iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 3 **Issue:** VII **Month of publication:** July 2015

DOI:

www.ijraset.com Volume 3 Issue VII, July 2015
IC Value: 13.98 ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Comparative Studies on Seismic Analysis of Regular and Vertical Irregular Multistoried Building

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Abstract--It is understood that buildings which are regular in elevation (regular building) perform much better than those which have irregularity in elevation (irregular building) under seismic loading. Irregularities are not avoidable in construction of buildings. However a detailed study to understand structural behaviour of the buildings with irregularities under seismic loading is essential for appropriate design and their better performance. The main objective of this study is to understand the effect of elevation irregularity and behaviour of 3-D R.C. Building which is subjected to earthquake load. In the present study, a 5 bays X 5 bays, 16 storied structure with provision of lift core walls and each storey height 3.2 m, having no irregularity in elevation and plan, is considered as the normal 3-D structure to compare with the irregular i.e. soft storey building. Both the regular and irregular buildings are assumed to be located in all zones. Linear dynamic analysis using Response Spectrum method of the irregular building is carried out using the standard and convenient FE software package. For this the behaviour parameters considered are 1) Maximum displacement 2) storey drift, 3) Base shear, 4) Time period.

Key Words: asymmetric building, soft story, base shear, displacement, storey drift, time period.

I. INTRODUCTION

Earthquakes are one of the most devastating natural hazards that cause great loss of life and livelihood. An earthquake is a spasm of ground shaking caused by a sudden release of energy in earth's lithosphere. This energy arises mainly from stresses built up during tectonic processes, which consists of interaction between the crust and the interior of the earth. Human activity also sometimes modifies crustal stresses enough to trigger small or even moderate earthquakes, such as the swarms of minor tremors resulting from mining in the Midlands of England, or sometimes larger events induced by the impounding of large amounts of water behind dams, such as the earthquakes associated with the construction of Koyna dam in central India in 1967 and recently in Nepal in 2015, 7.8 intensity earthquake has occurred. Earthquake Ground Motions (EQGMs) are the most dangerous natural hazards where both economic and life losses occur. Most of the losses are due to building collapses or damages. Earthquake can cause damage not only on account of vibrations which results from them but also due to other chain effects like landslides, floods, fires etc. Therefore, it is very important to design the structures to resist, moderate to severe EQGMs depending on its site location and importance of the structure. If the existing building is not designed for earthquake then its retrofitting becomes important. Seismic requirements were not included in building codes as early as those for wind, although some experimentation had taken place in Europe and even more in Japan, which suffered from frequent seismic activity. Some of the early approaches yielded little result, but that did not stop curious minds from experimenting. The first application of Newton's first law to building codes dealing with seismic design was reportedly made in Italy following the 1911 Messina earthquake. Mindful that the force is equal to mass times acceleration, the regulations there started to require that all buildings should be designed for a static horizontal force equal to 10% of their weight. Seismic forces are caused by inertia of the structure, which tries to resist ground motions. As the shifting ground carries building foundations along with it, inertia keeps rest of the structure in place for a short while longer. The movement between two parts of the building creates a force, equal to the ground acceleration time's mass of the structure. In order to have a minimum force, mass of the building should be as low as possible since there can be no control on the ground acceleration being an act of God! The point of application of this inertial force is the centre of gravity of the mass (CM) on each floor of the building. Once there is a force, there has to be an equal and opposite reaction to balance this force. The inertial force is resisted by the building and the resisting force acts at the centre of rigidity (CR) at each floor of the building. The Present work is focused on the study of Seismic demands of different vertical irregular R.C buildings using various analytical techniques for the different seismic zones (medium soil) of India. The configuration involves vertical irregularities such as stiffness irregularity. From the study of research paper given by RAVI KUMAR CM and BABU NARAYAN K on the effect of irregular configurations on seismic vulnerability of RC buildings, The present paper made an attempt to study two kinds of irregularities in the building models namely plan irregularity with geometric and diaphragm discontinuity and vertical irregularity with setback and sloping ground. It is also examined the effect of three different lateral load patterns on the performance of various irregular buildings in pushover analysis. This study creates awareness about seismic vulnerability concept on practicing engineers.

