Performance of Building in Different Zones Under SeismicLoading

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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.

Keywords: RC Building, Earthquake Zones, Indian Codal Provision, Pushover Analysis

1. 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 epicenter, 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.

2. Literature review

In order to get a firsthand knowledge of the various seismic design and pushover analysis approaches, various research articles, design codes and relevant books were meticulously studied to understand the effect of seismic parameters on design & detailing of RC buildings. This helped in deciding requisite modeling methods and parameters to be used in seismic analysis and comparisons.

Since a long time, researches are taking place regarding earthquake-resistant design of structures. Past earthquakes have been analysed by many and further research have been carried out to provide technical solutions that will bring down the loss of life and property during an earthquake to a minimum.

Another facet of this study involves performance evaluation of the designed buildings for various seismic zones and detailing provisions using computer based "PUSH-OVER" Analysis. The need of such an exercise has been well illustrated by Ghosh and Munshi (1998) in which it has been stated that the aim of the design codes is cardinally to minimize the life hazards and maintain a reasonable level of continued functionality of the essential components of building, thereby codal design provisions allow some extent of damage such as cracking of concrete and yielding of steel at certain locations at certain predisposed locations. In this work a 12-storey RC has been analysed for inelastic seismic performance under several earthquake ground motions.

The method of pushover analysis proposed by Hasan *et al.* (2002), to use a plasticity-factor to precisely monitor the progressive plastification (stiffness degradation) of frame members under effect of increasing loads. The method has been illustrated by analyzing a three and a nine storey steel moment frame.

An extensive review of previous research papers related to the present work and existing seismic design guidelines was done so that a proper methodology could be planned in order to do the design, comparisons and subsequent pushover analysis of the three buildings with varying storey heights as proposed in this present work.

3. Seismic Design and Comparisons

3.1 Building Geometry and Design Considerations

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.

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.

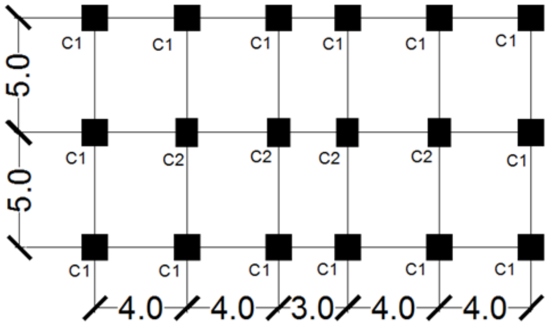

Fig 1: Plan of building.(all dimension in meters)

3.2 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

Table 3.1: member dimensions in "mm"

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 conditions
- 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.

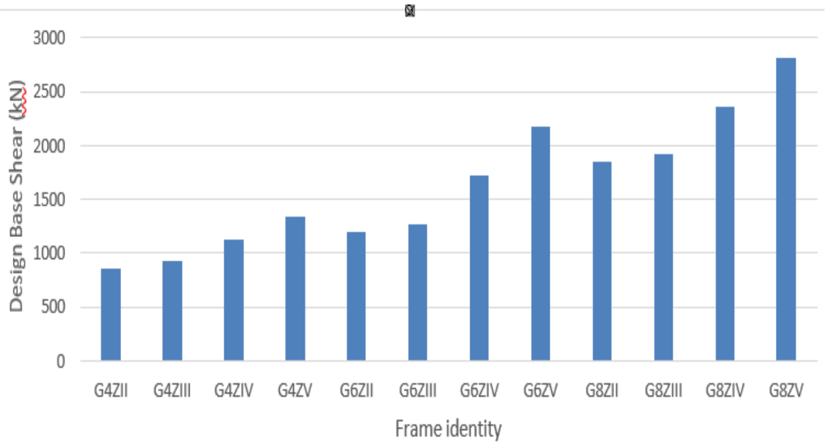

Fig.2 Comparison of Design Base shear values

3.4 COMPARISON OF PERCENTAGE OF LONGITUDINAL STEEL IN COLUMNS

Frame identity	percentage of longitudinal steel in columns	
	Exterior columns	Interior columns
G4ZII	.91	1.2
G4ZIII	1.3	1.8
G4ZIV	1.9	2.3
G4ZV	2.4	3.0
G6ZII	.97	1.32
G6ZIII	1.57	1.91
G6ZIV	2.1	2.5
G6ZV	2.7	3.1
G8ZII	1.13	1.39
G8ZIII	1.51	1.97
G8ZIV	2.2	2.6
G8ZV	2.7	2.89

Table 2- Comparison of percentage of longitudinal steel in columns

3.5 Detailing of selected beam and column for G+4 building

For the building in zone II, IS 456 has been used to make detailing, while for zone V,IS 13920 has been utilised for the detailing purposes. From the design results, the following detailing sketches have been drawn. The principal objectives of the ductile design of reinforced concrete members are to ensure both strength and ductility for the designed structures or members.

