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Seismic Performance of Soft Storey and Vertical Geometrical Irregular Structures

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***Abstract*: Soft storey collapse is one of the reasons for failure of framed structures during an event of an earthquake. Such irregularities are highly undesirable in the buildings built in earthquake prone areas. In such buildings, the stiffness of the lateral load resisting systems at that storey is quite less compared to other storey's. In high rise building or multi storey building, soft storey construction is a typical feature because of urbanization and the space occupancy considerations. These provisions reduce the stiffness of the lateral load resisting system and a progressive collapse becomes unavoidable in a severe earthquake for such buildings due to soft storey. This storey level containing the concrete columns which were unable to provide adequate shear resistance, hence damage and collapse are most often observed in soft story buildings during the earthquake. In the current study the focus is on the investigation of the effect of a soft storey and vertical geometrical irregularity on the masonry infill structure. In a vertically irregular structure, failure of structure starts at a 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. For example, structures with soft storey were the most notable structures which collapsed. So, the effect of vertically irregularities in the seismic performance of structures becomes really important. Height-wise changes in stiffness and mass render the dynamic characteristics of these buildings different from the regular building. For the present study ETABS software is used for modeling and analysis of structural members.**

***Keywords*: RC frames, Soft storey, ETABS, Vertical geometrical irregularity.**

1. Introduction

Concrete framed structure in recent time has a special feature i.e. the ground storey is left open for the purpose of social and functional needs like vehicle parking, shops, reception lobbies, a large space for meeting room or a banking hall etc. Such buildings are often called open ground storey buildings or soft story buildings. Again when a sudden change in stiffness takes place along the building height, the story at which this drastic change of stiffness occurs is called a soft story. The Indian code (clause no. 4.20) classifies a soft storey as, It is one in which the lateral stiffness is less than 70 percent of that in the storey above or less than 80 percent of the average lateral stiffness of the three storey's above (IS 1893:2002). Soft storey can form at any level of a high rise building to fulfill required functional necessity and serve various purposes. In a vertically irregular structure, 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. Irregular structures contribute a large portion of urban infrastructure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes. For example, structures with soft storey were the most notable structures which collapsed. So, the effect of vertically irregularities in the seismic performance of structures becomes really important. Height-wise changes in stiffness and mass render the dynamic characteristics of these buildings different from the regular building. IS 1893 definition of vertically irregular structure, 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. In the present study, seismic performance of 3D building frame with intermediately infill frame was studied. Performance of R.C. frame was evaluated considering different models for the soft storey. The main objective of the study was to investigate the behavior of high rise, multi-bay soft storey and vertical geometrical irregular building with infilled frames and to evaluate their performance levels when subjected to earthquake loading.

2. Objectives

As such, the goal of this research is to investigate various seismic responses of RC framed regular and vertical geometric and soft storey irregular structure. The comparison various seismic parameter would allow us to propose the best suitable building configuration on the existing condition. More specifically, the salient objectives of this research are:

- To understand the behavior of regular and irregular building (Vertical irregularities) under seismic loading.
- To study the influence of presence of soft storey and vertical geometrical irregularities on the seismic behavior of RC framed structures by equivalent static method using ETABS software.
- To compare the response between regular and

irregular structure for base shear, lateral displacement and bending moment.

3. Literature review

- Prakash Sangamnerkar et. al. has done the comparative study on the static and dynamic behavior of reinforced concrete framed regular building. Comparison of static and vibrant behavior of a six storey's structure is considered in this paper and it is analyzed by using computerized solution available in all four seismic zones i.e. II, III, IV and V.
- Mohit Sharma et. al. considered a G+30 storied regular reinforced concrete framed building. Dynamic analysis of multistoried Building was carried out. These buildings have the plan area of 25m x 45m with a storey height 3.6m each and depth of foundation is 2.4 m. & total height of chosen building including depth of foundation is 114 m.
- M. S. Aainawala et. al. done the comparative study of multistoried R.C.C. Buildings with and without Shear Walls. They applied the earthquake load to a building for G+12, G+25, G+38 located in zone II, zone III, zone IV and zone V for different cases of shear wall position.
- Anwaruddin M. et. al. carried out the study on non linear Static Pushover Analysis of G plus 3 medium rise reinforced cement concrete structure with and without vertical irregularity.
- Rui Pinho et.al. revised eurocode 8 formulae for periods of vibration and their employment in linear seismic analysis. This paper takes a critical look at the way in which seismic design codes around the world have allowed the designer to estimate the period of vibration for use in both linear static and dynamic analysis.