II. CRITREA FOR VERTICAL IRREGULARITIES IN BUILDING CODES

In the recent version of IS 1893 (Part 1)-2002, irregular configuration of buildings has been defined explicitly. As per this code, a structure is defined to be irregular if the ratio of one of the quantities (such as mass, stiffness or strength) between adjacent stories exceeds a minimum prescribed value. These values (such as 70-80% for soft story, 80% for weak story, and 150% for set-back structures) and the criteria that define the irregularities have been assigned by judgment.

III. METHODOLOGY

Structure has been defined into stiffness irregularity as specified in IS1893-2002 code. In this dissertation work, an effort is made to study the seismic effects on structures due to this irregularity. Different configurations of structures are considered for the FE analysis using ETABS software. FE analyses involving Modal, Equivalent Static, and Response Spectrum are studied for the structure and results like natural frequencies, accelerations, displacements and storey drifts are obtained for regular an irregular building.

A. Methods of Analysis

There are different types of earthquake analysis methods. Some of them used in the project are-
Equivalent Static Analysis
Response Spectrum Analysis

1) Equivalent Static Analysis: The response of a structure to earthquake-induced forces is a dynamic phenomenon. Consequently, a realistic assessment of the design forces can be obtained only through a dynamic analysis of the building models. Although this has long been recognized, dynamic analysis is used only in frequently in routine design, because such an analysis is both complicated and time-consuming. A major complication arises from the fact that most structures are designed with the expectation that they would be strained into the inelastic range when subjected to the design earthquake In the equivalent static analysis method, the response of the building is assumed as linear elastic manner. To calculate equivalent linear static the IS 1893 (Part I): 2002 has given a formula as below.
Determination of base shear (V_B) of the building

$$V_B = A_h \times W$$

Where,

$Ah = \frac{Z}{2}\frac{I}{R}\frac{Sa}{g}$ Is the design horizontal seismic coefficient, which depends on the seismic zone factor (Z), importance factor (I), response reduction factor (R) and the average response acceleration coefficients (Sa/g). Sa/g in turn depends on the nature of foundation soil (rock, medium or soft soil sites), natural period and the damping of the structure.

2) Response Spectrum Analysis: This approach permits the multiple modes of response of a building to be taken into account. This is required in many building codes for all except for very simple or very complex structures. The structural response can be defined as a combination of many modes. Computer analysis can be used to determine these modes for a structure. For each mode, a response is obtained from the design spectrum, corresponding to the modal frequency and the modal mass, and then they are combined to estimate the total response of the structure. In this the magnitude of forces in all directions is calculated and then effects on the building are observed. Following are the types of combination methods:
absolute -peak values are added together
square root of the sum of the squares (SRSS)
complete quadratic combination (CQC) -a method that is an improvement on SRSS for Closely spaced modes.

The result of a RSM analysis from the response spectrum of a ground motion is typically different from that which would be calculated directly from a linear dynamic analysis using that ground motion directly, because information of the phase is lost in the process of generating the response spectrum.

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IV. MODELING

A. Modeling Details Of 3d Models

Details of Buildings considered in this work are as follows:

Type of structure: Residential Building

Number of stories: 16

Height of typical floor: 3.2m

Column size: 300 mmX500 mm

Beam size: 300 mmX500 mm

Slab thickness: 150 mm

Masonry wall thickness: 230 mm

Live load: 2 KN/m^2

Floor finish: 1 KN/m^2

Soil types considered as type II – Medium soil.

All the columns are assumed to be fixed at their base.

