmful for the structures and it is important to have simpler and regular shapes of frames as well as uniform load distribution of load around the building.

N. Anvesh *et.al. (2015)* analysis the building considering mass irregularity building and building without mass irregularity analyse as per code IS 875 Part III (criteria for wind loads) and Refuse area is placed at 3rd and 6th story and their Shear force, Bending Moment, Displacement & story drift are noticed.

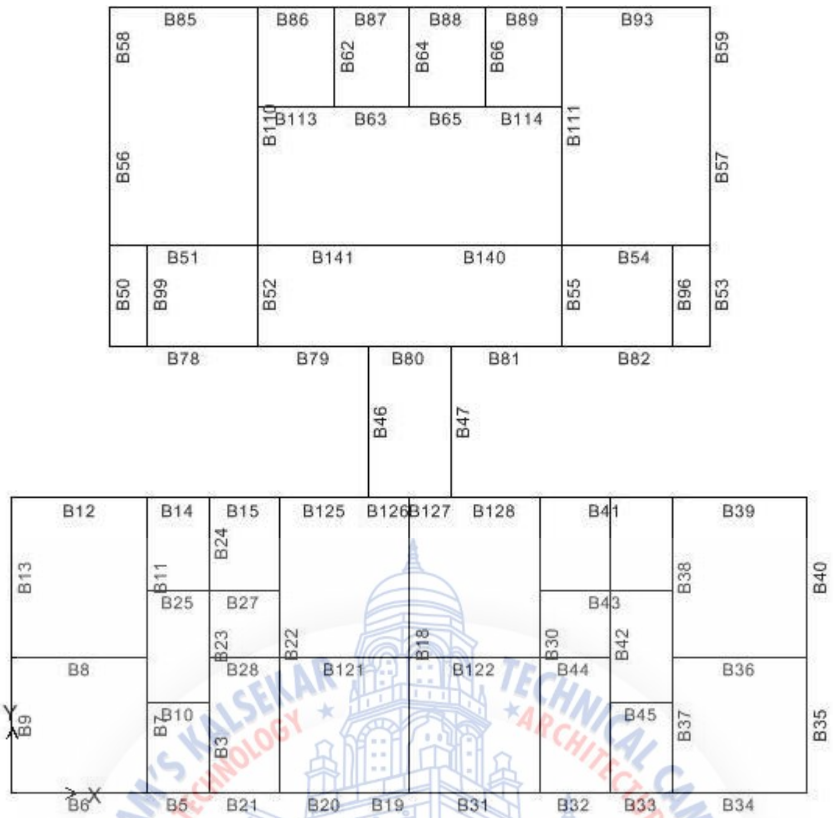


Figure 2.36. Beam Labels [10]

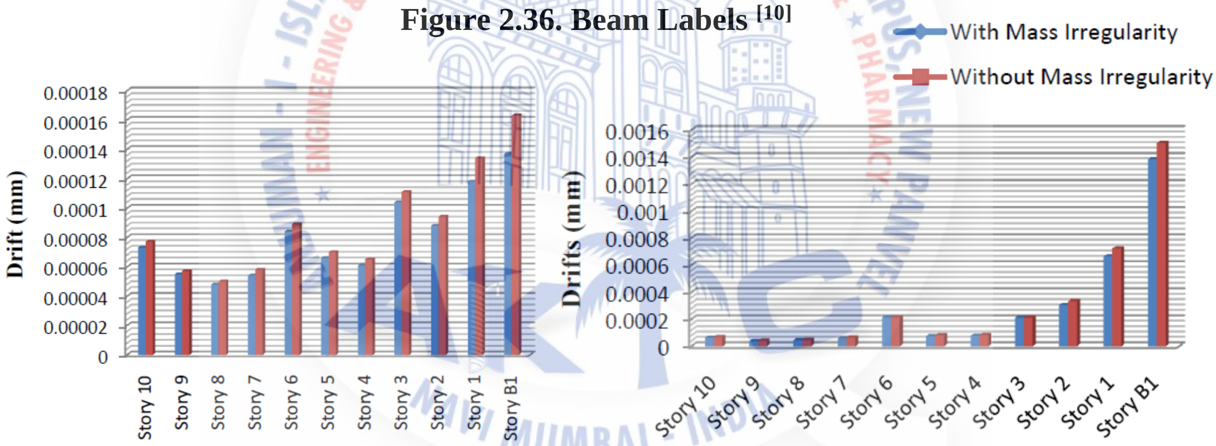


Figure 2.37. Comparison of Drift in X and Y direction [10]

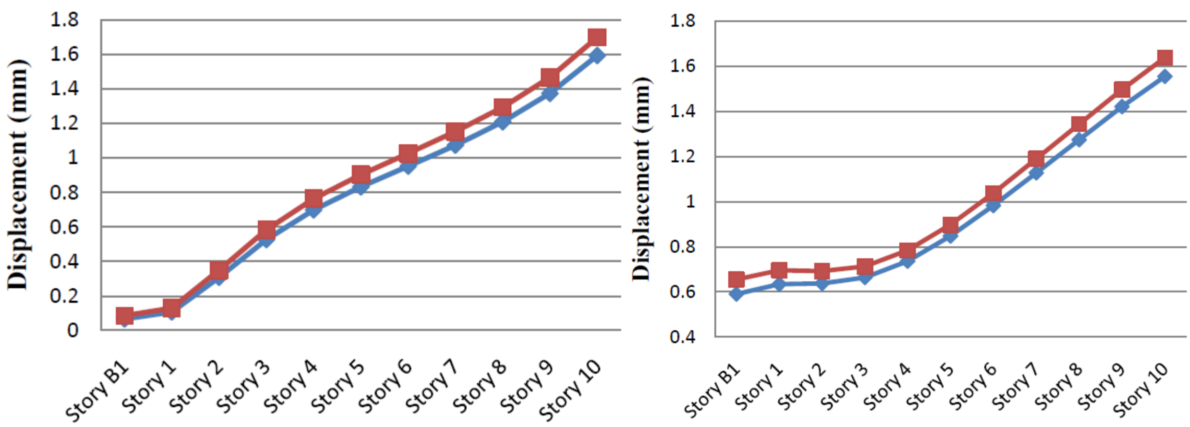


Figure 2.38. Displacement in X and Y direction [10]

It concluded that Beams in refuse area are have more shear force, bending moment, drift deflection when compared to building without mass irregularity.

