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# A Case Study on Seismic Response of Buildings with Re Entrant Corners

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***Abstract*— Plan irregular configuration of buildings has been one of the major issues to be addressed, for those located in earthquake prone areas. This paper deals with re-entrant corner irregularity. There have been many researches on buildings with re – entrant corners by considering few standard shapes such as L, H, T shapes and analyzed using linear dynamic analysis. There is a need for extensive study on re-entrant corners using non linear dynamic analysis. The objective of this study is to compare a building containing re-entrant corners with a building of regular plan configuration by performing non linear time history analysis and also to study the behavior of the re-entrant building located in different seismic zones. A regular residential building with re-entrant corners has been chosen. While modeling, the plan area of the re – entrant and the regular building models has been made approximately equal in order to facilitate the comparison. Linear and non linear dynamic analysis has been carried out. The results obtained of both the models have been compared for maximum storey displacement, storey drift, and modal periods. Re-entrant buildings undergo larger displacement when compared with regular buildings. The floor response curves of these structures have been presented to understand the difference in their behavior due to plan irregularity. Also, the performance of the re – entrant building in different seismic zones has been studied. Buildings with re-entrant corner are more vulnerable to seismic damages and are susceptible to earthquakes corresponding to time periods of lower order. Hence, the building plan must be of regular configuration to possess significant seismic resistance.**

***Keywords*— Re-entrant corner; Response spectrum analysis (RSA); Non linear time history analysis; El Centro earthquake; Bhuj earthquake.***

## I. INTRODUCTION

In the present scenario, majority of the buildings have irregular configurations which can be either in plan or elevation or both. Any irregularity will lead to an abrupt change in strength or stiffness of the structure. Past earthquake experiences implicate that, buildings with irregularity are prone to earthquake damages. Therefore, it is essential to study the seismic response of the structure especially the irregular ones even in low seismic zones to reduce the damages in building as in future these buildings have the probability of being subjected to more devastating earthquakes. In such a case, it is necessary to understand the behavior of the structures in order to make it possess sufficient seismic resistance.

The present study makes an attempt to study the effect of re-entrant corners in a building plan on its seismic performance. In order to assess the seismic performance of the considered irregularity, two analytical approaches are performed which includes both linear and nonlinear analysis. Two residential building models are chosen for the analysis. One of the models chosen has re – entrant corners. While the other model has regular plan configuration.

IS 1893 (PART 1): 2002 states that any corner in a plan of a structure is considered as a re – entrant corner, if both the projections of the structure beyond that corner are greater than 15% of its plan dimension in the given direction. Also, buildings having projection less than 15% of its plan dimension in the given direction is safe. Whereas 15 to 20% is considered deficient and greater than 20% is treated as highly deficient.

Re – entrant corners mainly cause two problems, one is torsion and the other is difference in the stress induced in different wings of the building causing stress concentration at the corner. This paper presents an overview of the progress in research regarding seismic response of plan irregular buildings in various seismic zones of India.

Fig. 1 - Damages caused to the roof diaphragm at the re- Entrant Corner of West Anchorage High School, Alaska, during 1964 Earthquake.

## II. METHODS 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 use the concept of force based design, in which individual components of the structure are designed for strength based on the results obtained from elastic analysis. The seismic analysis of structures carried out by considering the peak values of ground acceleration as in case of equivalent static method or linear static method is not sufficient to understand its behavior, as the response of the structure depends on the natural frequency content and dynamic properties of ground motion. Buildings having plan irregularity must be analyzed dynamically.

In linear dynamic analysis i.e., response spectrum analysis (RSA), maximum response of the building is estimated directly from design spectrum which represents the design earthquake considering the site condition and the characteristics of the building. In RSA, seismic forces are based on the natural vibration modes of the building based on the distribution of mass and stiffness over the height of the building. Square root of sum of squares (SRSS) method has been adopted for modal combination as well as directional combination. However, this method ignores behavior of the structure in non linear region. Hence, non linear dynamic analysis (time history analysis) has been employed to completely understand the seismic performance of building.

This analysis is aims at setting up an environment which imitates the real time earthquake ground motions and gives a more realistic picture of the possible deformation and collapse mechanism formed in a structure. Time history method of analysis makes use of ground motion data of previously occured earthquakes to assess the structural behavior. In this method, the structure will be assigned with plastic hinges to study the structural behavior in the non linear region or in other words material non linearity is considered. In this study, the ground motions of El Centro (1940) and Bhuj (2001) has been considered.