Characteristic compressive strength of concrete, f_{ck}: 20 N/mm^2

Grade of steel: 500N/mm^2

Density of Concrete: 25N/mm^2

Modulus elasticity of concrete: 2000N/mm^2

Poison's ratio of concrete, μ: 0.3

Density of brick masonry, ρ: 19.2 KN/m^3

Modulus of elasticity of brick masonry: 14000 N/mm^2

Poison's ratio of brick masonry: 0.2

Damping ratio: 5%

1) *Seismic Calculations:*

Table 1: Seismic Calculations for All Zones

Characteristics	ZONE 2	ZONE 3	ZONE 4	ZONE 5

Number of stories	16	16	16	16
Typical storey height, m	3.2	3.2	3.2	3.2
Seismic zone, Z	0.10	0.16	0.24	0.36
Response reduction factor, R	3	3	3	3
Importance factor, I	1	1	1	1
Soil type	II	II	II	II

Seismic zone, Z (IS 1893 – 2002, clause 6.4.2, table 2)

Response reduction factor, R (IS-1893-2002, clause 6.4.2, Table 7)

Importance factor, I (IS 1893 – 2002, clause 6.4.2, table 6)

Soil type (IS 1893 – 2002, clause 6.4.5, pg 16)

Calculation of Time period [without infill]: (IS-1893-2002, clause 7.6.1, pg 24)

$T = 0.075h^{0.75}$

2) Regular Model:

ELEVATION 3D VIEW

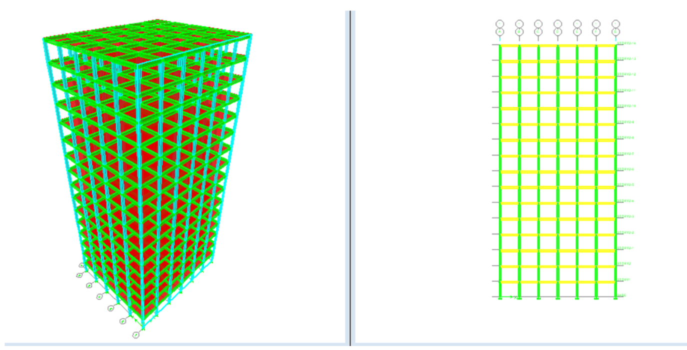

Fig 1: ETABS Model Screen shot of a regular 16 Storied Building

3) Irregular Model (Stiffness Or Soft Storey): In this irregularity, the changes made with respect to regular building are, the base story is made as soft story by increasing the height of it from the following equation,

$$0.7\times12EI/L^3 = 12EI/L_1^3$$

$L_1^3 = L^3/0.7$ Where, $L_1 =$ Ht. Of soft storey

$L_1 = 1.126L$ L= Ht. Of regular storey

$$L_1 = 3.6m$$

ELEVATION 3D VIEW

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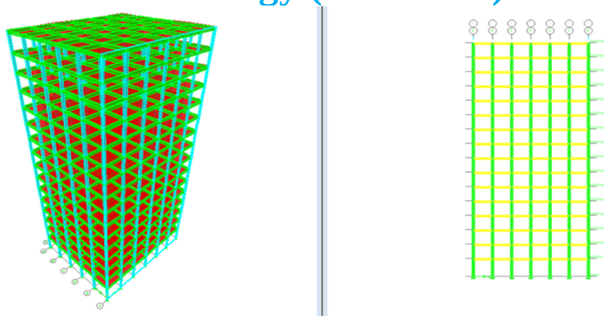

Fig 2: ETABS Model Screen shot of an irregular 16 Storied Building

V. RESULTS AND DISCUSSIONS

The results of regular and irregular (soft storey) building model are presented in this chapter. The analysis carried out is equivalent static analysis and Dynamic analysis. The result of Base shear, Lateral displacement, story drift, Fundamental time period at the first, second and third mode were presented for different irregularities and regular structure for different seismic zones of India.

A. Analysis Results Of 3d Models

1) Base Shear of Regular Model:

