SEISMIC RESPONSE OF BUILDINGS WITH RE - ENTRANT CORNERS IN DIFFERENT SEISMIC ZONES

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Abstract

Buildings with re - entrant corner are commonly encountered when there is a scope for maximum utilization of the minimum available space. Also, these buildings respond differently when located in various seismic zones. One of the major problems associated with re - entrant corner is torsion. It also leads to difference in the stress induced in different wings of the building leading to stress concentration at the re - entrant corner. This study focuses on the response of the building with a re - entrant corner located in various seismic zones. The major objective is to study the response of a building in different seismic zones and also, to compare a building containing re - entrant corners with a building of regular plan configuration by performing linear dynamic analysis. A regular residential building with re - entrant corners and with a rectangular plan configuration has been chosen. While modeling, the plan area of both the models has been made approximately equal in order to facilitate comparison. The design spectrum being applied to the building models has been studied in order to understand the seismic demand in different seismic zones. The results obtained are compared for different seismic zones in terms of storey drift, joint displacement, and storey displacement. Along with this, the force to which the column located near a re - entrant corner is subjected is studied. When the re - entrant building was compared with regular building, it was observed that the former undergoes larger storey displacement and drift than the latter. Buildings with re - entrant corner are more vulnerable to seismic damages and are susceptible to earthquake corresponding to time periods of lower order; hence, the building plan must be of regular configuration in order to possess significant seismic resistance.

Keywords: *re - entrant corner, response spectrum analysis (RSA), storey drifts, joint displacement.*

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1. INTRODUCTION

Vulnerability atlas of India [8] states that, there are about 11 million seismically vulnerable houses in zone V and 50 million in zone IV. Overall, 80 million building units are vulnerable. Any building unit becomes seismically vulnerable when there is an irregularity in terms of plan, elevation or along the height of the building. Any irregularity will cause an abrupt change in strength or stiffness of the structure. This paper focuses on re - entrant corners, which is one among the plan irregularities or horizontal irregularities in a building. The main aim is to understand the seismic behavior of re - entrant corners by studying their response in terms of storey drift, maximum storey displacement and joint displacement.

Indian code for seismic resistant design of buildings, IS 1893 (PART 1) [3] classifies the whole of India into four seismic zones. The considered building models have been studied for all the seismic zones. There are two major problems associated with re - entrant corners. One is torsion and another is that they tend to produce differential motion between different wings of the building leading to local stress concentration at the re - entrant corner. Re - entrant corner arises in case of plans in H, I, T, L, C, U shapes.

However in the present study a practical example has been considered and analyzed dynamically for all the seismic zones. The severity of the seismic damages in re - entrant corners depends on characteristics of ground motion, seismic weight of the building, structural systems typology, length of the wings and their aspect ratio, height of the wings and their height to depth ratio. Also, buildings having projection less than 15% of its plan dimension in that direction is safe [3]. Whereas 15 to 20% is considered deficient and greater than 20% is treated as highly deficient.

There are many evidences from the past earthquakes illustrating the fact that re – entrant corners cause huge damages to the building. Hence, this study is to create awareness about seismic vulnerability of buildings and necessity for engineered buildings.

2. METHOD OF ANALYSIS

As per IS 1893 (PART 1): 2002, clause 7.8.1(b) response spectrum method shall be performed for irregular buildings of height greater than 12m in zones IV & V (zone factor, Z = 0.24 & Z = 0.36 respectively) and those greater than 40m in zones II & III (Z = 0.10 & Z = 0.16 respectively). Code design practices have been traditionally based on the force based design concept, in which individual components of the structure are designed for strength on the basis of internal forces computation from elastic analysis. Further, the seismic analysis of structures carried out based on the peak values of ground acceleration is not sufficient to understand the seismic behavior. Moreover, the response of the structure depends on the frequency content and dynamic properties of ground motion. Buildings having plan asymmetry must be analyzed dynamically.

In linear dynamic analysis i.e., response spectrum analysis (RSA), maximum response of the building is estimated directly from elastic design spectrum which indicates the design earthquake for the site and considering the performance criteria for building. In RSA, lateral forces are based on properties of natural vibration modes of the building which are determined by the distribution of mass and stiffness over the height. Square root of sum of squares (SRSS) method has been adopted for modal combination as well as directional combination. The response acceleration values depend on percentage of damping and time period.

