Study on Design and Performance Comparison of RC Buildings Designed for Various Indian Seismic Zones

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Abstract- **Reinforced concrete (RC) buildings are routinely designed and detailed to have somewhat higher strengths than those required for actual service load conditions. Generally, the members are provided with larger sizes and greater material strengths than the minimum design requirements a stipulated in the building design codes. The present design procedures for seismic design also results in greater strengths. Moreover, the redundancy in the structure on account of in redistribution of stresses will also lead to increased overall strength. This study deals with the comparison of percentage longitudinal steel, reinforcement detailing and design base shear of three RC framed buildings with varying storey heights in different Indian seismic zones. Moreover, it also comprises of performance based analysis of the buildings taken under consideration and designed as per Indian codal provisions in terms of their over-strength factor using computer-based push-over analysis.**

I. INTRODUCTION

A severe earthquake is one of the most destructive phenomena of nature. It is quite impossible to precisely predict and prevent an earthquake , but the damage to a structure can be reduced by its proper design. Hence it is prudent to do the seismic analysis and design to prevent structures against any catastrophe. The severity of the damage depends on the combination of several factors such as-earthquake magnitude, proximity to epicentre, and the local geological conditions, which affect the seismic wave propagation. The lateral forces due to earthquake cause the maximum problem for structures.

Earthquake resistant design is thereby primarily concerned with limiting the seismic risk associated with man-made structures to socio-economically acceptable levels. It aims to foresee the potential consequences of an earthquake on civil infrastructure and to ensure the design & construction of buildings complies with design codes in order to maintain a reasonable level of performance with some accepted level of damage during an earthquake exposure .The ductility of a structure acts like a shock absorber and helps in dissipating a certain amount of seismic energy.

PUSHOVER ANALYSIS

It is a non-linear structural analysis technique in which an incremental lateral load is applied to the structure under consideration. The sequential progress of crack formation, plastification, inter-storey drift and yielding can be aptly monitored through this method. It is an iterative process and continues till the design fulfills some pre-defined criterion such as target roof displacement. Roof displacement is often taken as the failure criteria because of the ease associated with its estimation. This has become a widely used tool for the purpose of seismic analysis and design of new as well as existing buildings.

II. METHODOLOGY

The present study comprises of two stages-

1. Comparison of design and detailing requirement of an RC building for all the four earthquake zones (II, III, IV, and V),i.e, as in India. This will be done for 3 buildings with varying heights of five, seven and nine storey respectively. For every building, It will consist of the following steps-
    - Modelling of the building with all the requisite parameters.
    - Designing the building for all the four earthquake zones(as in India)
    - Comparing of design and detailing for different earthquake zones.

2. A comparison of performance of designed buildings for various seismic zones and detailing provisions using computer based "PUSH-OVER" analysis.

III. SEISMIC DESIGN AND COMPARISONS

The plan of the building frame considered the present study is shown in Fig 3.1. The building with the plan shown in this figure is considered for three different number of storeys five, seven and nine. Each of the building with their specific height are designed for all the seismic zones. The building designations with the seismic zone considered are shown in Fig 3.2. The designation, 'G4ZII' represents G+4 building designed for seismic zone II.

All the buildings are designed as per IS 1893 (2002) considering medium soil conditions.. The buildings in this study have column 3m , slab thickness 125mm and plinth level as 0.6m as observed from the study of typical existing residential buildings. Considering unit weight of concrete as 25Kn/m3 and weight of floor finishes to be 1Kn/m2,the slab dead load comes out to be 4.125kN/m2. Taking the Live Load intensity as 3Kn/m2 for floor slabs and 1.5kN/m2 for roof slabs into account, and the earthquake loads as per IS 1893(part-1); all the thirteen load combinations have been considered for analysis (as in the code IS 1893(part-1). Buildings in zone II are designed considering them as OMRF and detailed according to IS:456, whereas Buildings in zone III,IV and V are designed considering them as SMRF and detailed according to IS:13920. The characteristic strength of concrete and steel are taken as 25MPa and 415MPa respectively