Table 2: Base shear of model for different zones

ZONES	BASE SHEAR IN KN
2	442.15
3	707.46
4	1061.18
5	1591.75

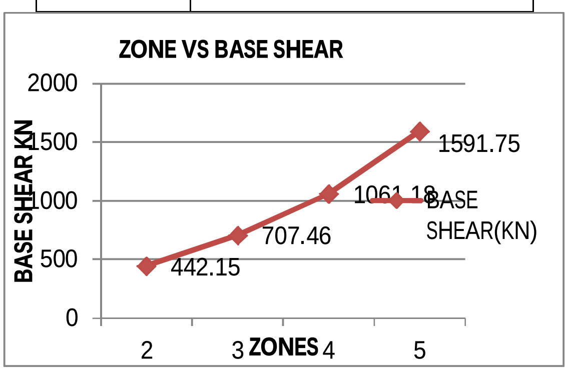

Fig 3: Graph of Zone v/s Base shear for regular model

Figure 1 shows the graph of Zone v/s Base shear of a Regular model. It shows that as the zone increases Base shear also increases, so the maximum Base shear is 1591.75KN in zone 5, i.e. zone 5 base shears is 4 times greater than zone 2 which is the most vulnerable seismic zone of India.

2) Base Shear of Irregular Model (Soft Storey):

Table 3: Base shear of model for different zones

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ZONES	BASE SHEAR IN KN
2	437.09
3	699.32
4	1048.98
5	1573.51

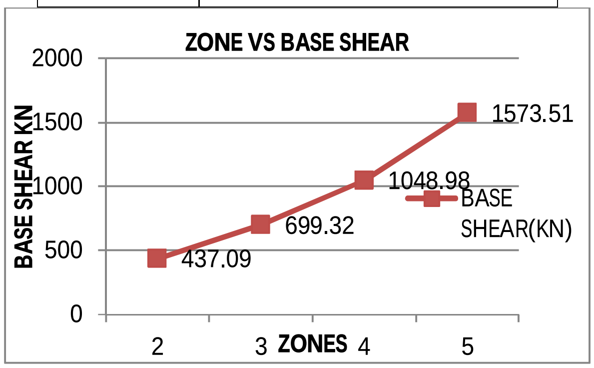

Fig 4: Graph of Zone v/s Base shear for irregular model

Figure 4 shows the graph of Zone v/s Base shear of an Irregular model i.e. Stiffness irregularity (Soft storey). It shows that as the zone increases Base shear also increases, so the maximum Base shear is 1573.51KN in zone 5, .e. zone 5 base shears is 4 times greater than zone 2 which is the most vulnerable seismic zone of India.

3) Base Shear Of Both The Models For Different Zones: In this, the base shear of different models was tabulated for different seismic zones.

Table 4: Base shear of both the models

ZONES	BASE SHEAR IN KN	
	REGULAR	IRREGULAR(soft storey)
2	442.15	437.09
3	707.46	699.32
4	1061.18	1048.98
5	1591.75	1573.51

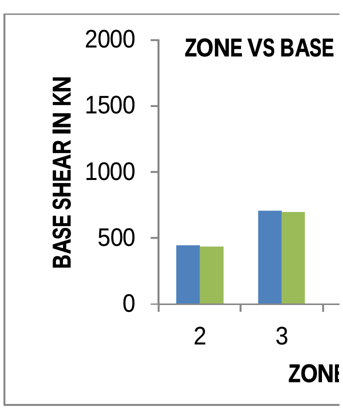

Fig 5: Graph of Zone v/s Base shear

Figure 5 shows the graph of Zone v/s Base shear of regular (Type 1) and Irregular model (type 3) i.e. Stiffness irregularity (Soft

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storey). It shows that as the zone increases Base shear also increases for type 1and type 2, so the maximum Base shear in soft storey is 1573.51KN in zone 5 which is the most vulnerable seismic zone of India.

4) Results Of Top Storey Displacement Of Regular Model For Different Zones:

Table 5: Displacement of regular model for different zones

ZONES	DISPLACEMENT IN MM
2	22
3	35.2
4	52.8
5	79.1

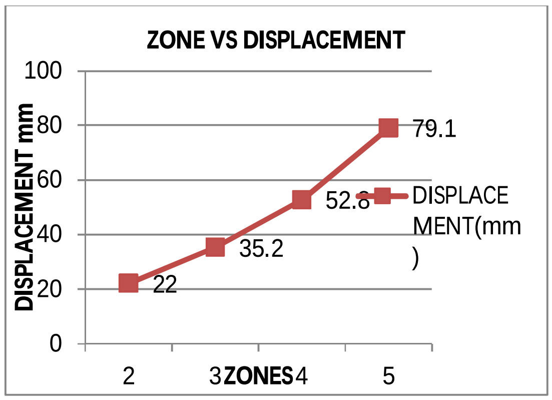

Fig 6: Graph of Zone v/s Displacement for regular model

Figure 6 shows the graph of Zone v/s Displacement of a Regular model. It shows that as the zone increases Displacement also increases i.e. in zone 5 displacements is 3.5 times greater than zone 2, so the maximum Displacement is 79.1mm in zone 5 which is the most vulnerable seismic zone of India.

