Seismic Analysis of Vertically Irregular RC Building Frames

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Abstract-*Many buildings in the present scenario have irregular configurations both in plan and elevation. This in future may subject to devastating earthquakes. In case, it is necessary to identify the performance of the structures to withstand against disaster for both new and existing one. This paper is concerned with 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.*

Keywords-Seismic behavior, Reinforced concrete frame, Structural Irregularities, lateral displacement, storey drifts, base shear, soft story.

I. INTRODUCTION

Response spectrum is one of the useful tools of earthquake engineering for analyzing the performance of structures especially in earthquakes, since many systems behave as single degree of freedom systems. Thus, if you can find out the natural frequency of the structure, then the peak response of the building can be estimated by reading the value from the ground response spectrum for the appropriate frequency. In most building codes in seismic regions, this value forms the basis for calculating the forces that a structure must be designed to resist (seismic analysis).

Response-spectrum analysis (RSA) is a linear-dynamic statistical analysis method which measures the contribution from each natural mode of vibration to indicate the likely maximum seismic response of an essentially elastic structure. Response-spectrum analysis provides insight into dynamic behavior by measuring pseudo-spectral acceleration, velocity, or displacement as a function of structural period for a given time history and level of damping. It is practical to envelope response spectra such that a smooth curve represents the peak response for each realization of structural period.

IS 1893 definition of Vertically Irregular structures-

The irregularity in the building structures may be due to irregular distributions in their mass, strength and stiffness along the height of building. When such buildings are constructed in high seismic zones, the analysis and design becomes more complicated.

1. Plan Irregularities
2. Vertical Irregularities.

Vertical Irregularities are mainly of five types-

i) Stiffness Irregularity — a) Soft Storey-A soft storey is one in which the lateral stiffness is less than 70 percent of the storey above or less than 80 percent of the average lateral stiffness of the three storeys above.
   b) Extreme Soft Storey-An extreme soft storey is one in which the lateral stiffness is less than 60 percent of that in the storey above or less than 70 percent of the average stiffness of the three storeys above.
ii) Mass Irregularity-Mass irregularity shall be considered to exist where the seismic weight of any storey is more than 200 percent of that of its adjacent storeys. In case of roofs irregularity need not be considered.
iii) Vertical Geometric Irregularity- A structure is considered to be Vertical geometric irregular when the horizontal dimension of the lateral force resisting system in any storey is more than 150 percent of that in its adjacent storey.
iv) In-Plane Discontinuity in Vertical Elements Resisting Lateral Force-An in-plane offset of the lateral force resisting elements greater than the length of those elements.
v) Discontinuity in Capacity — Weak Storey-A weak storey is one in which the storey lateral strength is less than 80 percent of that in the storey above.

As per IS 1893, Part 1 Linear static analysis of structures can be used for regular structures of limited height as in this process lateral forces are calculated as per code based fundamental time period of the structure. Linear dynamic analysis are an improvement over linear static analysis, as this analysis produces the effect of the higher modes of vibration and the actual distribution of forces in the elastic range in a better way.

1.1 Scope of the thesis:

1. Regular and symmetrical structures exhibit more favourable and predictable seismic response characteristics than irregular structures. Therefore, the use of irregular structures in earthquake-prone areas should be avoided if possible.
2. In case of stiffness irregular structure concentration of mass on floor level causes grater effect on inter storey drift so that proper design is necessary

1.2 Objectives

This thesis addresses the major objectives of the research work are as follows:
1. To study the effect of vertical geometric irregularity and performance level of the structure.
2. Comparison between regular and vertical irregular frame on the basis of shear force, bending moment, storey drift & node displacement etc.
3. To obtain the Seismic performances of different irregular buildings located in severe earthquake zone (III) of Maharashtra, India, and also identify the most vulnerable building among them.
4. Evaluation of design lateral forces on buildings with irregularities namely vertical geometric irregularity (irregular shear wall), mass irregularity and stiffness irregularity subjected to biaxial excitation and to compare the results of different structures. A comparative study was performed on 3-D analysis model created in ETABS, a commercial computer program for the analysis of structures.
5. Implement the proposed multi-scale modeling technique to assess the seismic performance of the vertical irregularity of RC building frames to evaluate the seismic safety and collapse vulnerability of existing buildings.

II. ANALYSIS METHODS

Seismic analysis is a subset of structural analysis and is the calculation of the response of the building structure to earthquake and is a relevant part of structural design where earthquakes are prevalent. The seismic analysis of a structure involves evaluation of the earthquake forces acting at various level of the structure during an earthquake and the effect of such forces on the behaviour of the overall structure. The analysis may be static or dynamic in approach as per the code provisions.