The whole of dynamic analysis has been carried out using FE software.

## III. STRUCTURAL MODELLING DETAILS:

Two building models with ground and four upper stories were considered. One building model with a re-entrant corner (Fig. 2) and another of regular plan configuration (Fig. 3). 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.4 and Fig. 5.

TABLE I: STRUCTURAL DETAILS

| | |
|---|---|
| Plan area of re-entrant 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 (special moment resisting frame, SMRF) |
| Material used | M20 and Fe 415 |
| Damping | 5% |

TABLE II: DETAILS OF TIME HISTORY DATA

| Earth quake | El Centro | Bhuj |
|---|---|---|
| Date | 18/05/1940 | 26/01/ 2001 |
| Time | 21:35 | 8:46:42 |
| Magnitude | 7.1 | 7.6 |
| Latitude | 32.733 N | 23 02 N |
| Longitude | 115.5 W | 72 38 E |
| Initial Displacement (mm) | 400 | 3.97 |
| Peak acceleration (m/s$^2$) | 3.12 | 1.0382 |

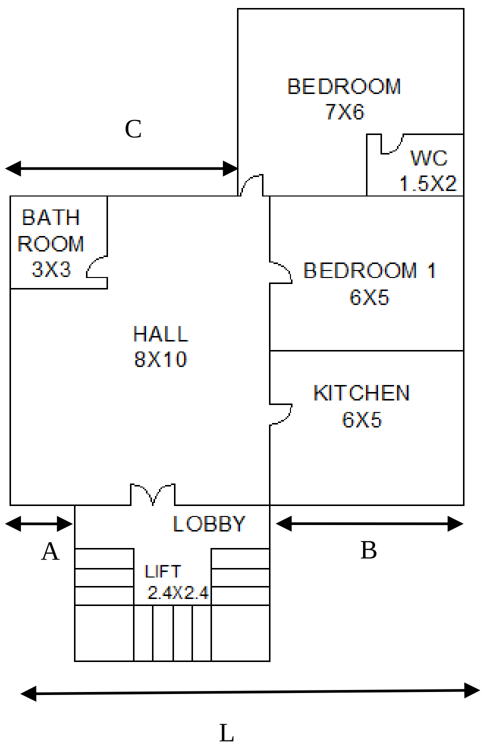



Fig. 2 - Plan of re-entrant building.

The percentage re-entrant is calculated by the ratio A/L for joint 1, B/L for joint 2 and C/L for joint 3[3]. Therefore, the percentage re-entrant for joints 1, 2 & 3 are 23.8%, 42.8% & 50% respectively.