Hema Mukundan, S. Manivel ***(2015)*** found shear wall provision in building has been effective and economical. A 10 storey building in Zone IV is tested to reduce the effect of earthquake using reinforced concrete shear walls in the building.

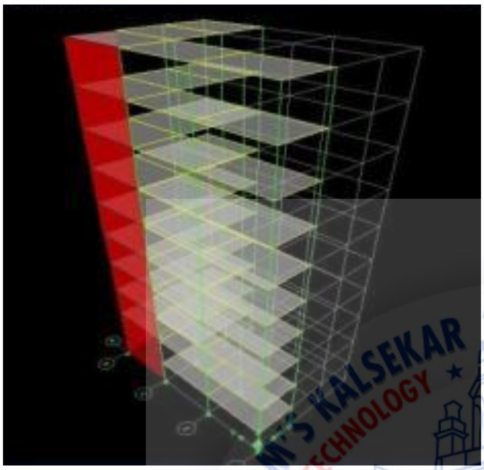


Figure 2.39. Plan Irregularity L shaped [6]

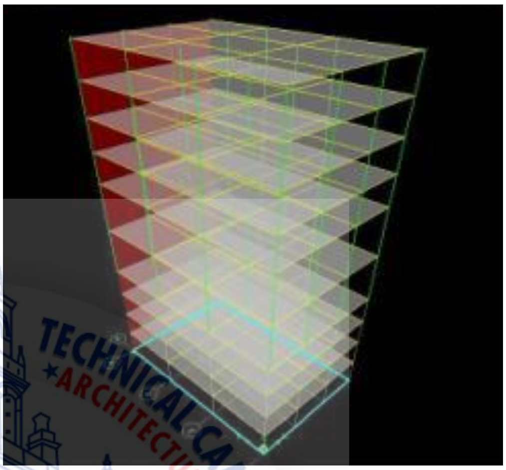


Figure 2.40. Stiffness Irregularity [6]

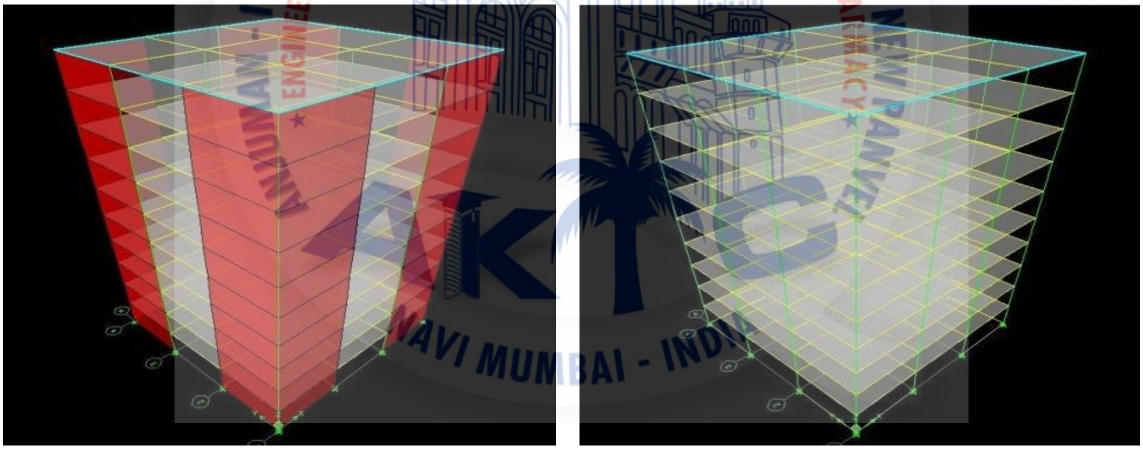


Figure 2.41. G + 9 Storey Building with and without Shear wall [6]

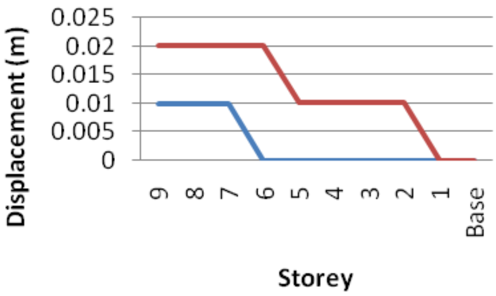


Figure 2.42. Store Displacement [6]

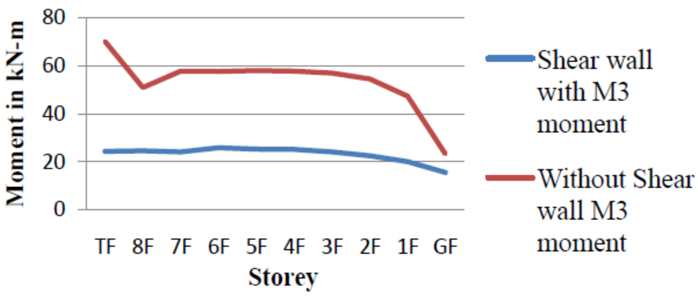


Figure 2.43. Moment Distribution [6]

The results are presented after analysing model using ETABS software and RSA method is used. Researchers also studied results varying thickness of shear walls. It is concluded that shear walls are more resistant to lateral loads in regular/Irregular structure and for safer design, the thickness of the shear wall should range between 150mm to 400mm.