5) Results Of Top Storey Displacement Of Irregular Model (Soft Storey) For Different Zones:

Table 6: Displacement of model for different zones

ZONES	**DISPLACEMENT IN MM**
2	23
3	36.8
4	55.1
5	82.7

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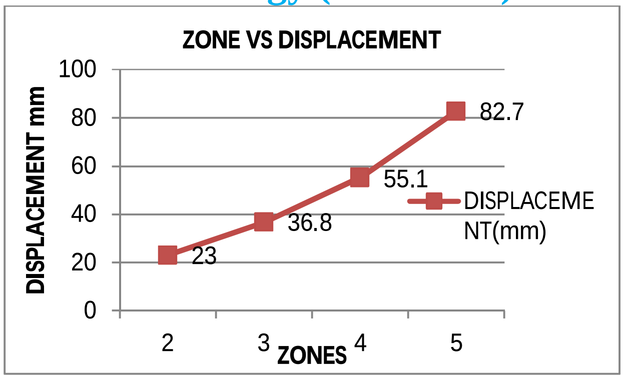

Fig 7: Graph of Zone v/s Displacement for irregular model

Figure 7 shows the graph of Zone v/s Displacement of an Irregular model i.e. Stiffness irregularity (soft storey). It shows that as the zone increases Displacement also increases i.e. in zone 5 displacements is greater than 3.6 times zone 2, so the maximum Displacement is 82.7mm in zone 5 which is the most vulnerable seismic zone of India.

6) Displacement Of Both The Models For Different Zones:

Table 7: Displacement of both the models

ZONES	DISPLACEMENT IN KN	
	REGULAR	IRREGULAR(soft storey)
2	22	23
3	35.2	36.8
4	52.8	55.1
5	79.1	82.7

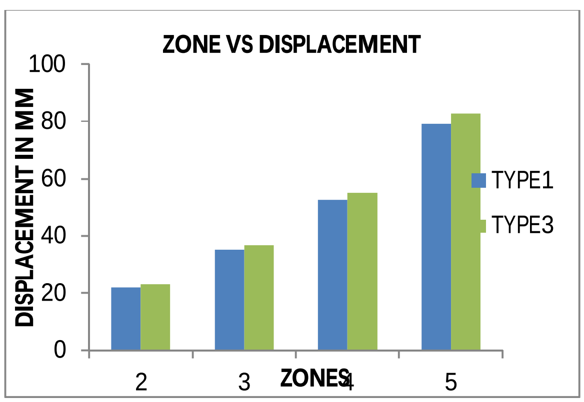

Fig 8: Graph of zone v/s Displacement

Figure 8 shows the graph of Zone v/s Displacement of regular (type 1) and Irregular model (type 3) i.e. Stiffness irregularity (soft storey). It shows that as the zone increases Displacement also increases, so the maximum Displacement is 82.7mm in zone 5 which is the most vulnerable seismic zone of India, so we conclude that regular building displace less due to earthquake than irregular.