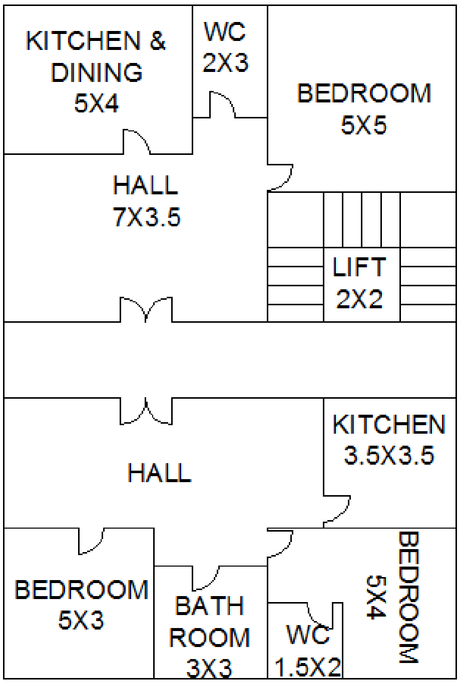



Fig. 3 - plan of regular building

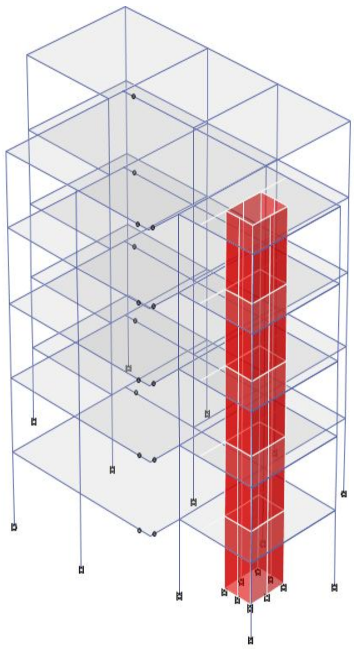


Fig. 4 - re-entrant building model

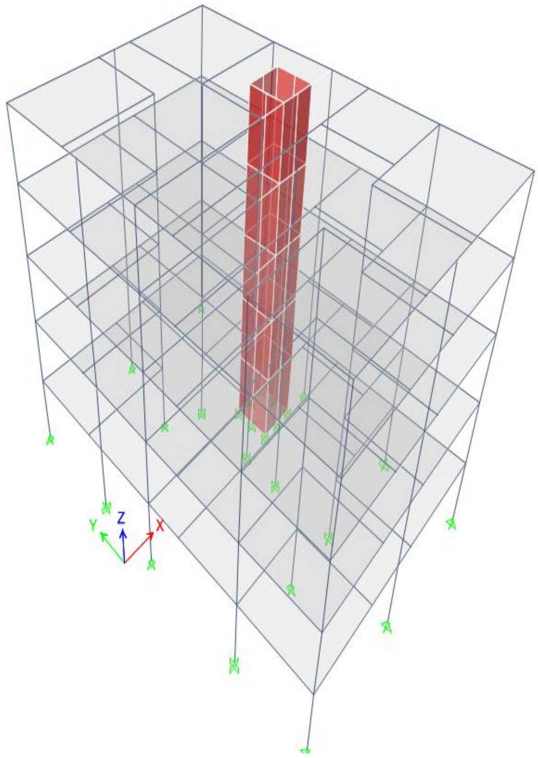



Fig. 5 - regular building model

## IV. 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 fig. 6. 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.

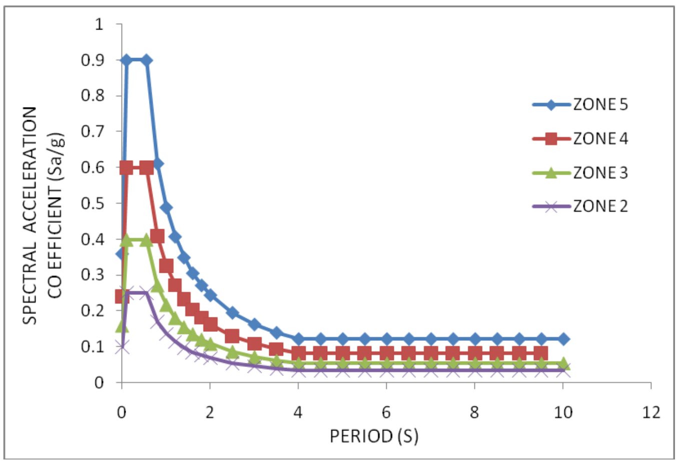



Fig. 6 – design spectrum

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 7, 8 & 9 shows the displacement of these joints respectively. Joints undergo maximum displacement in case 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 fig. 9.