S. C. Pednekar *et.al. (2015)* study the effect of increase in number of storey on seismic responses by performing pushover analysis. Reinforced concrete structures of G+4, G+5 and G+ 6 storey have been modelled and analysed using CSi ETABS 9.7.4 software. Comparison of seismic responses of the structure in terms of base shear, time period and displacement has been done by performing nonlinear static pushover analysis.

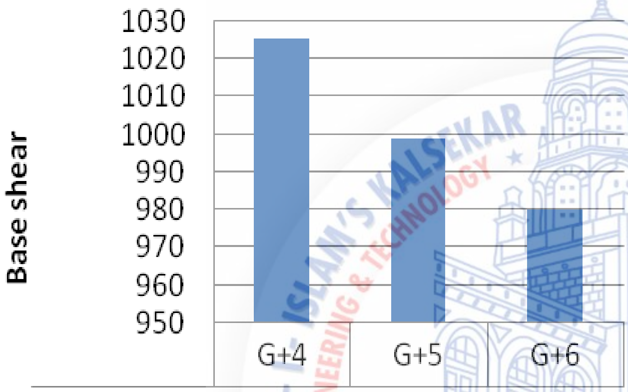


Figure 2.44. Base Shear [17]

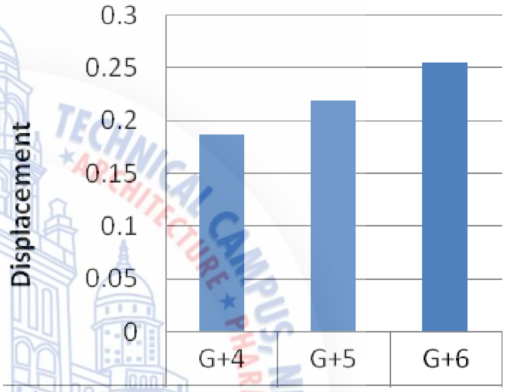


Figure 2.45. Displacement [17]

Table 2.2. Comparison of Performance Points [17]

Storey number	G+4	G+5	G+6
Spectral acceleration	0.151	0.124	0.105
Spectral displacement	0.088	0.105	0.122
Damping	0.249	0.269	0.258
Base shear (kN)	962.606	941.212	922.680
Time period (seconds)	1.493	1.832	2.094
Displacement (m)	0.107	0.128	0.148

From analysis results it has been observed that base shear and spectral acceleration is reduced, whereas displacement, time period, spectral displacement is increased as the number of storey increases. Analysis also shows location of plastic hinges at performance point of the structures with different number of storey.

S. Varadharajan *et.al. (2015)* summarizes the research works done in the past regarding different types of structural irregularities i.e. Plan and vertical irregularities. Criteria and limits specified for these irregularities as defined by different codes of practice (IS1893:2002, EC8:2004 etc.) have been discussed briefly.

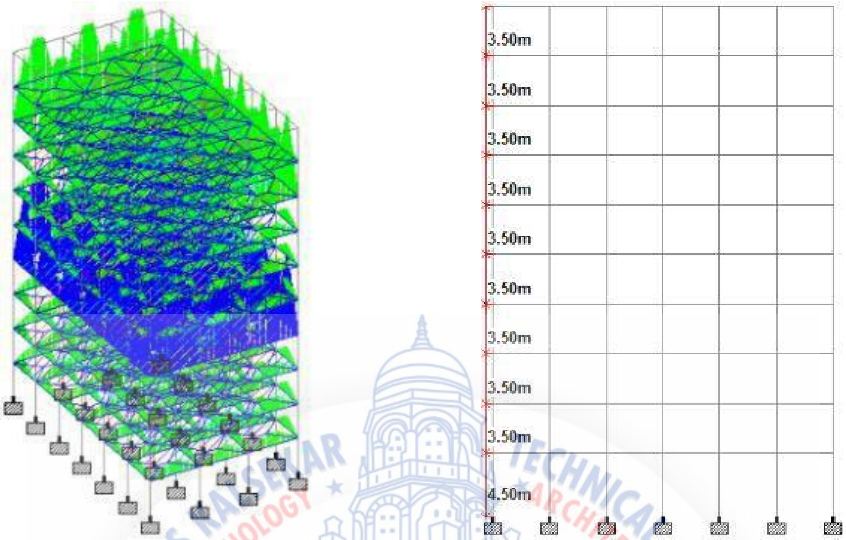


Figure 2.46. Stiffness Irregular Structure (10 storeys) [18]

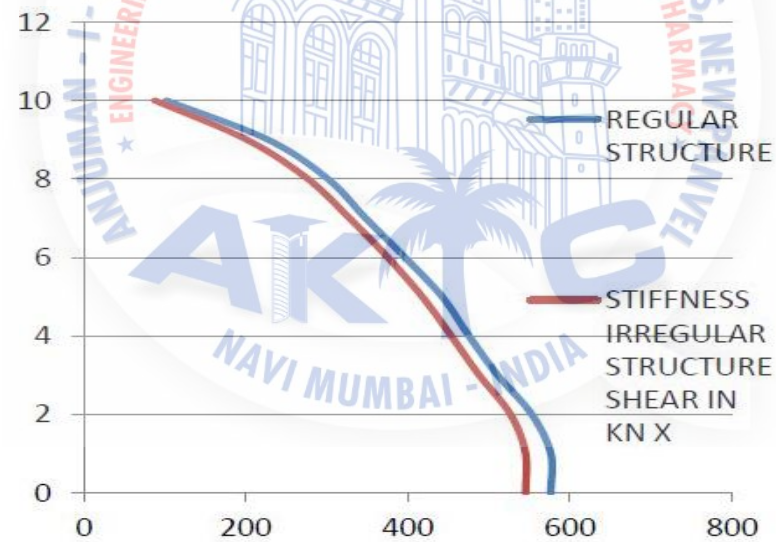


Figure 2.47. Comparison of Peak Storey Shear Forces of Regular and Stiffness Irregular Structure in X Direction [18]

It was observed that the limits of both Plan and vertical irregularities prescribed by these codes were comparable. Regarding the vertical irregularities it was found that strength irregularity had the maximum impact and mass irregularity had the minimum impact on seismic response regarding the analysis method MPA (Modal pushover analysis) method even after much improvement was found to be less accurate as compared to dynamic analysis.