7) Storey Drift At Each Floor For Regular Model:

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Table 8: Storey drift of regular model for all storey**’s**

STOREY	STOREY DRIFT			
	ZONE II	ZONE III	ZONE IV	ZONE V
0	0	0	0	0
1	0.000136	0.000204	0.000296	0.000432
2	0.000177	0.000281	0.000419	0.000625
3	0.000226	0.000361	0.000542	0.000812
4	0.000267	0.000428	0.000642	0.000962
5	0.0003	0.000479	0.000719	0.001078
6	0.000325	0.00052	0.00078	0.00117
7	0.000347	0.000555	0.000833	0.001249
8	0.000367	0.000587	0.00088	0.00132
9	0.000384	0.000615	0.000922	0.001383
10	0.0004	0.00064	0.00096	0.001439
11	0.000414	0.000663	0.000994	0.001491
12	0.000429	0.000687	0.00103	0.001545
13	0.000445	0.000711	0.001067	0.0016
14	0.000457	0.000732	0.001098	0.001646
15	0.000454	0.000726	0.001088	0.001632
16	0.000318	0.000508	0.00076	0.001139

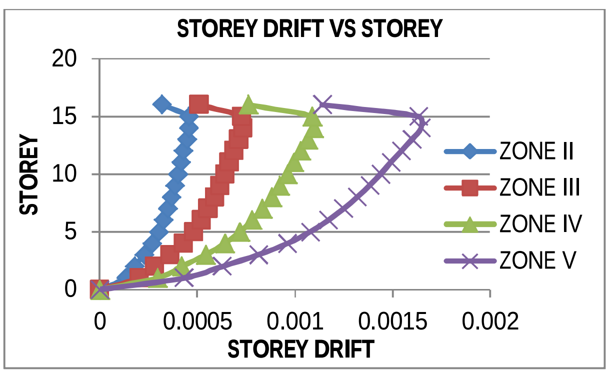

Fig 9: Graph of Storey drifts v/s Storey for regular model

Figure 9 shows the graph of Storey drifts v/s Storey of Regular model in all seismic zones. It shows that from base storey to 14th storey the storey drift gradually increases but in 15th and 16th storey it decreases because usually storey drift is maximum in middle portion of the structure.

8) Storey Drift At Each Floor For Irregular Model (SOFT STOREY):

Table 9: Storey drift of soft storey for all storey’s

STOREY	STOREY DRIFT			
	ZONE II	ZONE III	ZONE IV	ZONE V
0	0	0	0	0
1	0.000144	0.000211	0.000301	0.000435
2	0.000175	0.000275	0.00041	0.000611
3	0.00022	0.000352	0.000527	0.00079

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4	0.000261	0.000417	0.000626	0.000938
5	0.000293	0.000469	0.000703	0.001055
6	0.000319	0.00051	0.000765	0.001147
7	0.000341	0.000545	0.000817	0.001226
8	0.00036	0.000576	0.000864	0.001297
9	0.000378	0.000605	0.000907	0.00136
10	0.000393	0.000629	0.000944	0.001416
11	0.000407	0.000652	0.000978	0.001466
12	0.000421	0.000674	0.001011	0.001516
13	0.000436	0.000697	0.001045	0.001568
14	0.00045	0.00072	0.00108	0.00162
15	0.000472	0.000752	0.001125	0.001686
16	0.000449	0.000715	0.001071	0.001604

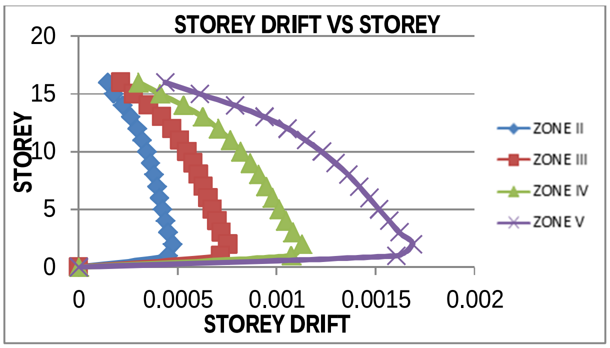

Fig 10: Graph of Storey drifts v/s Storey for irregular model

Figure 10 shows the graph of Storey drifts v/s Storey of an Irregular model i.e. stiffness irregularity (soft storey) in all seismic zones. It shows that from base storey to 14th storey the storey drift gradually increases but in 15th and 16th storey it decreases because usually storey drift is maximum in middle portion of the structure.