Thus broadly we can say that linear analysis of structures to compute the earthquake forces is commonly based on one of the following three approaches.
1. An equivalent lateral procedure in which dynamic effects are approximated by horizontal static forces applied to the structure. This method is quasi-dynamic in nature and is termed as the Seismic Coefficient Method in the IS code.
2. The Response Spectrum Approach in which the effects on the structure are related to the response of simple, single degree of freedom oscillators of varying natural periods to earthquake shaking.
3. Response History Method or Time History Method in which direct input of the time history of a designed earthquake into a mathematical model of the structure using computer analyses.

Two of the above three methods of analysis, *i.e*. Seismic Coefficient Method and Response Spectrum Method, are considered for the analysis of buildings studied here. Details of these methods are described in the following section. The seismic method of analysis based on Indian standard 1893:2002 (Part – 1) is described as follows

2.1 Equivalent Static Analysis

This is a linear static analysis. This approach defines a way to represent the effect of earthquake ground motion when series of forces are act on a building, through a seismic design response spectrum. This method assumes that the building responds in its fundamental mode. The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces. In the equivalent static method, the lateral force equivalent to the design basis earthquake is applied statically. The equivalent lateral forces at each storey level are applied at the design 'centre of mass' locations. It is located at the design eccentricity from the calculated 'centre of rigidity (or stiffness)'.

The base dimension of the building at the plinth level along the direction of lateral forces is represented as d (in meters) and height of the building from the support is represented as h (in meters). For the purpose of determining the design seismic forces, the country (India) is classified into four seismic zones (II, III, IV, and V). Previously, there were five zones, of which Zone I and II are merged into Zone II in fifth revision of code. The design horizontal seismic forces coefficient Ah for a structure shall be determined by following expression.

$$Ah = \frac{Z\ I\ Sa}{2\ R\ g}$$

Z = zone factor for the maximum considerable earthquake (MCE) and service life of the structure in a zone. Factor 2 in denominator is to reduce the MCE to design basis earthquake (DBE).

I = importance factor , depending on the functional purpose of the building, characterized by hazardous consequences of its failure , post earthquake functional needs, historical value , or economic importance.

R = response reduction factor, depending upon the perceived seismic damage performance of the structure, characterized by ductile or brittle deformations however the ratio *I/R* shall not be greater than 1.

S_a/g = average response acceleration coefficient

For Type I soil (rock or hard soil sites):

$$\frac{Sa}{g} = \begin{cases} 1+15T & (0.00 \le T \le 0.10) \\ 2.50 & (0.10 \le T \le 0.40) \\ 1.00/T & (0.4 \le T \le 4.00) \end{cases}$$

For Type II soil (medium soil):

$$\frac{Sa}{g} = \begin{cases} 1+15T & (0.00 \le T \le 0.10) \\ 2.50 & (0.10 \le T \le 0.55) \\ 1.36/T & (0.55 \le T \le 4.00) \end{cases}$$

For Type III soil (soft soil):

$$\frac{Sa}{g} = \begin{cases} 1+15T & (0.00 \le T \le 0.10) \\ 2.50 & (0.10 \le T \le 0.67) \\ 1.67/T & (0.67 \le T \le 4.00) \end{cases}$$

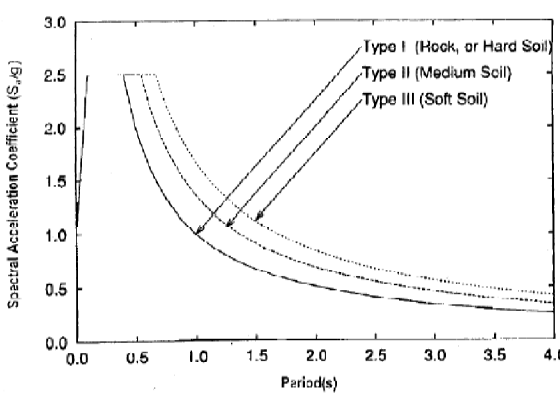


Figure 2.1Design response spectra curve as per IS: 1893-2002 code

2.2 Design Lateral Force

The total design lateral force or design seismic base shear (V_b) along any principal direction of the building shall be determined by the following expression

$V_b = A_h W$

Where A_h is the horizontal seismic forces coefficient and *W* is the seismic weight of building.