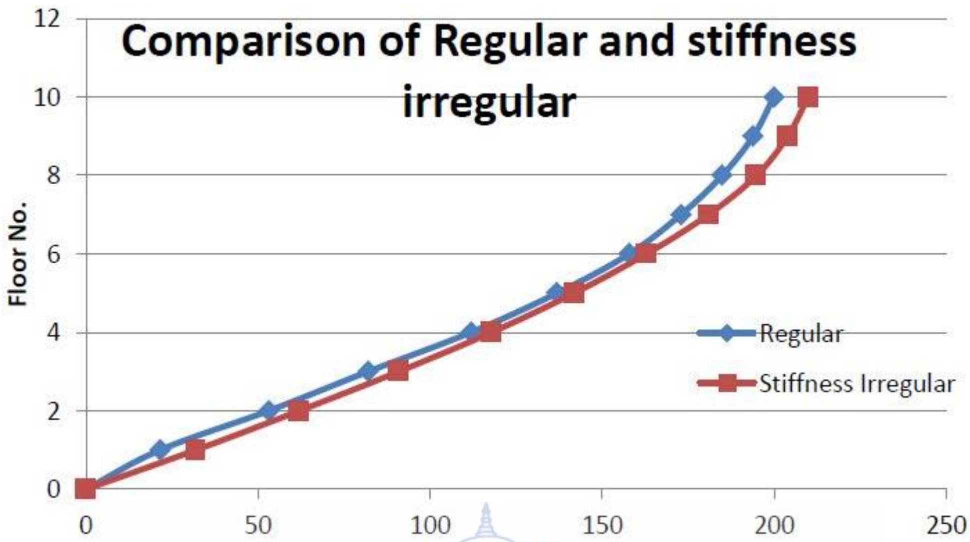


Figure 2.48. Comparison of Displacements along X-Direction of Different Floors of Regular and Stiffness Irregular Structure [18]

Nuthan L Pathi ***et.al. (2015)*** determine the response of 7 storey RC frame structure i.e., base shear and lateral displacement by Equivalent static lateral force method and performance point by pushover analysis considering regular building and irregular building (stiffness irregularity, mass irregularity, vertical geometric irregularity, in-plane discontinuity in vertical elements resisting lateral force) modelling and analysis are achieved using ETABS a finite element software.

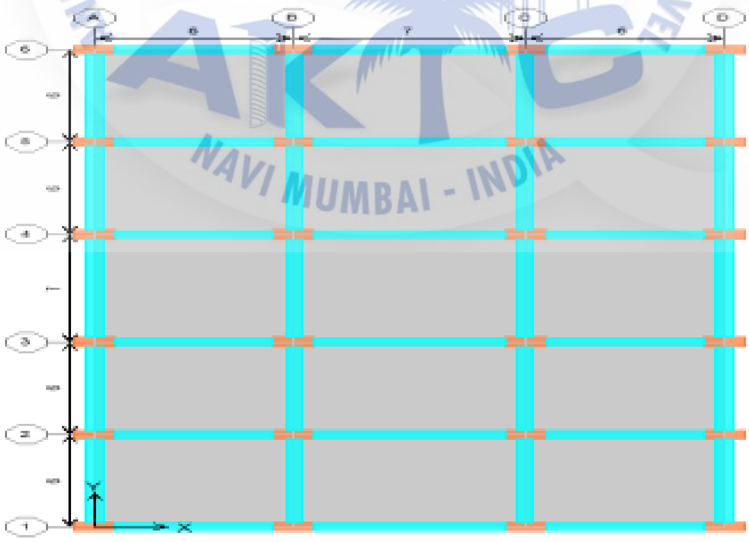


Figure 2.49. Plan of Regular Building [12]

It concluded that mass irregular frame is more critical than other frames with different irregularities.

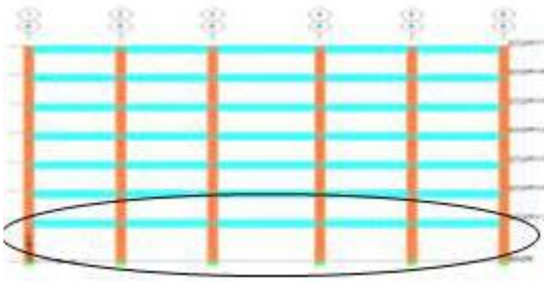


Figure 2.50. Elevation of Stiffness Irregular Building [12]

Figure 2.51. Elevation of Mass Irregular Building [12]

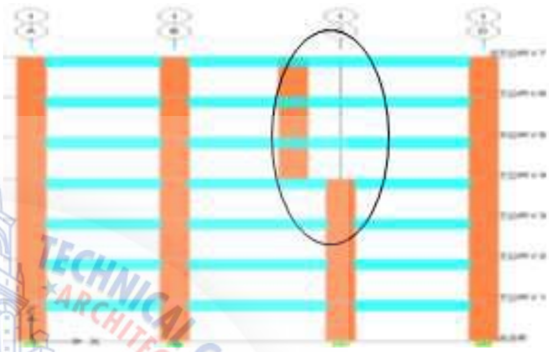


Figure 2.52. Elevation of Vertical Irregular Building [12]