3. STRUCTURAL MODELING AND ANALYSIS

Two building models with ground and four upper stories were considered. One building model with a re - entrant corner (Fig. 1) and another of regular plan configuration (Fig. 2). The plan area of both the building models has been made approximately equal so that the floor loads acting on the models is same facilitating the comparison as shown in Fig.3 and Fig. 4.

3.1 Details of Modeling:

Plan area of reentrant building	210m^2
Plan area of regular building	216m^2
Number of stories	5
Floor to floor height	3m
Beam sizes	250 x 400mm, 200 x 350mm & 300 x 450mm
Column sizes	300 x 450mm & 300 x 600mm
Slab thickness	150mm
Shear wall	200mm
Dead load	self weight of the slab + floor finish (inclusive of ceiling finish) = 3.75kN/m^2 + 1.3 kN/m^2 = 5.05 kN/m^2
Live load	3kN/m^2
Live load after applying reduction factor	3 X 0.25 = 0.75 kN/m^2
Roof live load	2kN/m^2
Seismic zones	II, III, IV, V
Zone factor	0.10, 0.16, 0.24, 0.36
Importance factor	1
Soil type	Medium (II)
Response reduction factor	5
Material used	M20 and Fe 500

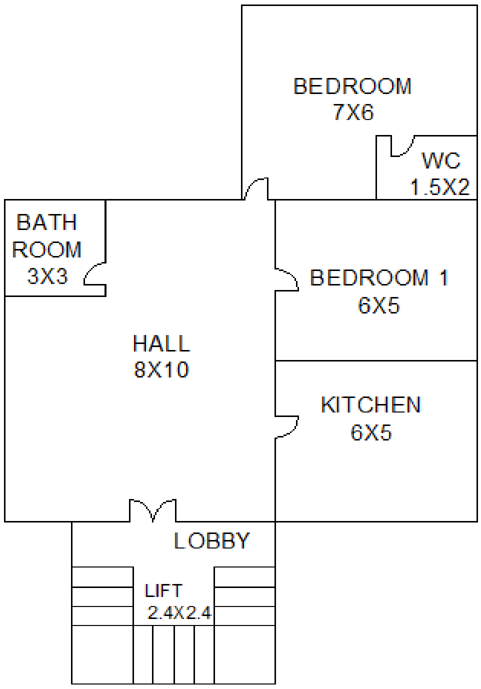

Fig 1: plan of re - entrant building

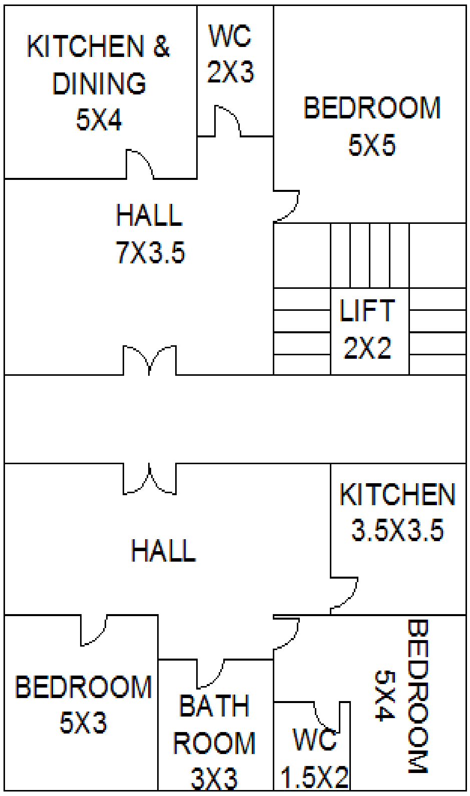

Fig 2: plan of regular building

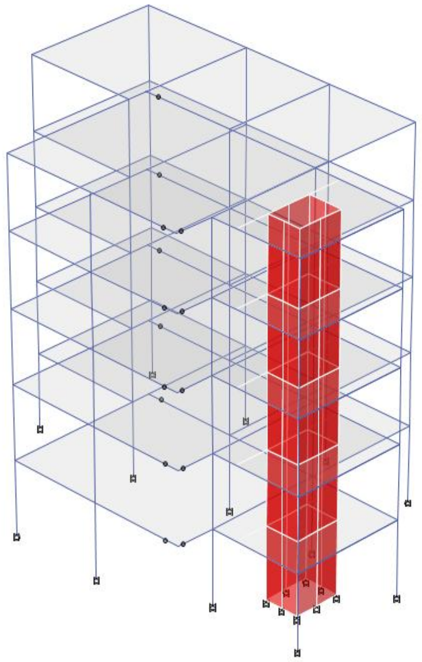

Fig 3: re - entrant building model