4. Methods of analysis

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.

A. *Method in the IS code.*

1. 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.
2. 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.

One of the above three methods of analysis, equivalent static method is considered for the analysis of building studied here. Details of these models are described in following section. The seismic of analysis based on Indian standard 1893:2002 (part-1) is described as follows.

B. *Equivalent static method*

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,

$$A_h = \frac{Z\ I\ S}{2\ R_g}$$

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.

Sa /g = average response spectrum

C. Design of 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, Ah = horizontal seismic forces coefficient

W = seismic weight of building.

D. Fundamental design 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

$$T_a = 0.075h^{0.75}$$

Where, h= height of the building in m.

E. 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,

$$Q_i = V_b = \frac{W_i h_i^2}{\sum W_i h_i^2}$$

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.

5. Structural modelling

In the present study, we have considered typical four and eight story buildings with regular and irregular (with vertical geometrical and soft storey) configuration for the comparison of their seismic performance. Lateral displacement, Storey shear and Base shear of vertically regular and irregular structures is identified. Significance and effects of different parameters are studied in detail. Seismic analysis is carried as per IS 189(part1): 2002 guidelines. Pushover analysis is adopted and analysis is carried out using ETABS 2015 v 15.2.2 software package.

Table 1

Data of modeled structure considered for the study

No of stories	5
Storey type	Moment resisting frame
Typical storey height	3.5
Grade of concrete	M30
Grade of steel	Fe 500
Size of beam	300X450mm
Size of column	450X450mm
Thickness of slab	150mm
Seismic zone	III (Z=0.36)
Importance factor	1
Soil type	Medium

A. Buildings with Vertical Geometrical Configuration

Fig. 1. shows the 4-storey buildings with regular and irregular configuration in vertical geometrical. The amount of irregularity is gradually increased from model irregular 1 to irregular 3.

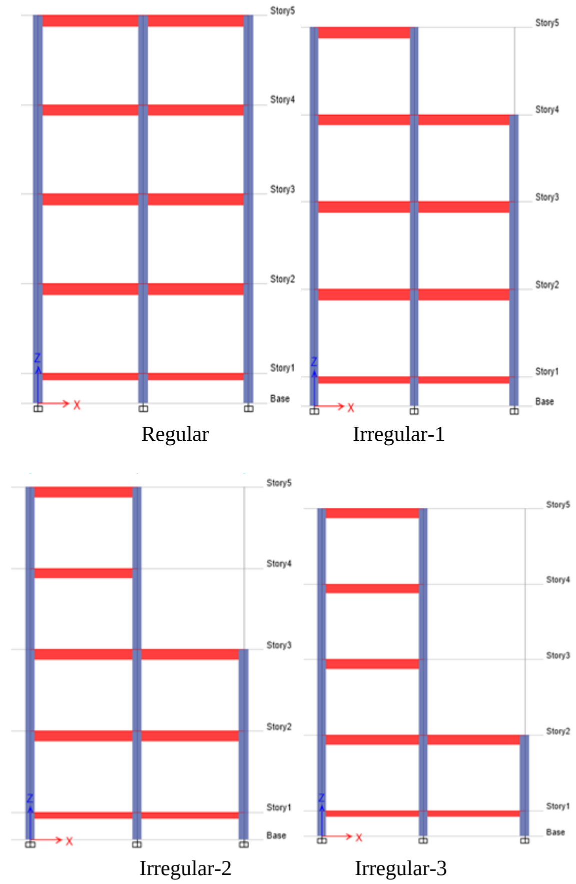
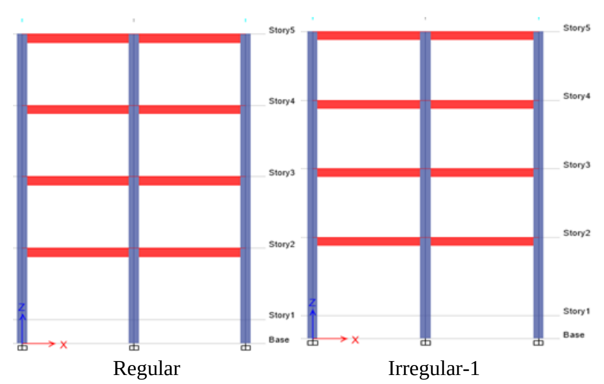
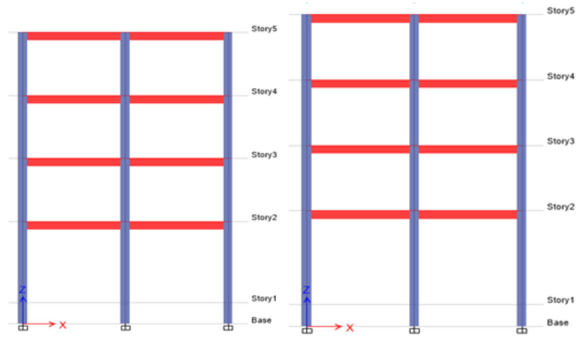