2.3 Fundamental Natural Period

The fundamental natural time period as mentioned in *clause 7.6 IS 1893 (part 1): 2002* for moment resisting RC frame building without brick infill walls and moment resisting steel frame building without brick infill walls, respectively is given by

$Ta = 0.075h^{0.75}$

$Ta = 0.085h^{0.75}$

where, *h* = height of the building in 'm' excluding basement storey, if it is connected with the ground floor decks or fitted in between the building column.

If there is brick filling, then the fundamental natural period of vibration, may be taken as

$Ta = 0.09h/\sqrt{d}$

Where, *h* = height of the building in m, as defined above, and *d* = base dimension of the building at the plinth level, in meter, along the considered direction of the lateral force

2.4 Distribution of Design Force

The design base shear, $V_b$computed above shall be distributed along the height of the building as per the following expression,

$$Q_i = \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j h_i^2}$$

Where, Q_i = design lateral force at ith floor

W_i = seismic weight of ith floor

H_i = height of ith floor measured from base, and

n = numbers of storey in the building is the number of the levels at which the masses are located.

2.5 General Codal Provisions

Dynamic analysis should be performed to obtain the design seismic force, and its distribution to different levels along the height of the building and to various lateral load resisting elements, for the following buildings:

- Regular buildings- Those are greater than 40 m in height in zone IV, V and those are greater than 90 m height in zones II,III, and
- Irregular buildings-All framed buildings higher than 12 m in zone IV and V, and those are greater than 40 m in height in zone II and III.

III. STRUCTURAL MODELLING

A) Response Spectrum Analysis

Response Structure analysis was performed on regular and various irregular buildings using ETAB. The storey shear forces were calculated for each floor and graph was plotted for each structure.

Four types of Irregular buildings were considered, Regular structure, Mass irregular structure, structure with ground storey as the soft storey and vertically geometric irregular building. The structures were 15 storeyed.

Problem Statement-

Following data is used in the analysis of the RC frame building models

- Type of frame: Special RC moment resisting frame fixed at the base
- Seismic zone: ш
- Number of storey: G+14
- Floor height: 3.0 m
- Depth of Slab: 125 mm
- Size of beam: (350 × 450) mm
- Size of column: (400 × 600) mm
- Spacing between frames: 4 m along X directions
  3 m along Y directions
- Floor finish: 2 KN/m^2
- Density of concrete: 25 KN/m^3
- Materials: M 25 concrete, Fe 415 steel
- Live load on floor: 4 KN/m^3
- Type of soil: Medium
- Terrace water proofing: 1.5 KN/m^2
- Response spectra: As per IS 1893(Part-1):2002
- Damping of structure: 5 percent
- Poison Ratio of concrete: 0.2