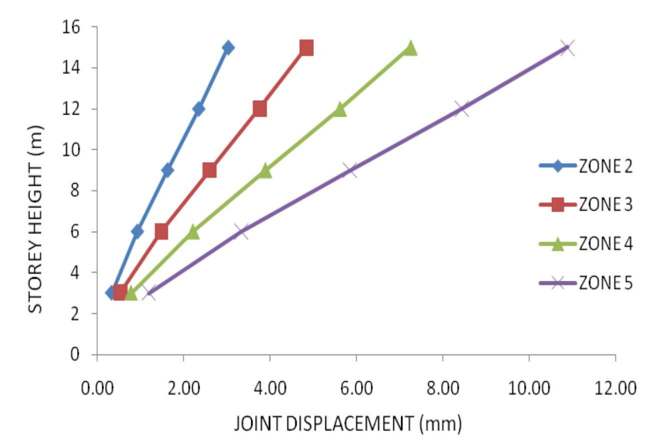



Fig. 7 – displacement of joint 1

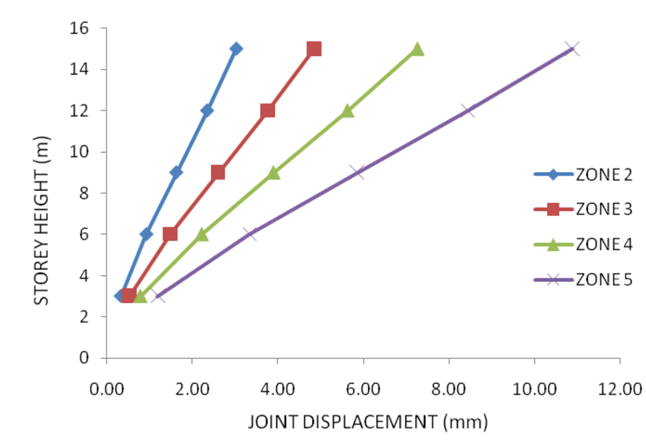



Fig. 8 - displacement of joint 2.

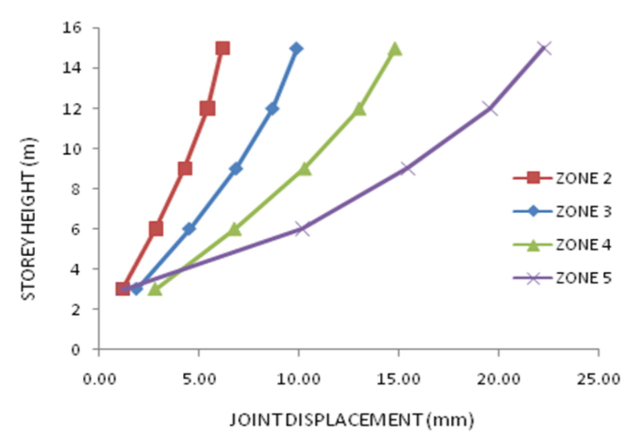



Fig. 9 – displacement of joint 3.

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. Fig. 10 shows maximum displacement along the height of the building for different seismic zones.

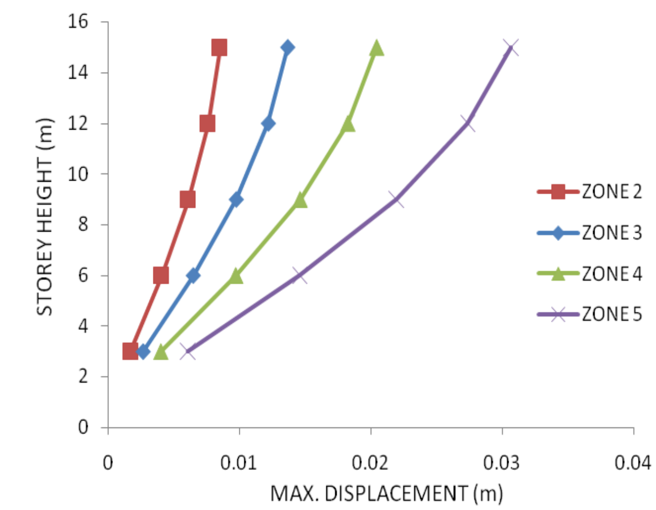



Fig. 10 – maximum storey displacement.

Displacement is an 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 fig. 11. Also the drift experienced by the building is highest in zone V. Fig. 11 represents the storey drift for re-entrant building along the storey height for various seismic zones. The percentage increase in drift from zone 2 to zone 3 is around 60.20%, whereas from zone 3 to zone 4 is about 49.68% and from zone 4 to zone 5 is 50%.

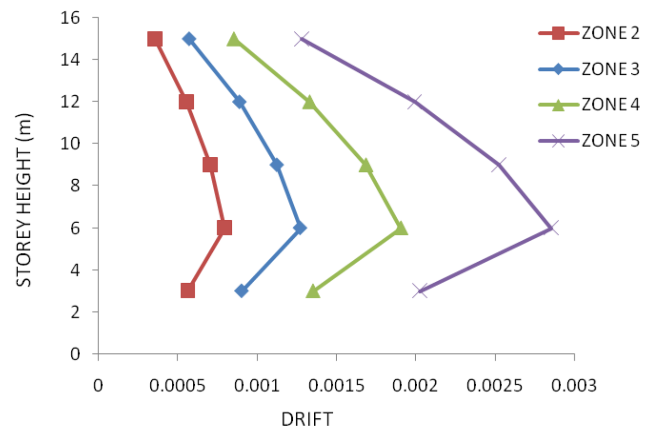



Fig. 11 – storey drift

The columns located 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 as shown in fig. 12.