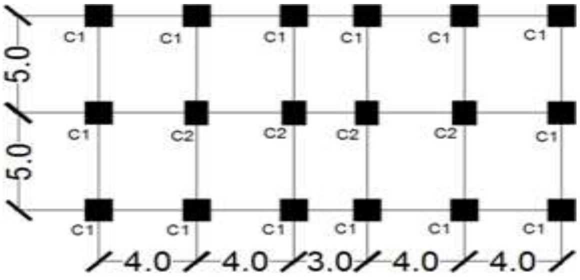
IV. UNITS

Use either SI (MKS) or CGS as primary units. (SI units are strongly encouraged.) English units may be used as secondary units (in parentheses). This applies to papers in data storage. For example, write —15 Gb/cm2 (100 Gb/in2).‖ An exception is when English units are used as identifiers in trade, such as —3½ in disk drive.‖ Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity in an equation.

The SI unit for magnetic field strength H is A/m. However, if you wish to use units of T, either refer to magnetic flux density B or magnetic field strength symbolized as μ0H. Use the center dot to separate compound units, e.g., —A•m2.‖

In order to study the design and detailing of the buildings selected, structural analysis is carried out for vertical and lateral loads. The comparison of design base shear, percentage of longitudinal steel in columns and beams are presented in the following sections. For all the three RC buildings, the following assumptions are made in this work-

- There is a common plan for all the buildings of dimensions 19 m x 10 m located on medium soil.
- The effect of finite size of joint width (e.g., rigid offsets at member ends) is not considered in the analysis.
- The floor diaphragms are assumed to be rigid.
- For analysis and design the Centre-line dimensions are considered.



• Schedule of member sizes:-

Table 3.1 represents the beam and column sizes of the members for all the three buildings as chosen for design and subsequent detailing.B1 and B2 refer to interior and exterior beams, and similarly C1 and C2 refer to interior and exterior columns.

Type of building	B1	B2	C1	C2
G+4	350X300	450X300	400X400	500X400
G+6	400X300	600X300	450X450	600X450
G+8	500X300	600X450	500X500	600X500

3.3 COMPARISON OF DESIGN BASE SHEAR

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. Calculations of base shear depend on:

- Soil condition
- Proximity to sources of seismic activity (such as geological faults)
- probability of significant seismic ground motion
- The level of ductility and over-strength associated with various structural configurations and the total weight of the structure
- The fundamental (natural) period of vibration of the structure.

The design base shear is calculated for all the different cases of varying storey heights and seismic zones as per equivalent static method (IS 1893, 2002) and is shown in table 3.2.From the design base shear results, it can be clearly observed that there is a significant increase in base shear as we move from zone II to zone V, indicating the increase in severity of earthquakes occurring in these regions. Moreover, from the Fig 3.3, it is evident that magnitude of design Base Shear increases with the increase in height of a building.

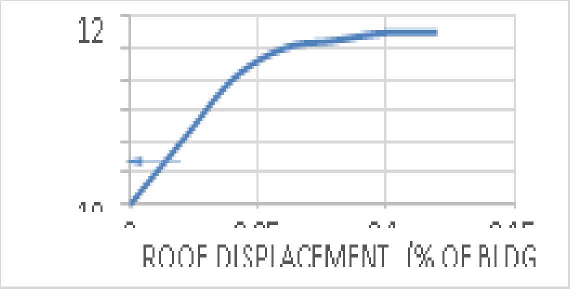
Frame identity	Design Base Shear(kN)
G4ZII	858
G4ZIII	921
G4ZIV	1125
G4ZV	1340
G6ZII	1190
G6ZIII	1272
G6ZIV	1723
G6ZV	2170
G8ZII	1851
G8ZIII	1920
G8ZIV	2362
G8ZV	2814