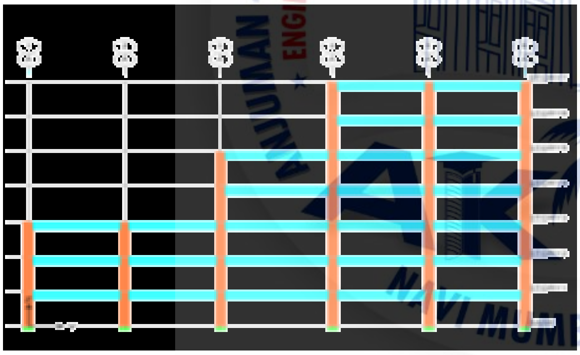


Figure 2.53. Elevation of In-Plane Discontinuity Building [12]

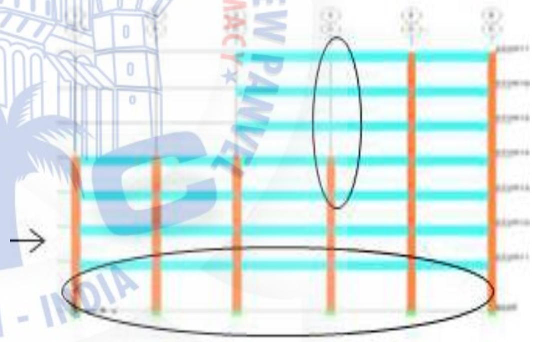


Figure 2.54. Elevation of Combination Of Irregular Building [12]

Sagar B. Patil, Gururaj B. Katti ***(2015)*** study to understand different irregularity and tensional, deflection, story displacement, story displacement response due to plan and vertical irregularity and to analyze cross shape and +, T,L shape building while earthquake forces acts in various zones. Concluded that the storey displacement was maximum in irregular structure and if the shape of the structure is irregular in plan or in vertical dimension it directly affects the whole structure in seismic action.

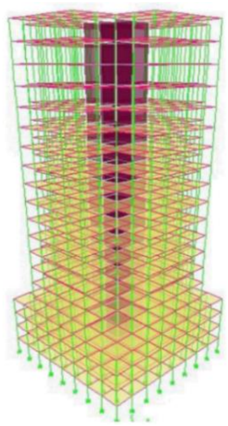


Figure 2.55. Structure with Plan Irregularity [19]

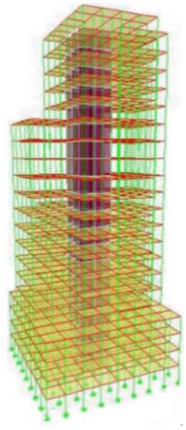


Figure 2.56. Plan and Vertical Irregularity [19]

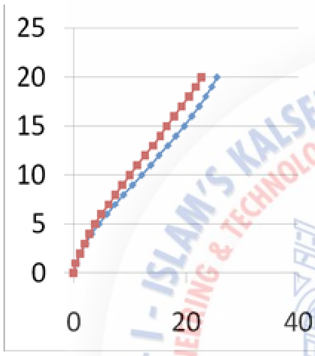


Figure 2.57. Comparison of Story Displacement [19]

Figure 2.58. Comparison of Story Drift[19]

Shruti. A. G, Shivraj. S. Mangalgi ***(2015)*** focuses on study of SMRF building with irregular plan and strengthening the re-entrant corners at inner and outer notch with shear wall and bracings for different soil conditions.

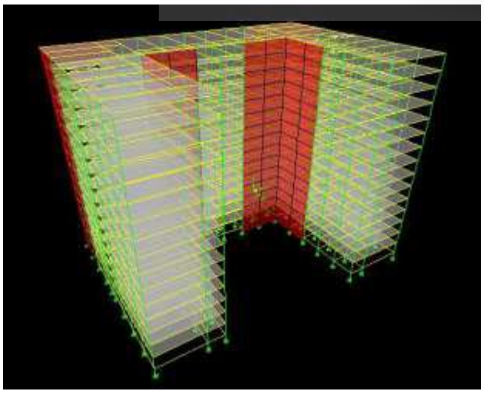


Figure 2.59. Model 2, Model 5 and Model 8 [21]

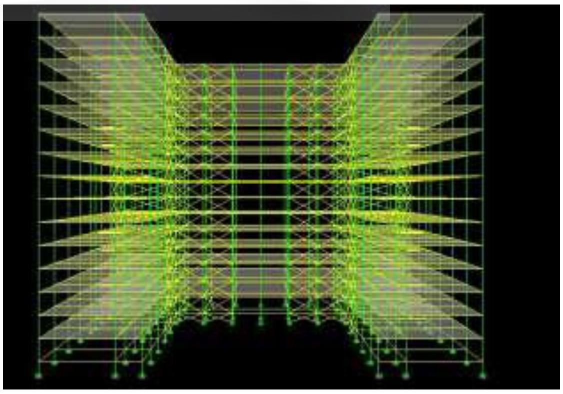


Figure 2.60. Model 3, Model 6 and Model9[21]

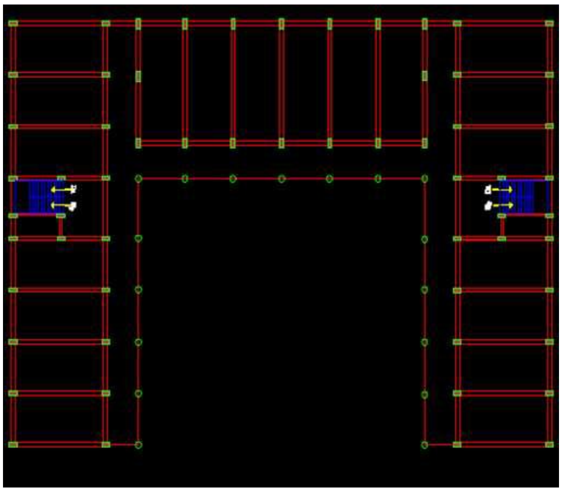


Figure 2.61. Building Plan [21]