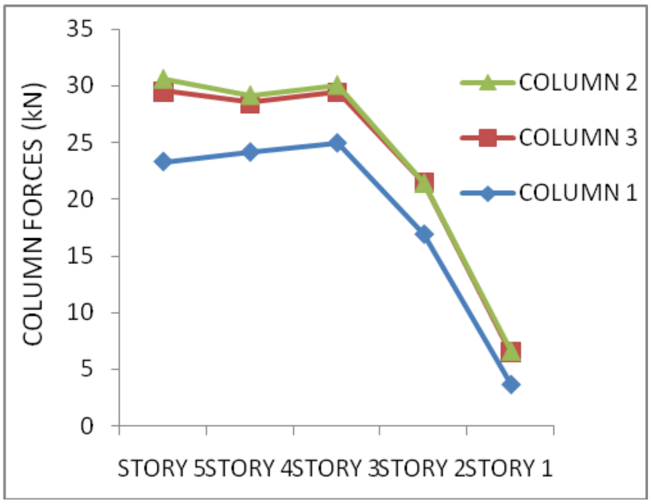



Fig. 12 – column forces at the re- entrant corner.

The comparison of building performance with re-entrant corners for various seismic zones was studied from fig. 6 to 11. However, fig. 13 gives a comparison between regular and re-entrant building in terms of joint displacement. Joint 1, 2 & 3 has a re-entrant of 23.2%, 50% and 42.85%. Re-entrant building undergoes larger joint displacement when compared to regular building.

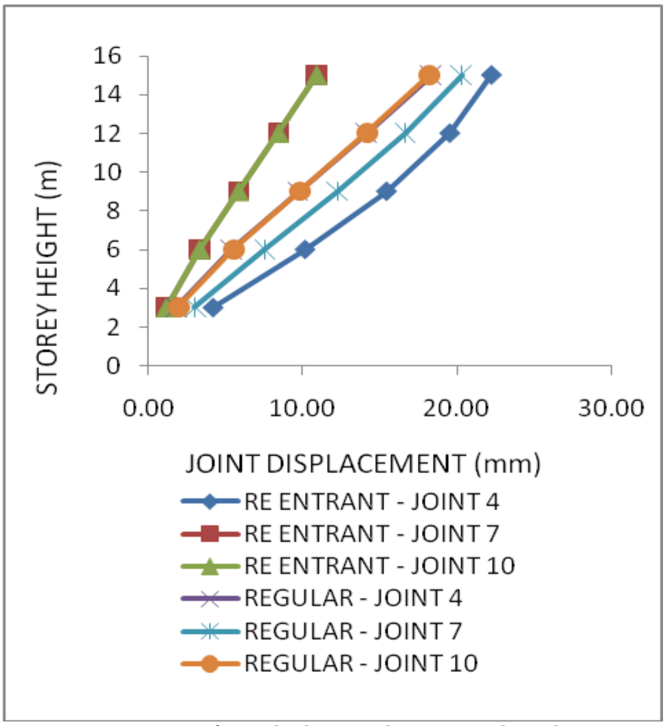



Fig. 13 - comparison of joint displacement between regular and re-entrant building.

The storey drift undergone by a re-entrant building is more than the regular building as evident from fig. 14. However, the drift observed in the top most storey is slightly higher in regular building. Fig. 14 represents the storey drift along the height of the building for both re-entrant as well as regular building.

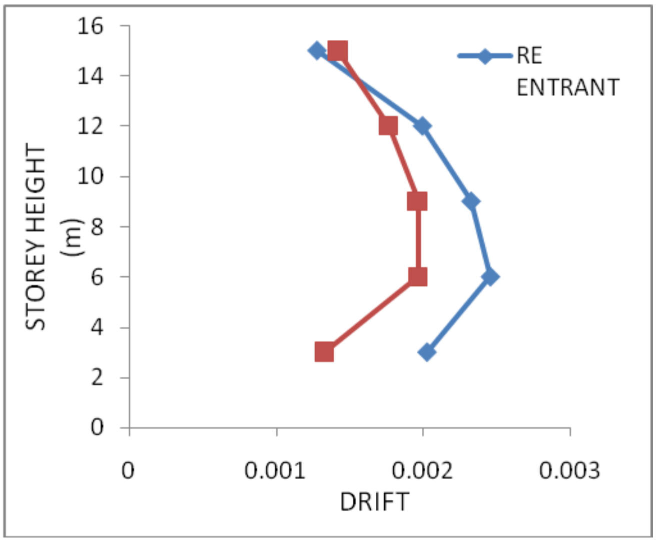



Fig. 14 - storey drift

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. Fig. 15 shows the modal periods for different modes.