Fig. 1. Elevation View of buildings with regular and irregular (Vertical geometrical) Configuration (4-Storey)

B. Buildings with Storey shear Configuration

Fig. 2, shows the 4- storey buildings with regular and irregular configuration in vertical geometrical. The amount of irregularity is gradually increased from model irregular 1 to irregular 3.





Irregular-2 Irregular-3

Fig. 2. Elevation View of buildings with regular and irregular (Storey shear) Configuration (4-Storey)

6. Results and discussion

Structures listed above are subjected to Equivalent static as per IS1893:2001 using ETABS software. The results are discussed below.

A. Base shear

Table 2
Base shear obtained for regular and irregular 4 – storey building

Models	Base shear (kn)
Regular	321.163
Irregular-1	320.014
Irregular-2	312.612
Irregular-3	295.34
Irregular-4	321.163

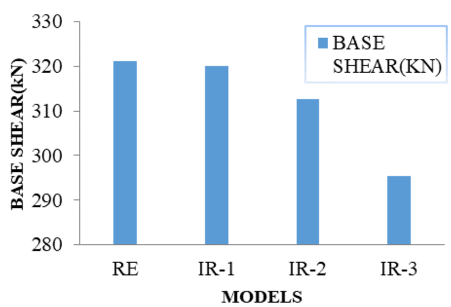


Fig. 3. Base shear diagram for regular and Irregular building of four storey building

B. Displacement

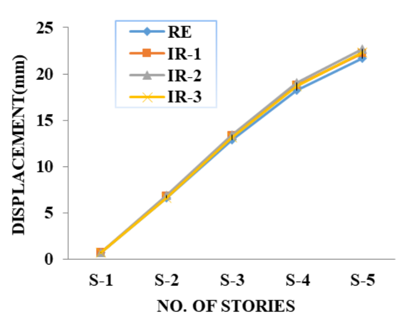


Fig. 4. Displacement diagram for regular and irregular 4-storey building

Table 3
Displacement obtained for regular and irregular 4 – storey building

MODELS	DISPLACEMENT (MM)
Regular	21.662
Irregular-1	22.254
Irregular-2	22.683
Irregular-3	22.301
Irregular-4	21.662

C. Storey shear

Table 4
Storey shear obtained for regular and irregular 4 – storey building

MODULE	RE	IR-1	IR-2	IR-3
S-5	151.685	133.081	139.651	136.877
S-4	102.356	112.371	95.405	93.508
S-3	50.277	55.851	57.921	45.932
S-2	16.518	18.348	19.254	18.65
S-1	0.327	0.363	0.382	0.374