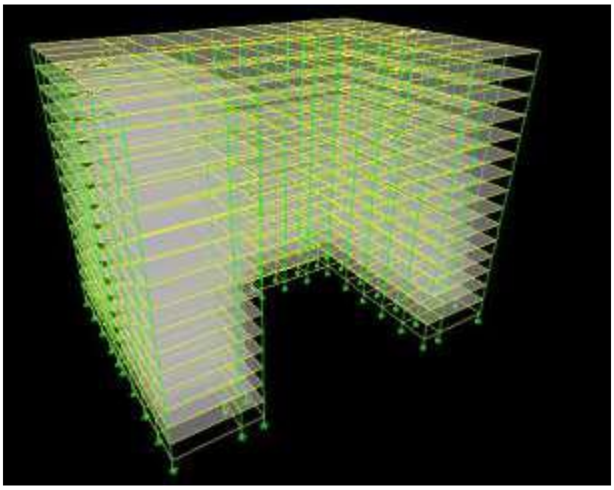


Figure 2.62. Mode l1, Mode l4 and Model7[21]

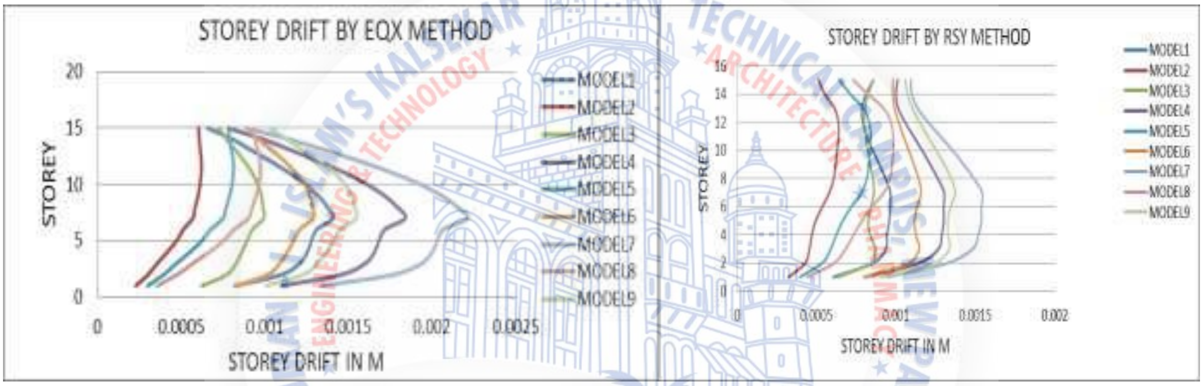


Figure 2.63. Results [21]

The building was modelled and analysed using Equivalent static method, response spectrum method and pushover analysis for seismic parameters like base shear, storey drift, lateral displacement. It was observed that SMRF with shear wall and bracings were more effective in seismic resistant of a structure when compared to SMRF. Comparing all the three frames, SMRF with shear all was more effective in all soil types. Extreme increase in base shear, lateral drift and displacements was observed in models with soft soil. Comparing all the three seismic analysis pushover analysis is more accurate since it consists of non-linearity behaviour of the material.

Mangesh S. Suravase, Prashant M. Pawar ***(2017)*** Consider the modern days structures which involves with architectural importance and it is highly difficult to plan with regular shapes. This leads to planning with irregularity in the structure. Tested the behaviour of G+10 storied R.C frame buildings with different geometrical irregularities. Kept volume and height of all shape building model.

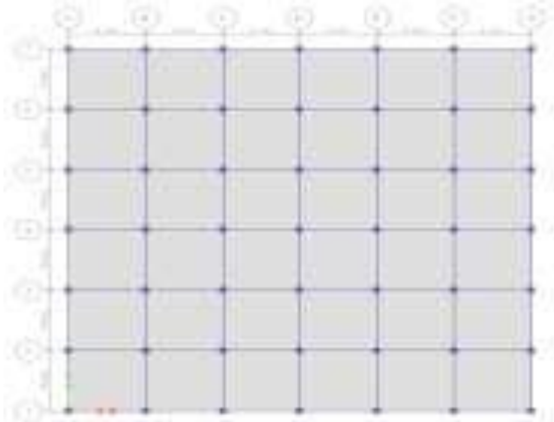


Figure 2.64. Regular Model [9]

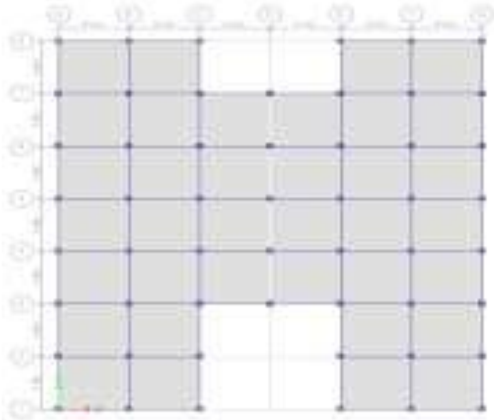


Figure 2.65. H –Shape Plan [9]

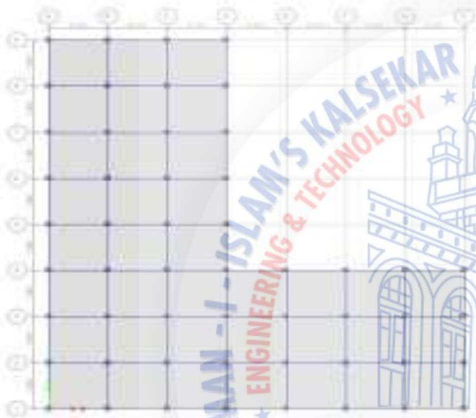


Figure 2.66. L –Shape Plan [9]