9) Time Period At Different Mode Of Regular Model :

Table 10: Time period in different modes

MODES	TIME PERIOD(SECS)
1	2.98
2	2.24
3	2.16
4	0.99
5	0.74
6	0.71

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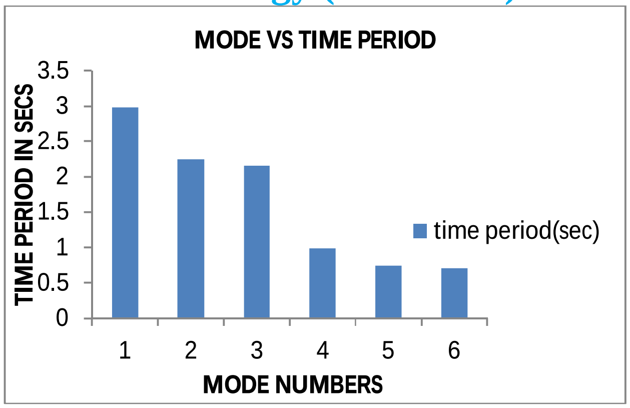

Fig 11: Graph of Mode v/s Time Period for regular model

Figure 11 shows the graph of Mode v/s Time period of a Regular model. It shows that as the mode number increases the Time period decreases, so the maximum Time period is 2.98secs in mode 1.

10) Time Period At Different Mode Of Irregular Model (SOFT STOREY)

Table 11: Time period in different modes

MODES	TIME PERIOD(SECS)
1	3.13
2	2.33
3	2.24
4	1.04
5	0.77
6	0.74

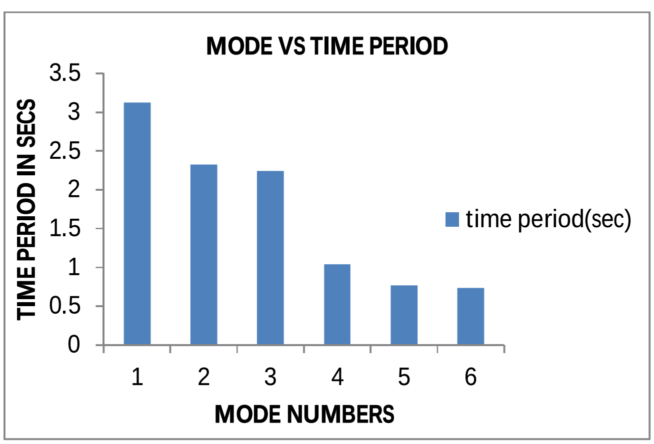

Fig 12: Graph of Mode v/s Time Period for irregular model

Figure 12 shows the graph of Mode v/s Time period of an Irregular model i.e. stiffness irregularity (soft storey). It shows that as the mode number increases the Time period decreases, so the maximum Time period is 3.13secs in mode 1.

VI. CONCLUSIONS

When irregular buildings are analyzed using linear equivalent static analysis and Response spectrum analysis considering different seismic zones according to code provisions, the results obtained highlights the importance of stiffness of the structure. Following broad conclusions can be made in this respect:

This study quantifies the effect of vertical irregularities in stiffness on seismic demands.

The Base shear and lateral displacements are gradually increased with increase in zone factors for both the models.

The lateral displacement is less in regular model compare to vertical irregular model.

The base shear is almost same in regular model and irregular model, max base shear is in zone 5 in regular is 1591.75KN and in irregular 1573.51KN.

The regular model shows less displacement compare to irregular model (soft storey), max displacement in zone 5 in regular is 79.1mm and in irregular it is 82.7mm.

The drift is observed in the storey in which the stiffness is reduced.

As stiffness increases frequency of the structure increases.

Stiffness is dependent on mass of the structure, as height of the structure increases mass also increases.

From the overall study and observation it can be conclude that, Base shear and lateral displacement will increases as the seismic intensity increases from zone-2 to zone-5 which indicates more seismic demand the structure should meet.

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BIOGRAPHIES

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Gargi Danda De, Assistant Professor of Bhilai Institute of Technology, Durg, CG. has 11 years field and teaching experience. She has several papers in reputed national and international journals and conferences. She is a member of Indian Institute of Engineers (India).

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