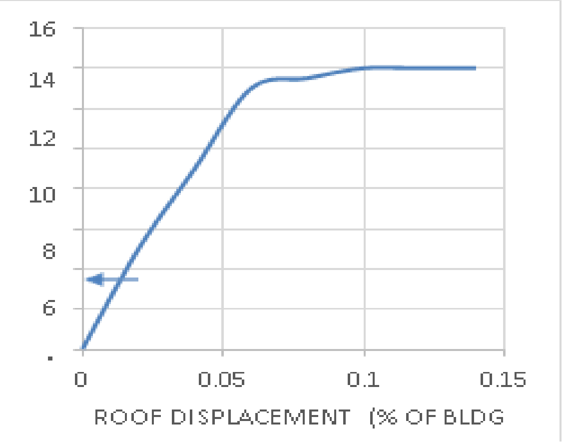
All the aforementioned buildings were designed appropriately as per their respective zones and then detailed accordingly. The results were carefully evaluated. It can be clearly seen that there is significant increase in base shear as we move from zone II to zone V, indicating the increase in severity of earthquakes occurring in these regions. In addition to this, from the base shear variation, it is evident that magnitude of Base Shear increases with the increase in height of a building. It can be concluded that as far as steel requirement in columns is concerned, it almost increased to 43%(for exterior as well as interior columns) on average when we move from zone II to Zone V. The detailings were meticulously drawn so as to give a clear picture of the differences in codal provisions with seismic zones. In the next chapter, pushover analysis of all these buildings has been done to determine their over-strength factors.

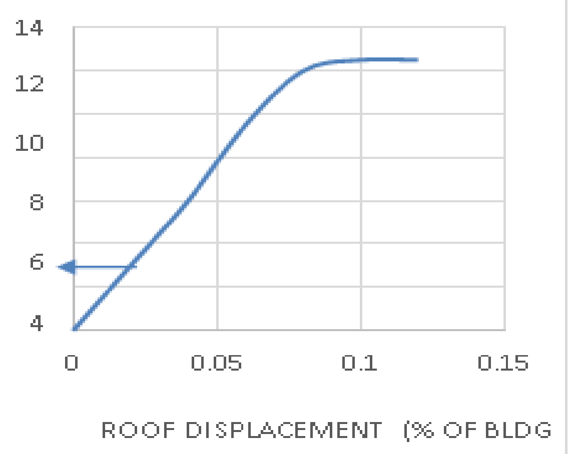
V. PUSHOVER ANALYSIS

Pushover analysis is a non-linear, structural analysis procedure, which is widely used to explain structural behavior due to various types of loads resulting from an earthquake. In this study, over-strength factor obtained from the pushover curve of the buildings was used as the parameter to assess this amount of reserve strength when the buildings have been designed as per the Indian seismic codal provisions.

In order to perform the pushover analysis, the buildings were modelled with all the appropriate previously determined member sizes and reinforcements. Then non-linear hinges were defined with appropriate non-linear properties (force-displacement or moment-rotation diagrams) in a structure model. Thereafter, hinges were assigned to all the beams and columns. This was followed by assigning each floor slab a rigid diaphragm. A set of lateral forces was defined subsequently, and the nature of force was taken to be non-linear and displacement controlled. Finally, all other parameters of the non-linear analysis were defined. After completion of the analysis, the Over-strength factor was determined from the respective Pushover curves. The pushover curves obtained have been made dimension-free by dividing the roof displacement with height of the building (abscissa) and base shear with the building's seismic weight (ordinate).Fig 4.1 depicts the non-dimensional pushover curves obtained for all the three buildings in the various seismic zones (the arrowheads indicate the amount of Base shear for which the building has been designed).Pushover curves have been shown below for the all the RCC framed buildings considered. The first set of curves is for G+4 building, followed by G+6 and G+8 building respectively .It is found that after zone III there is a significant increase in the base shear which can be seen from the pushover curves for zone IV and zone V respectively, indicating the increase in severity of earthquakes occurring in these regions







From the pushover curve obtained for the building, we can see that the building has been designed to resist a base shear of 1125.1 kN, but actually it is capable of taking upto about 3500Kn

Thus, the over-strength factor is equal to Over-strength Factor = 3500/1125.2= 3.21

Thus, the G+4 building when designed according to the Indian Codal provisions for seismic zone IV, has an actual ability to take 3.21 times more force to which it has been designed for.