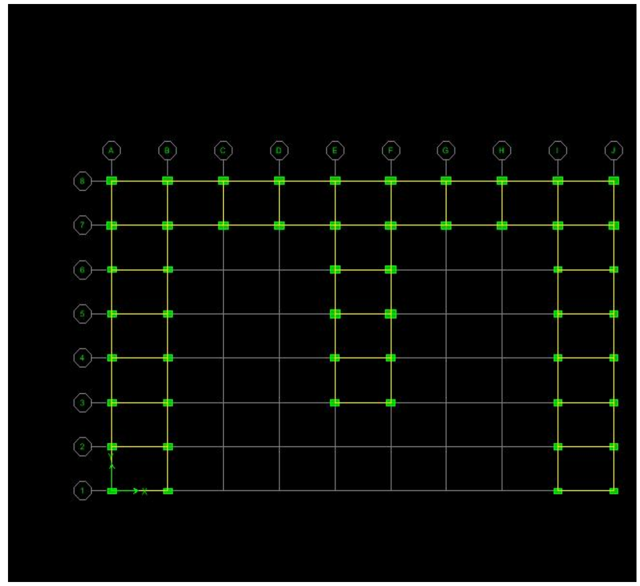


Figure 3.1: plan of structure

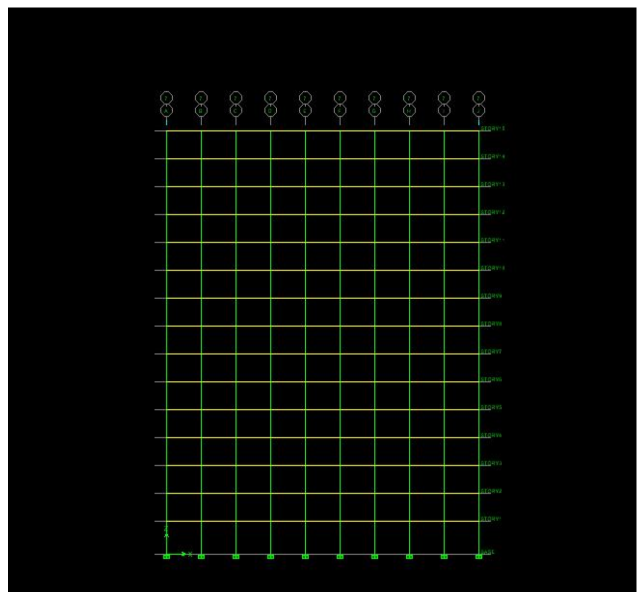


Figure 3.2 Elevation of model

Model properties-

1. Regular structure- In this model only frame is model. Effect of vertical irregularity is not considered in this model.
2. Mass Irregular Structure- The structure is modeled as same as that of regular structure except the loading due to swimming pool is provide in the fifth and tenth floor.
3. Stiffness Irregular Structure (Soft Storey): The structure is same as that of regular structure but the first storey has a height of 3.5 m and doesn‘t have brick infill.
4. Vertically Geometric Irregular- The structure is 15 storeyed with steps in 1st to 14th floor. The setback is along X and Y direction.
5.

1. Regular structure (15 storeys):

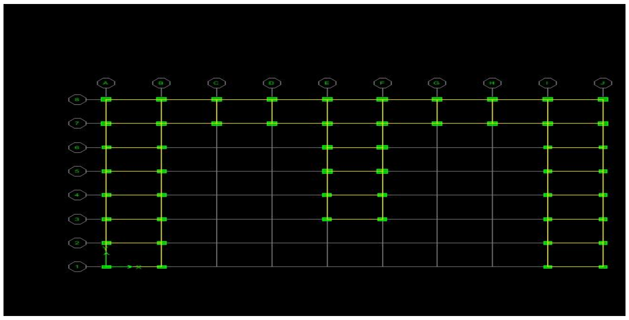


Figure 3.3: plan of regular structure

II. Mass Irregular Structure (15 storeys):

The structure is modeled as same as that of regular structure except the loading due to swimming pool is provide in the fifth and tenth floor.

Height of swimming pool considered- 1.8m
Loading due to swimming pool -18kN/m^2
Weight of 5^{th} story = 2 * Weight of adjacent stories (Mass Irregularity)

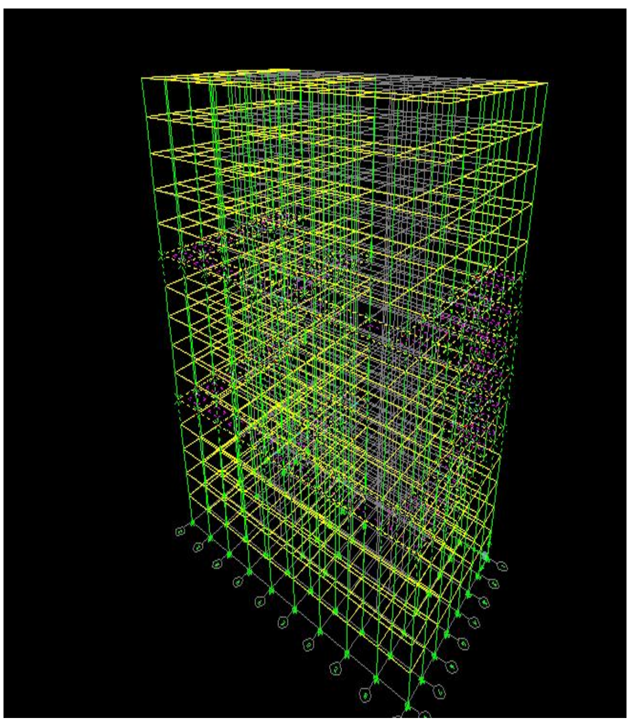


Figure 3.4: Mass regular structure with swimming pools on 5th storey

III. Stiffness Irregular Structure (Soft Storey):

The structure is same as that of regular structure but the ground storey has a height of 4.5 m and doesn‘t have brick infill.

Stiffness of each column= $12EI/L^3$
Therefore,
Stiffness of ground floor/stiffness of other floors= $(3.0/3.5)^3 = 0.63 < 0.7$
Hence as per IS 1893 part 1 the structure is stiffness irregular.