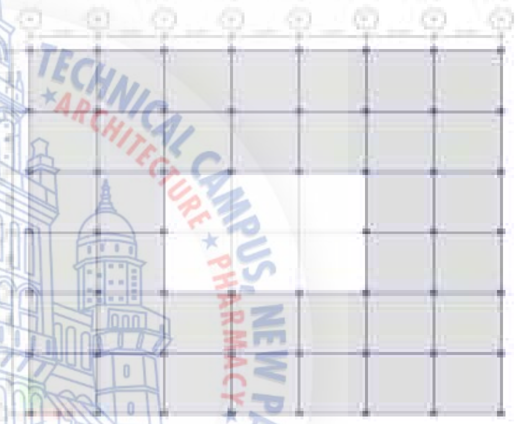


Figure 2.67. O –Shape Plan [9]

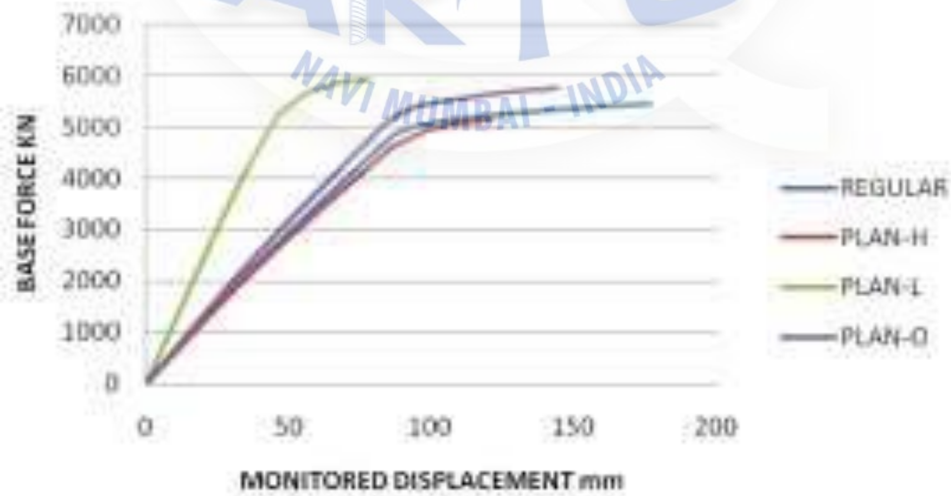


Figure 2.68. Monitored Displacement vs. Base Force for Comparison of all Model [9]

Displacement control pushover analysis is carried out. It was found that if there is an increase in the irregularity of a building having the same volume then buildings performance will decrease.

Kusuma B. ***(2017)*** analysis of G+49 RC framed structure with different irregularities under seismic conditions. Irregularities considered are Re-entrant corner, mass irregularity, vertical geometric irregularity, diaphragm irregularity and stiffness irregularity. Determine seismic responses such as the storey lateral displacement, storey drift, storey shear, storey stiffness by taking Equivalent static Analysis. The lateral displacement is increased in case of vertical irregular structure, re-entrant corner structure and stiffness irregular structure, from the storey where the irregularity is introduced.

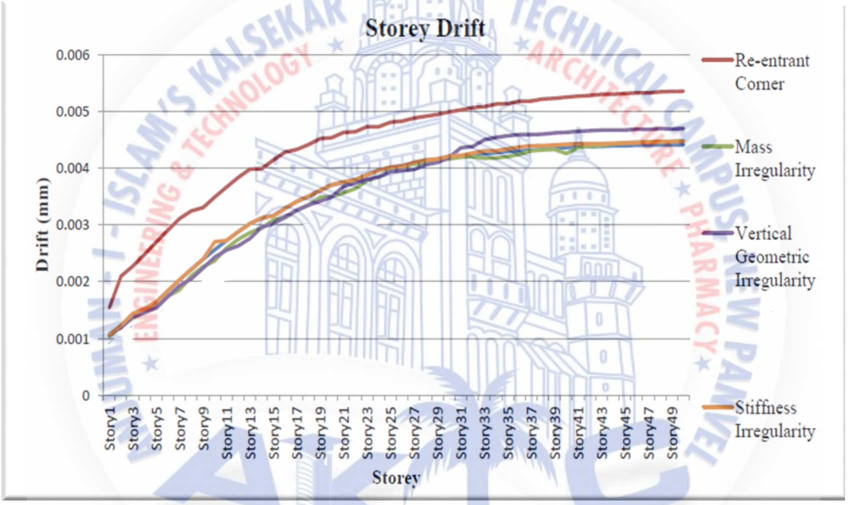


Figure 2.69. Story Drift [8]

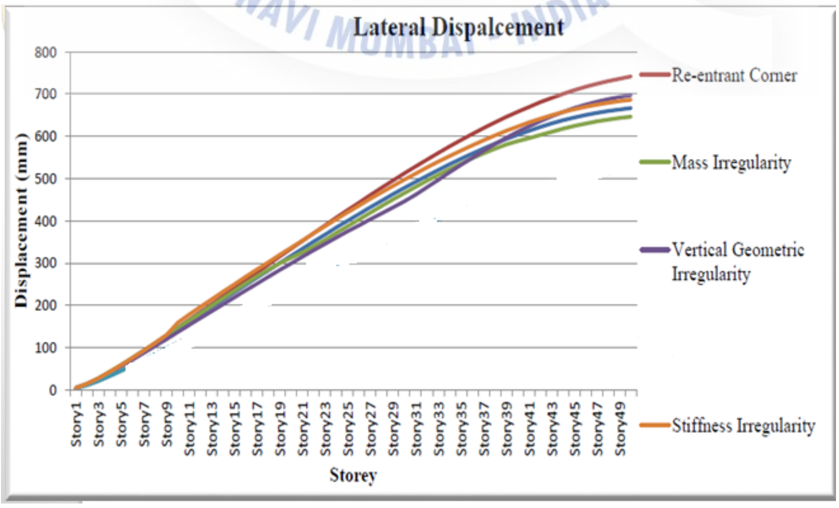


Figure 2.70. Lateral Displacement [8]

Piyush Mandloi, Rajesh Chaturvedi *(2017)* analysed four different building models which are vertically irregular and each model is analysed for without mass irregularity, with mass irregularity increasing from bottom to top, and with mass irregularity decreasing bottom to top. Combinations of four models and three mass irregularities are then also analysed against four different time histories which are Chichi (1999), Petrolia (1992), Friuli (1976), Northridge (1994) and Sylmar respectively.