From the obtained pushover curves, over-strength factors were calculated for the buildings table

4.1. From the analysis of over-strength factor in Fig 4.3 ,we find that it tends to decrease with increase in height of the building. The over-strength factors for all the buildings for the various seismic zones can be listed as follows-

Building	Over-Strength Factor			
	ZONE II	ZONE III	ZONE IV	ZONE V
G+4	2.3	2.73	3.21	3.77
G+6	2.16	2.51	3.1	3.41
G+8	2.03	2.28	2.92	3.23

Over-strength factor obtained from the pushover curve of the buildings was used as the parameter to assess this amount of reserve strength when the buildings have been designed as per the Indian seismic codal provisions. A total of twelve pushover curves were made, four for each building corresponding to the four Indian seismic zones. From the analysis of over-strength factor, we find that it tends to decrease with increase in height of the building. There is significant increase in base shear as we move from zone II to zone V, indicating the increase in severity of earthquakes occurring in these regions. Moreover, from the Base Shear curves, it is evident that magnitude of Base Shear increases with the increase in height of a building

VI. SUMMARY AND CONCLUSIONS

Analysis of several past numerous seismic tremors have demonstrated that building structures have the capacity to manage without any harm the seismic constraints bigger than those they were intended for during design. For the seismic design of structures most codes, indeed, indicate just a solitary configuration tremor which the building and its segments are required to maintain without breakdown. The building is expected to experience some basic and nonstructural damage amid the configuration earthquake. Furthermore, it is expected that the building outlined in this way will consequently meet the objective of no harm in a moderate intensity earthquake. Along these lines, a large number of the seismic design codes have a tendency of downsizing the design forces to record for reserve strength parameter which is crucial and simplifies the analysis as well .Pushover Analysis can help demonstrate how progressive failure in buildings really occurs, and identify the mode of final failure.

In this study, over-strength factor obtained from the pushover curve of the buildings was used as the parameter to assess this amount of reserve strength when the buildings have been designed as per the Indian seismic codal provisions. In addition to it, several other entities such as percentage steel and base shear were also compared to get an idea on the variation of these quantities with varying building heights and seismic zones. The conclusions obtained from the study and the future scopes of this research are quoted in this chapter.

The following are the major conclusions that can be made based on present work carried upon the three RC buildings with different heights designed for earthquake forces in all the seismic zones-

1. There is significant increase in base shear as we move from zone II to zone V, indicating the increase in severity of earthquakes occurring in these regions.
2. Moreover, from the Base Shear curves, it is evident that magnitude of Base Shear increases with the increase in height of a building.
3. As far as steel requirement in columns is concerned, it almost increased to 43%(for exterior as well as interior columns) on average when we move from zone II to Zone V.
4. The variation of percentage of longitudinal steel at support sections in external beams is approximately 0.54% to 1.23% and in internal beams is 0.78% to 1.4%.
5. In the external and internal beams, the percentage of bottom middle reinforcement underwent comparatively lesser increment to about 15-20% for different earthquake zones.
6. There has been a steady rise in overall steel requirements in the building to about 35%,as we move from zone III to zone V.
7. From the analysis of over-strength factor, we find that it tends to decrease with increase in height of the building.

On the basis of the present work done, the scope for future study is identified on the following aspects-

- In the present study, seismic design of buildings is carried out using Equivalent Static analysis.
    - Similar studies may be taken up with other methods such Response-spectrum Analysis, Time- History Analysis.
- In this work, only the Indian Seismic design codes have been taken into account, the work can be further extended by incorporation of British, American and other design codes as well.
- The present study considers only the over-strength factor obtained from the Pushover Analysis output. Several other parameters such as- Capacity spectrum, hinge-backbone results, etc., can also be augmented to it.
- Efforts may be made to take the soil-structure interaction into account as well.

- The present study is carried out on RC buildings. Similar studies may be taken up with Steel structures as well.
- Efforts may be made to study the pushover analysis using different software tools or some other procedures to validate the results.

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