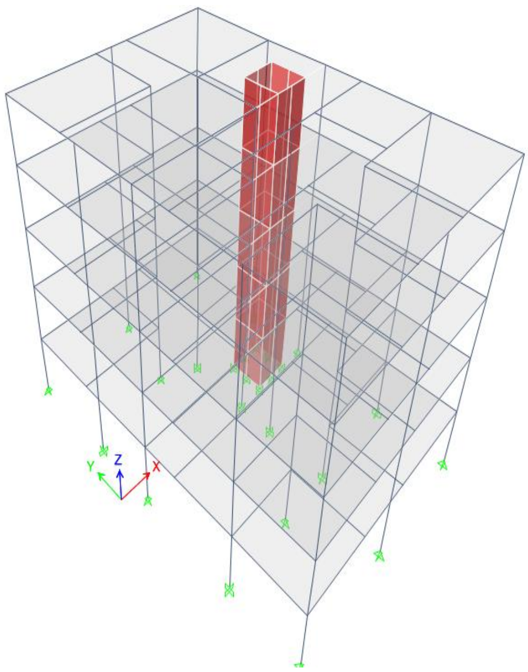

Fig 4: regular building model

4. RESULTS AND DISCUSSION

The response spectrum analysis was carried out for all the four seismic zones and their respective design spectrum showing spectral acceleration co efficient varying with period is shown in figure 5. The acceleration experienced by the buildings is least in seismic zone II and highest in zone V as evident from the graph below. The peak acceleration co efficient for zone II, III, IV & V is 0.10, 0.16, 0.24, and 0.36 respectively.

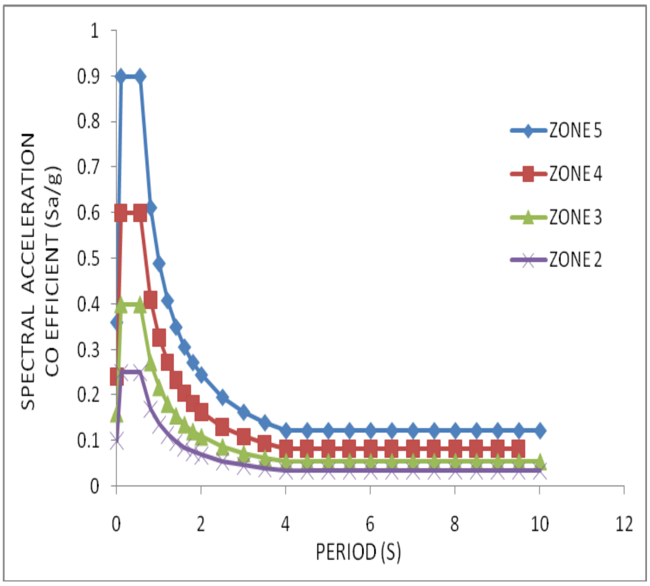

Fig 5: design spectrum

The displacement undergone by joints located near re - entrant corner is an important case of study in understanding the behavior of re - entrant corners. There are three such joints with a re - entrant percentage of 42.85%, 23.2% and 50%. Figures 6, 7 and 8 shows the displacement of these joints respectively. Joints undergo maximum displacement incase of zone V when compared with other seismic zones. Also, the displacement increases with increase in zone factor. Joint with re - entrant of 42.85% re - entrant undergo larger displacement as evident from figure 6.

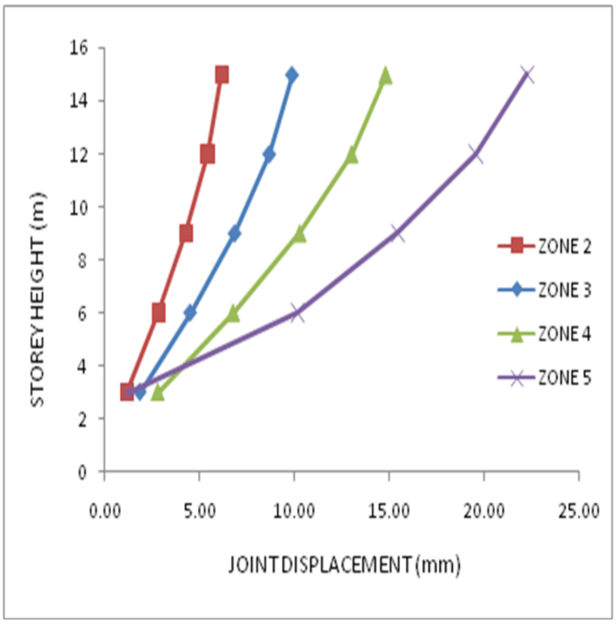

Fig 6: joint displacement with 42.85% re - entrant corner.