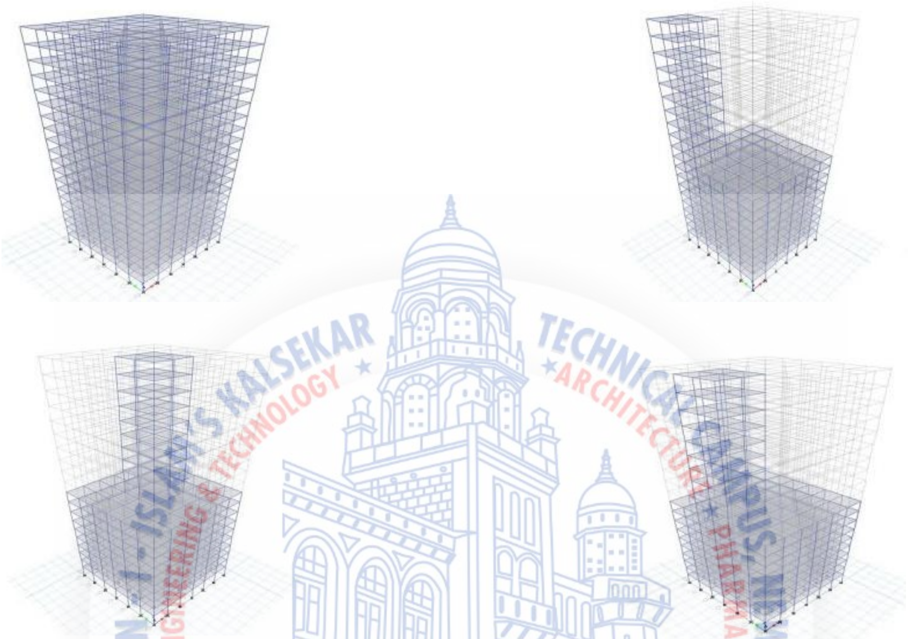


Figure 2.71. 3D View of Models [13]

All analysis are compared for outcomes such as story deflection, story drift, overturning moment and base reaction. Conclude that the outcomes varies from time history to time history. The designers worked for seismic zones must consider time history data while designing vertical and mass irregular buildings.

Ravindra N. Shelke, U. S. Ansari *(2017)* focus on the effects of various vertical irregularities on the seismic response of a structure. The objective of the project is to carry out Response spectrum analysis (RSA) of vertically irregular RC building. Comparison of the results of analysis and design of irregular structures with regular structure was done. Three types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered. The mass irregular structures were observed to experience larger base shear than similar regular structures. The stiffness irregular structure experienced lesser base shear and has larger inter-storey drifts. The absolute displacements obtained from time history analysis of geometry irregular structure at respective nodes were found to be greater than that in case of regular structure for upper stories but gradually as we moved to lower stories displacements in both structures tended to converge. Lower stiffness results in higher displacements of upper stories. Max story drift and story displacement will increase as the vertical irregularities increase in models respectively.

2.4 Critical Comments on Literature

1. Due to ever evolving pace of industrial and financial developments of the country, more and more complex structures are being constructed, which have many irregularities to meet the functional requirements.
2. Presence of any irregularity significantly affects the performance of the structure during an earthquake.
3. Structures with irregularity need careful analysis and design otherwise it will result in tragic loss of life and property as shown by many researchers in the past.
4. Indian Standard for Seismic Design has been revised in the year 2016, so there is a need to understand the intensions behind the changes in the clauses of design and illustrate the same to the engineers.
5. Plan and stiffness irregularities are found in almost all the structures which needs extensive analysis and design.

2.5 Problem Definition

It is proposed to design a structure with irregularity as per the revised IS 1893 code and compare the same with the previous code to understand and illustrate the intensions behind the changes.

2.6 Objectives

Following are the objectives of the study.

i. To understand fundamentals of seismic design.
ii. To understand various irregularities in the structure.
iii. To study the behavior of structure with and without Irregularities under seismic conditions.

iv. To understand the Response Spectrum method of seismic design.
v. To understand the revised IS 1893:2016
vi. To understand analysis and design of structures with irregularities.
vii. To illustrate the design of structure with irregularity per revised seismic design code IS 1893-2016

2.7 Methodology

To achieve above mentioned objectives, following methodology will be adopted.

i. Study of fundamentals of seismic design.
ii. Review of existing literature pertaining to design of structures with irregularity.
iii. Selection of structure with particular irregularity and its mathematical modelling in ETABS.
iv. Analysis and Design of the structure as per relevant clauses of IS 1893-2002 and IS 1893-2016 to compare and illustrate the intensions behind the change.

2.8 Aim

The project aims at illustrating the seismic design of an irregular structure as per revised seismic design code IS 1893-2016

2.9 Scope

The project is confined to the study of irregularities in the structure. No soil-structure interaction and wind load will be considered in the study. Non Linear Time History Analysis is also ignored. Only design as per IS 1893 code will be followed to illustrate the seismic design of structures with irregularity.

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