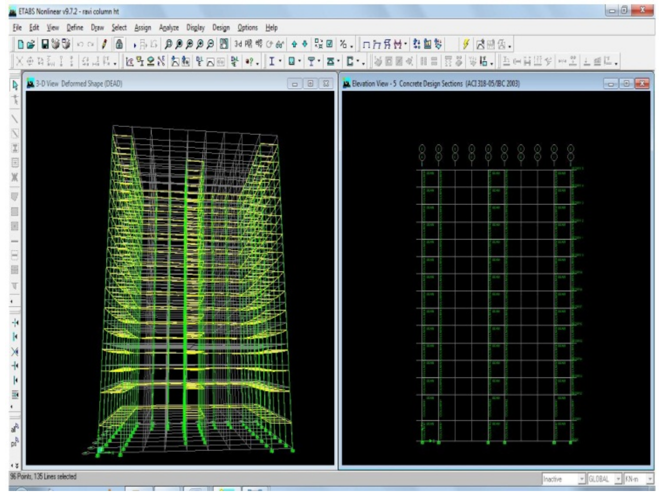


Figure 3.5: stiffness irregular structure

IV. Vertically Geometric Irregular

The structure is 15 storeyed with steps in 1st to 14th floor. The setback is along X and Y direction.
Width of top storey= 4 m
Width of ground storey=36 m
Vertically Irregular=36/4=9>1.5
Hence, as per IS 1893, Part 1 the structure is vertically geometric irregular structure.

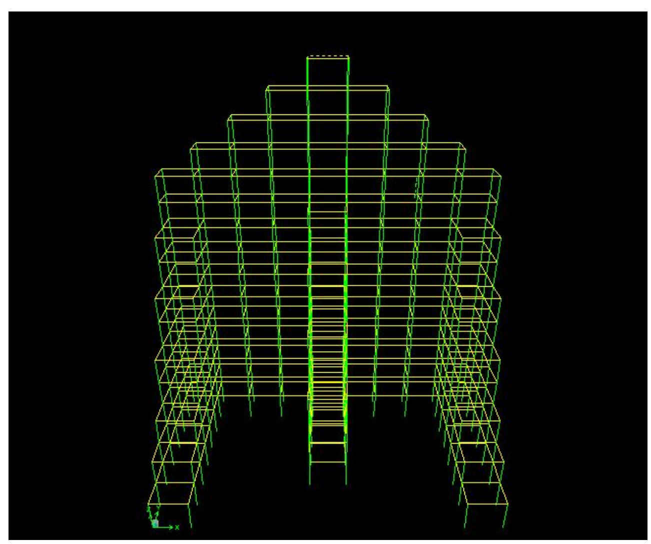
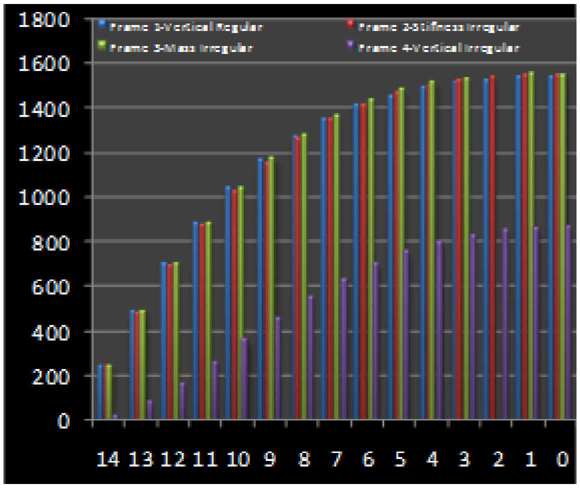
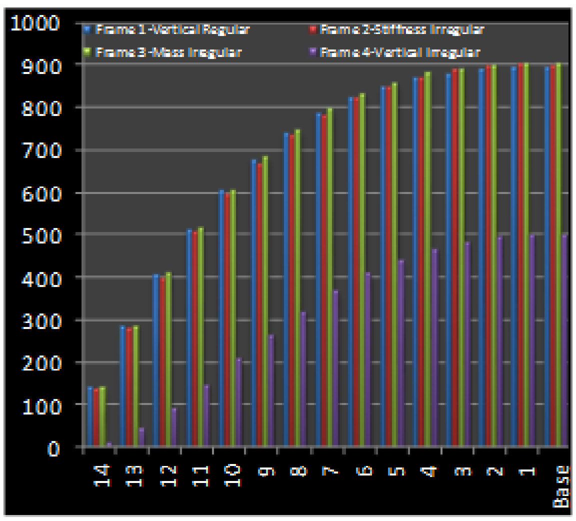