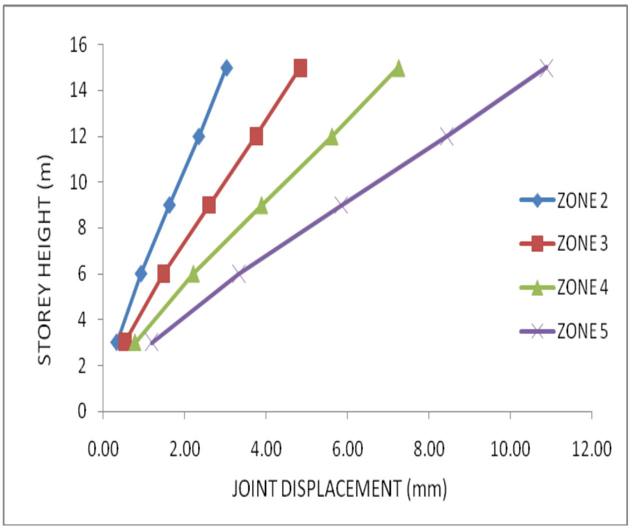

Fig 7: joint displacement with 23.2% re - entrant corner.

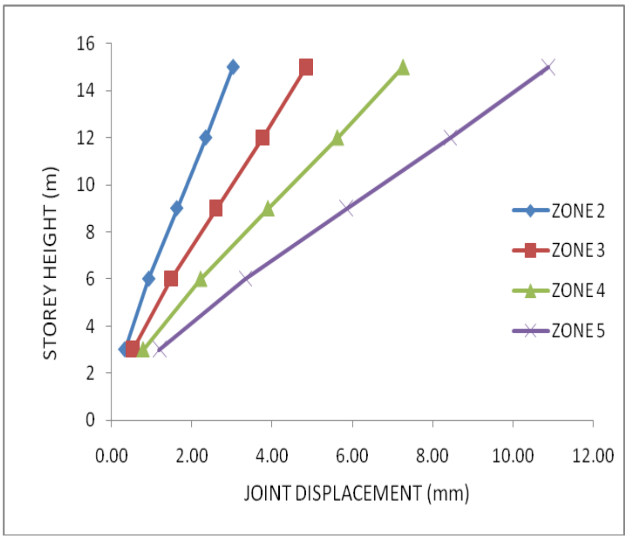

Fig 8: joint displacement with 50% re - entrant corner.

The maximum displacement of each storey is also of major interest in this study. Buildings located in seismic zone V undergo larger displacement while that in zone II undergoes smaller displacement in zone II. Figure 9 shows maximum displacement along the height of the building for different seismic zones.

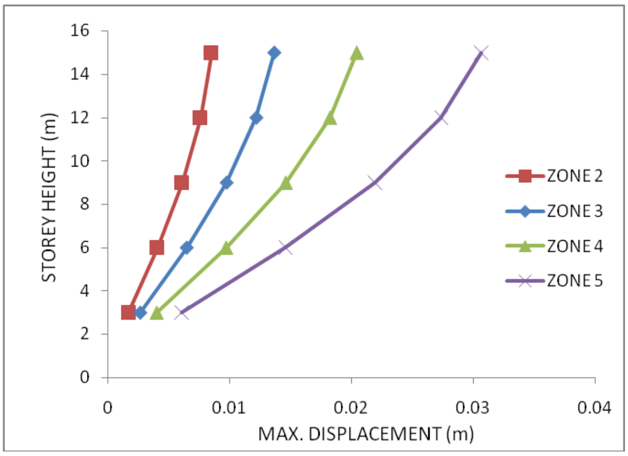

Fig 9: maximum storey displacement.

Displacement is a absolute term whereas drift is a relative term. The displacement undergone by an upper storey with respect to its immediate lower storey is termed as drift. Building undergoes maximum drift near second and third storey as evident from figure 10. Also the drift experienced by the building is highest in zone V. Figure 10 represents the storey drift for re - entrant building along the storey height for various sesimic zones.