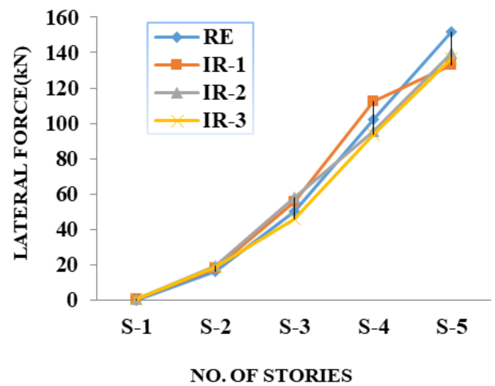


Fig. 5. Storey shear diagram for regular and irregular 4-storey building

From the above results it is clear that the buildings with irregular configuration undergoes higher displacement and storey shear and experiences much lesser base shear capacity compared to regular structures and the performance worsens with increase in the amount of irregularities.

D. Results for Buildings with soft storey Configuration

Fig. 7 and 8 shows the results of response equivalent static analysis of buildings with soft storey configuration

E. Base shear

Table 5
Base shear obtained for regular and irregular 4 – storey building

MODELS	BASE SHEAR (KN)
Regular	299.9
Irregular-1	282.776
Irregular-2	266.071
Irregular-3	250.061
Irregular-4	299.9

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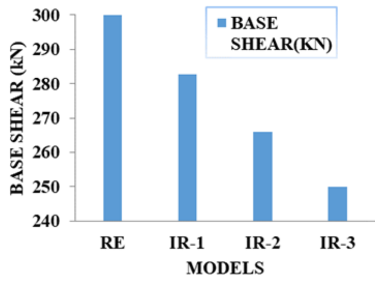

Fig. 6. Base shear diagram for regular and Irregular building of four storey building

F. Displacement

Table 6
Displacement obtained for regular and irregular 4 – storey building

MODELS	DISPLACEMENT (MM)
Regular	21.116
Irregular-1	21.749
Irregular-2	22.473
Irregular-3	23.293
Irregular-4	21.116

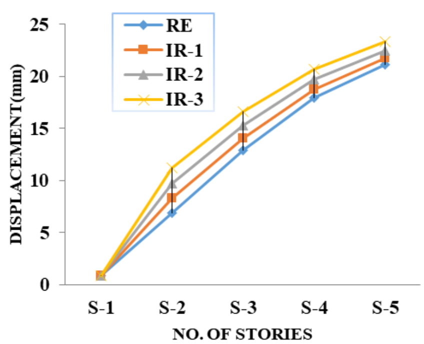

Fig. 7. Displacement diagram for regular and irregular 4-storey building

Table 7
Storey shear obtained for regular and irregular 4 – storey building

M	RE-1	RE-2	RE-3	RE-4
S-5	141.719	130.594	120.199	110.6
S-4	95.632	89.811	84.131	78.697
S-3	46.975	45.672	44.154	42.497
S-2	15.432	16.562	17.458	18.146
S-1	0.115	0.137	0.129	0.121

G. Storey shear

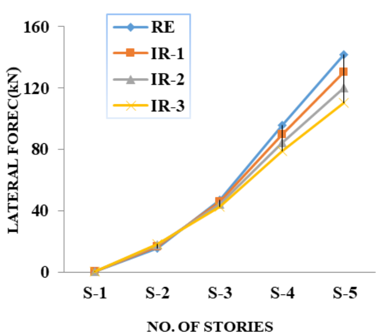

Fig. 8. Storey shear diagram for regular and irregular 4-storey building

From the above results it is clear that the buildings with irregular configuration undergoes higher displacement and storey shear and experiences much lesser base shear capacity compared to regular structures and the performance worsens with increase in the amount of irregularities.

7. Conclusion

As of urbanization, the world is facing a lot of scarcity of land, which has lead to the vertical development in the field of Civil Engineering. In order to meet the demand of people, the buildings are constructed in a more irregular way. So in the present study, it can be seen that the,

1. As building becomes more and more vertically irregular (Mass regular). The storey shear goes on increasing as compared to mass regular building.
2. Lateral displacement increases as the height of the building increases for both regular and irregular.
3. The complex shaped building are more popular but they carry a risk of sustaining damage during earthquake. Therefore, such buildings should be designed properly taking care of their dynamic behavior.

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