Figure 3.6: Vertical Geometric irregular structure

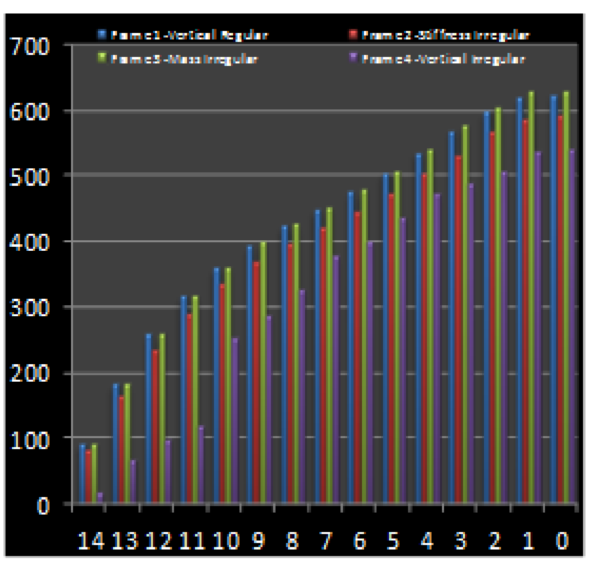
IV. RESULT AND DISCUSSION



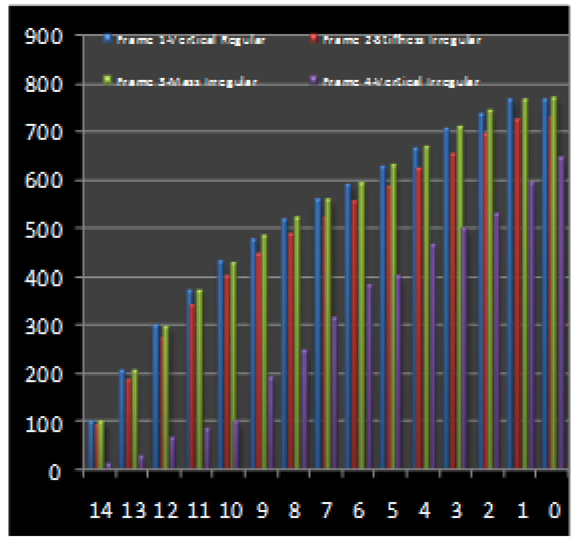
Graph 1-Story V/s Story shear static in X direction



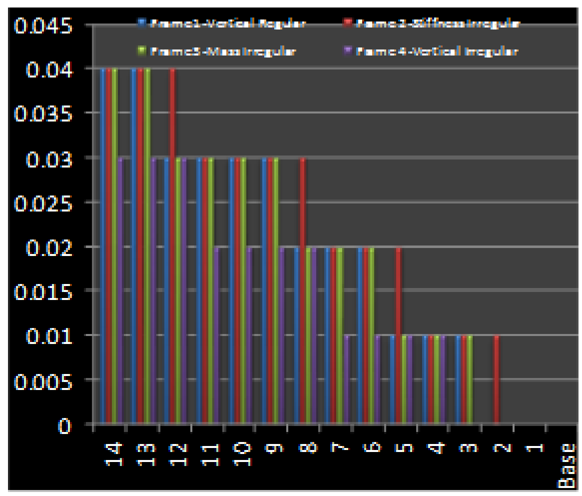
Graph 2-Story V/s Story shear static in Y direction



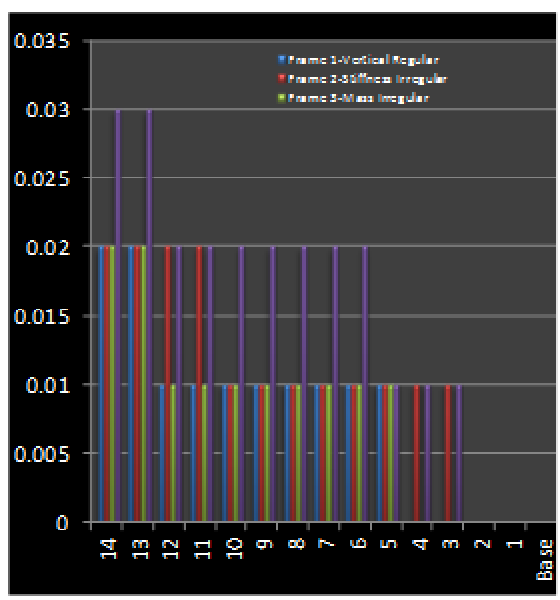
Graph 4.3-Story V/s Story shear dynamic in X direction