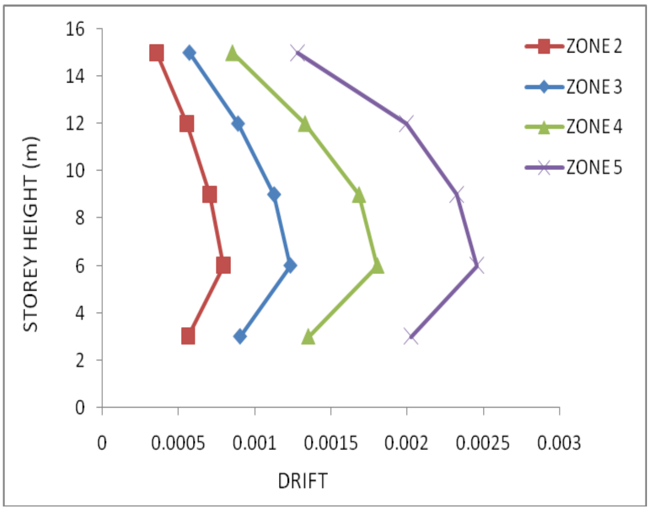

Fig 10: storey drift

The columns loacted near re - entrant corners are subjected to huge forces when compared to other columns as there is local stress concentration near the re - entrant corners. Column located near the corner with 50% re - entrant is subjected to highest force.

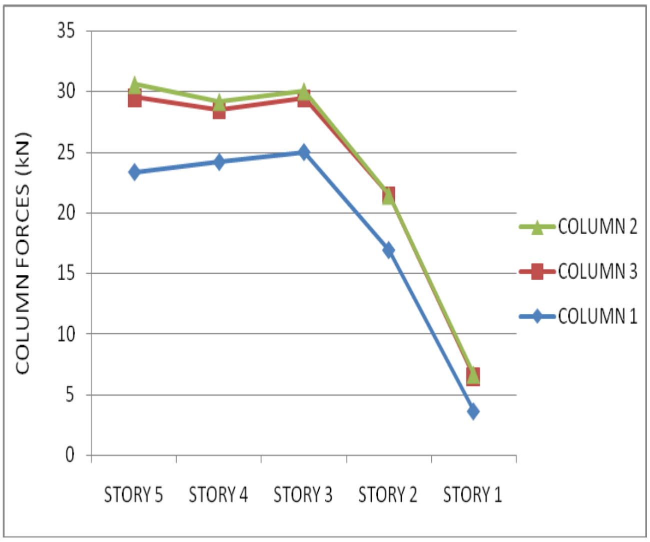

Fig 11: column forces

The comparison of building performance with re - entrant corners for various seismic zones was studied from figure 6 to 11. However, figure 12 gives a comparison between regular and re - entrant building in terms of joint displacement. Joint 4, 7 & 10 has a re - entrant of 42.85%, 23.2% and 50%. Re - entrant building undergoes larger joint displacement when compared to regular building.

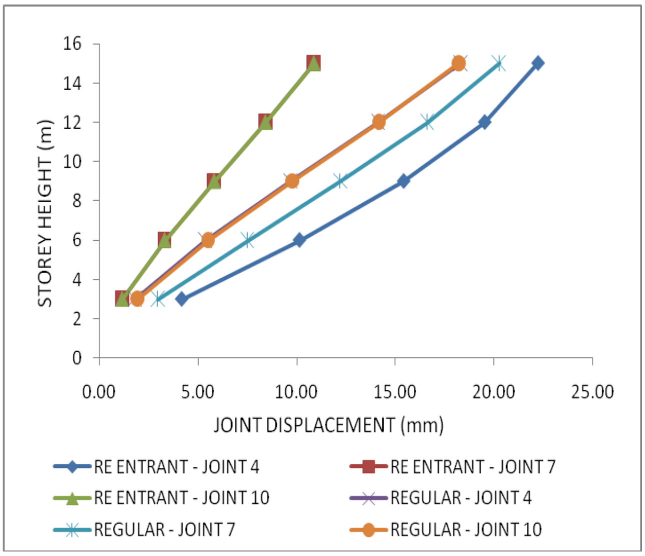

Fig 12: comparison of joint displacement between regular and re - entrant building.

The storey drift undergone by a re - entrant building is more than the regular building as evident from figure 13. However, the drift observed in the top most storey is slightly higher in regular building. Figure 13 represents the storey drift along the height of the building for both re - entrant as well as regular building.