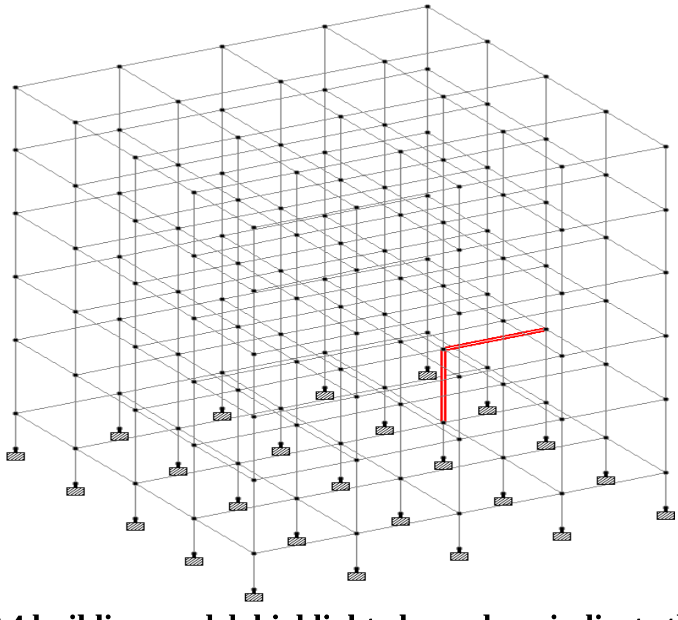

Fig 3: 3-d view of the G+4 building model, highlighted members indicate the ones which have been considered for detailing

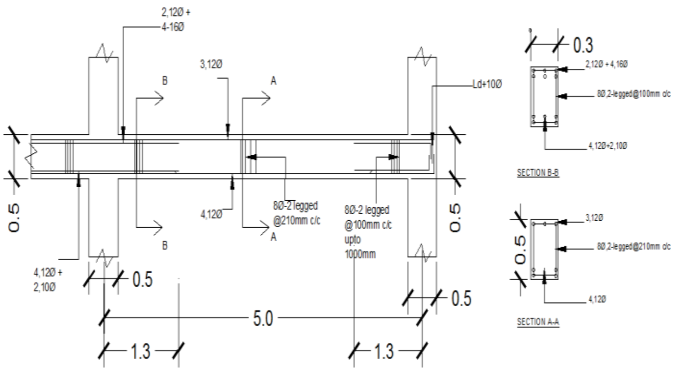

Fig 4- reinforcement detailing for an interior beam of G4ZV

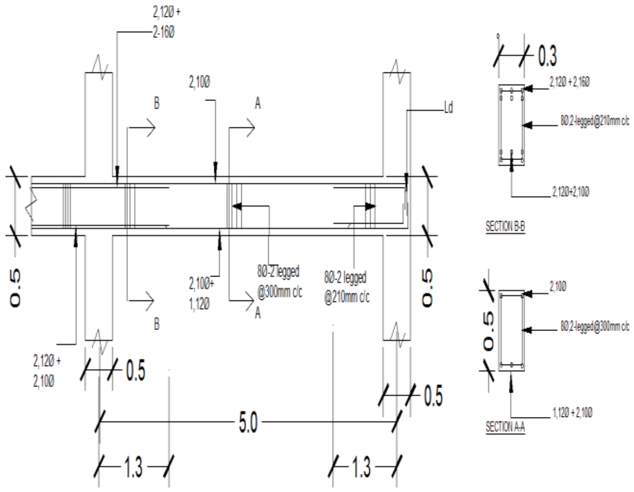

Fig 5- reinforcement detailing for an interior beam of G4ZII

4. 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.