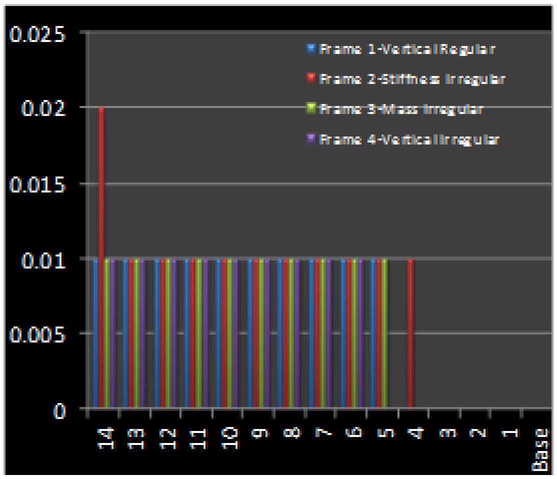
Graph 4-Story V/s Story shear dynamic in Y direction



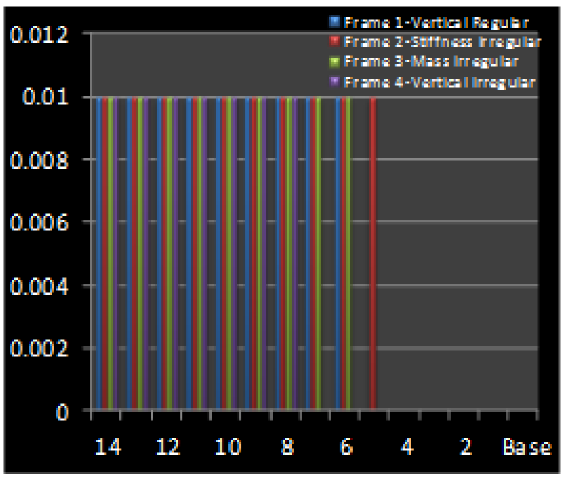
Graph 5-Story V/s Story displacements static in X direction



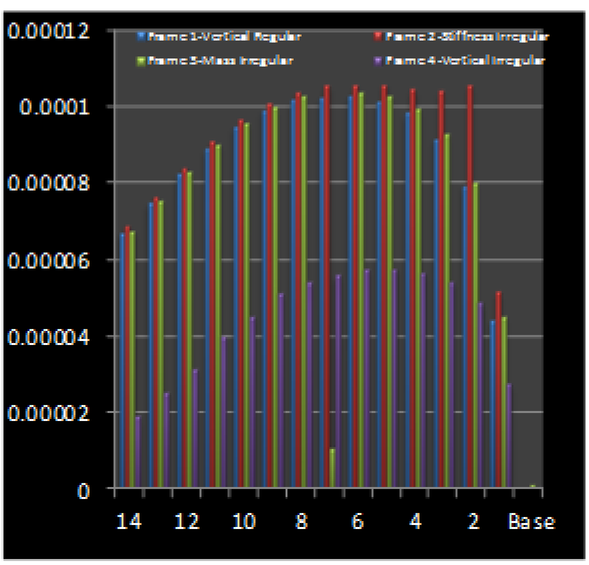
Graph 6-Story V/s Story displacements static in Y direction



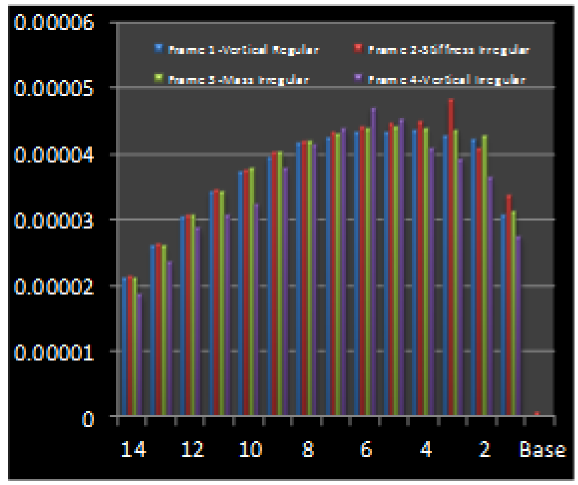
Graph 7-Story V/s Story displacements dynamic in X direction