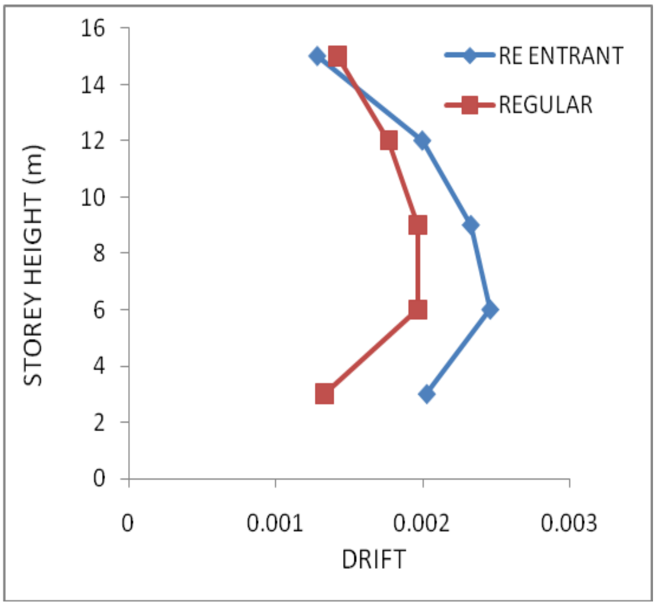

Fig 13: storey drift

The modal periods are characteristic of a building as it depends on the building stiffness and its seismic weight. According to IS1893 (PART 1) : 2002, the number of modes to be used in the analysis should be such that the total sum of modal masses of all modes considered is at least 90% of the seismic mass. Hence, the number of modes considered is 12. The modal period of regular building is higher than that of re - entrant building which makes the re - entrant building more susceptible to earthquakes with period of lower order. Figure 14 shows the modal periods for different modes.

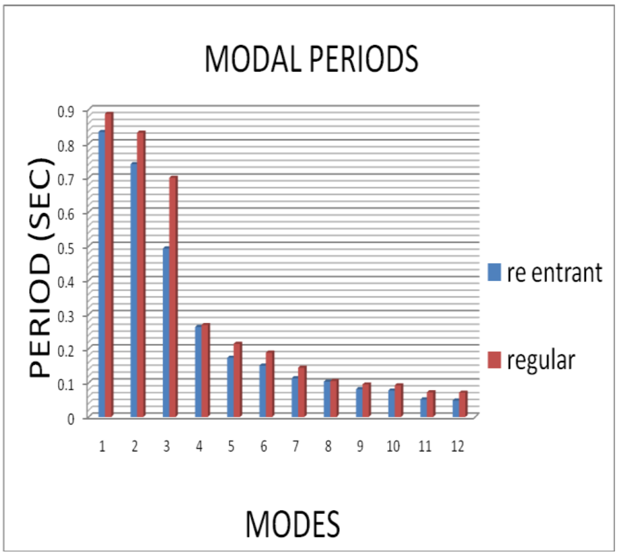

Fig 14: modal period

5. CONCLUSION

In the present study, an attempt has been made to compare an irregular building with respect to plan configuration with a regular building of rectangular configuration. Mainly the difference in their response to ground motion was studied and also the response of the re - entrant building located in different seismic zones was compared and the conclusion about various aspects has been listed below.

1. The ground acceleration to which the structure is subjected to is higher in zone V when compared to zone II. The peak acceleration increases from zone II to zone V.
2. The displacement undergone by the joint with re - entrant of 42.85% is highest when compared to other two joints. Also the joint displacement is highest in zone V.
3. The storey drift experienced by the building is highest in zone V and least in zone III.
4. The displacement undergone by each storey is greater in case of zone V when compared to other seismic zones.
5. The columns located near the re - entrant corners experience more seismic loads as compared to other interior columns. Hence, they require higher ductile detailing when compared to other columns.
6. Also, longer the cantilever projection of the building from the re - entrant corner greater the force experienced by the column located near to it.
7. Building model with higher percentage of re - entrant corner undergo larger joint displacement.
8. Re - entrant buildings undergo larger displacements and drifts when compared with regular buildings.
9. The modal time periods obtained from response spectrum analysis implicates that the regular buildings have longer time periods than re - entrant buildings.
10. As re - entrant buildings have lesser time periods, they are more susceptible to ground motions and the probability of undergoing damage due to high frequency ground motions is high.

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