4.1 MODELLING FOR PUSHOVER ANALYSIS

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

4.2 PUSHOVER CURVES FOR ALL THE DESIGNED BUILDINGS

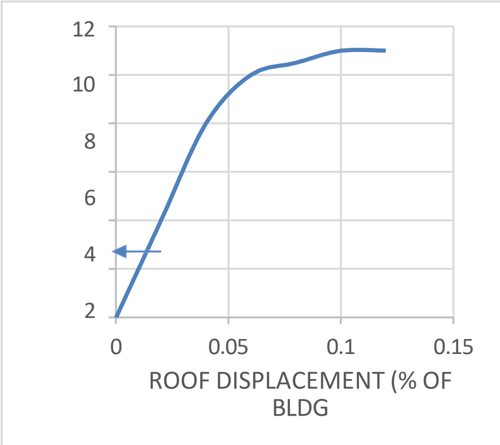

Fig.6- Pushover curve for G4ZII

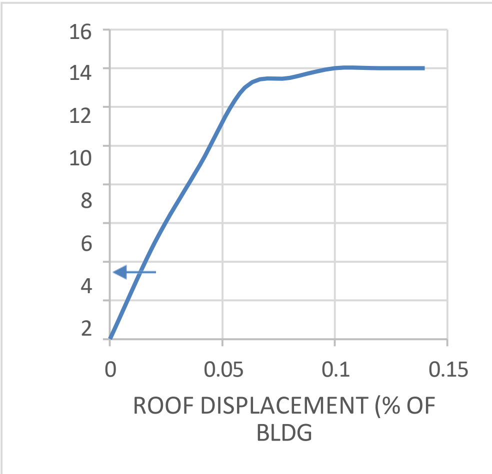

Fig.7- Pushover curve for G4ZIII

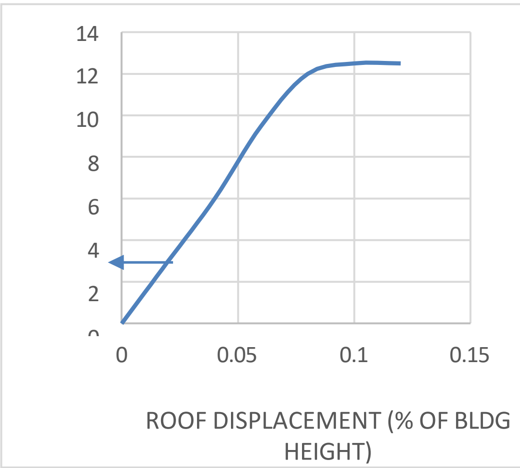

Fig.6 pushover performance curve

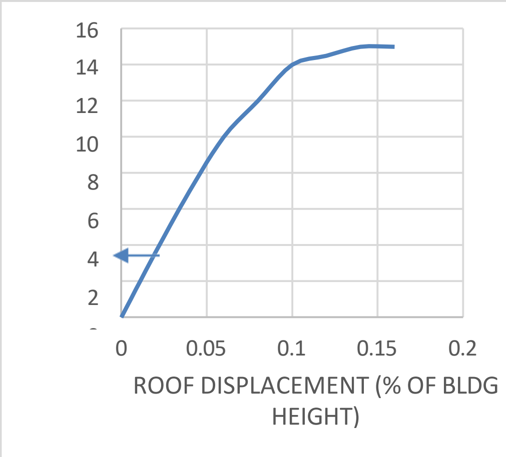

Fig.7- Pushover curve for G6ZII

4.3 Over-Strength evaluation of Frame G4ZIV

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.

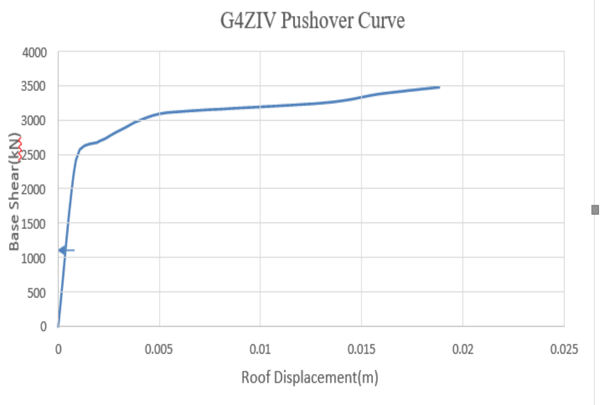

Fig.9-: Pushover curve for G+4 Building in Zone-iv

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.

4.4 COMPARISON OF OVER-STRENGTH FACTOR

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

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

5. Conclusion

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.

<u>Future scope</u>

- 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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