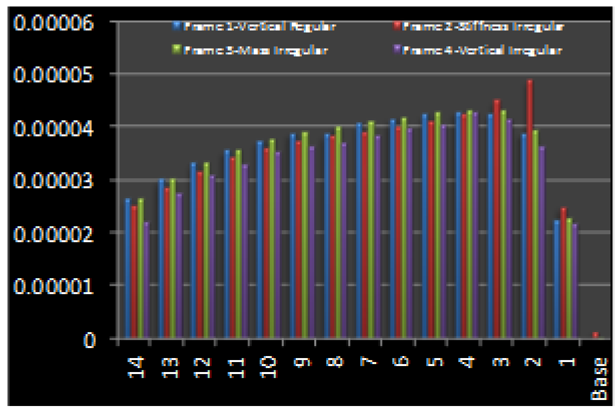
Graph 8-Story V/s Story displacements dynamic in Y direction



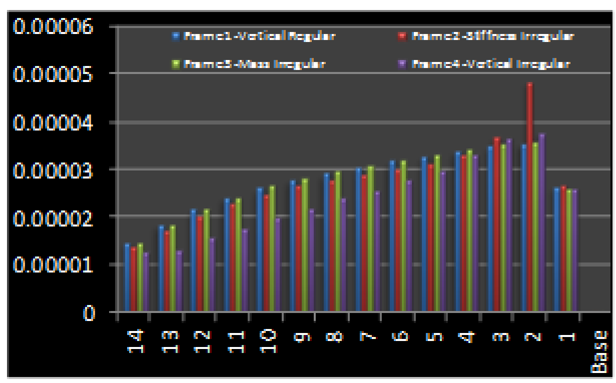
Graph 9-Story V/s Story drift static in X direction



Graph 10-Story V/s Story drift static in Y direction



Graph 11-Story V/s Story drift dynamic in X direction



Graph 12-Story V/s Story drift dynamic in Y direction

The storey shear force is maximum in ground storey and it decreases as we move up in the structure. Mass irregular storey shear force is more in lower storeys as compared to regular structure. The graph closes in as we move up the structure and the mass irregular storey shear force becomes less than that in regular structure.

The Stiffness Irregular structure has a first storey height of 3.5m (more than height of the above storeys). This makes the building less stiff than regular structure. Hence the inter storey drift is observe to be more in stiffness irregular structure. And hence, the storey shear force is more in regular structure as compared to stiffness irregular structure.

Due to less stiff ground storey the inter storey drift is found to be more in stiffness irregular structure. Hence, the floor displacement is more in stiffness irregular structure than regular structure.

Mass irregular structure has swimming pool in 5th floor hence the 5th storey displacement is more in mass irregular structure. The effect of extra mass is found to be more in 10th storey where higher inter storey drift is observed. Higher the position of extra mass the moment of the inertial force is more leading to larger displacement.

In geometry irregular structure the stiffness is far more than that of regular structure. So the displacement in lower storeys of geometry irregular structure is very less as compared to regular structure. But storey due to setback there is a sudden increase in the displacement and hence there is decrease in slope of the graph.

V. CONCLUSIONS

Three types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered .All three kinds of irregular RC building frames had plan symmetry. Response spectrum analysis (RSA) was conducted for each type of irregularity and the storey shear forces obtained were compared with that of a regular structure. Three types of ground motion with varying frequency content, i.e., low (imperial), intermediate (IS code),high (San Francisco) frequency were considered. Our results can be summarized as follows-

- According to results of RSA, the storey shear force was found to be maximum for the first storey and it decreased to a minimum in the top storey in all cases.
- According to results of RSA, it was found that mass irregular building frames experience larger base shear than similar regular building frames.
- According to results of RSM, the stiffness irregular building experienced lesser base shear and has larger inter storey drifts.
- The absolute displacements obtained geometry irregular building at respective nodes were found to be greater than that in case of regular building for upper stories but gradually as we move to lower stories displacements in both structures tended to converge. This is because in geometry irregular structure upper stories have lower stiffness than the lower stories. Lower stiffness results in higher displacements of upper stories.
- The equivalent static method doesn't consider the irregular effects in the building and since it depends only on empirical formula the results obtained will be abnormal in comparison to response spectrum method
- Base shear will increase when the zones changes from II to V and soil stratum III to I in Equivalent Static method as well as Response Spectrum (Dynamic Analysis) method.
- Max story drift and story displacement will increase as the vertical irregularities increase in models respectively.
- 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.
- Seismic coefficient method of dynamic analysis is not sufficient for high rise buildings or high rise irregular building as it is conservative as compared to response spectra method and it is necessary to provide dynamic analysis because of specific and non linear distribution of forces.
- The values of storey shear of static and dynamic analysis at top stories are insignificant but it increased in lower stories and reached at its peak in bottom storey therefore called the base shear of the whole building.

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