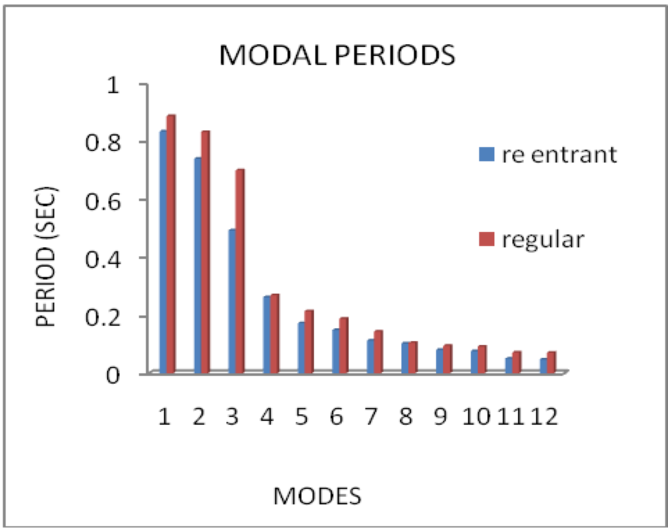



Fig. 15 – modal periods.

The time histories of Bhuj and El Centro were applied to the building models. The accelerogram of these two earthquakes have been shown in fig. 16 & 17. The details of these earthquakes have been shown in table 2. The following graphs (fig. 16 & 17) are a plot of acceleration against time recorded by the accelerogram.

These ground motion data were applied to the building to study the behavior of the building under an actual earthquake.

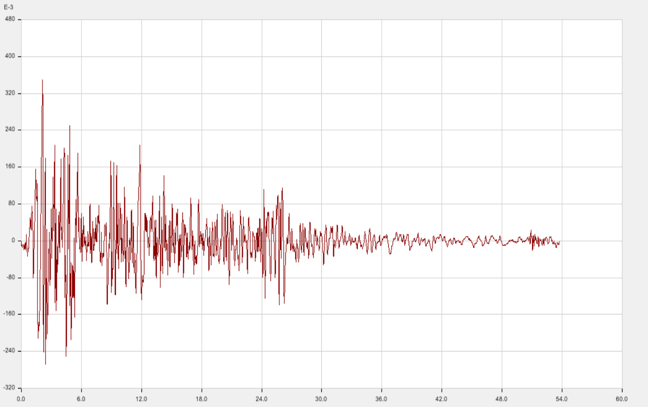


Fig. 16 - accelerogram of El Centro earthquake.

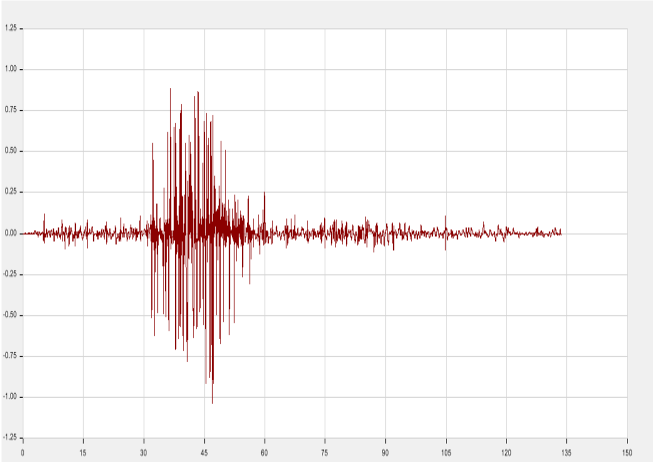


Fig. 17 - accelerogram of Bhuj earthquake.

The floor acceleration response spectra of the models after the application Bhuj and El Centro earthquake time history is shown in fig. 18, 19, 20 &21.

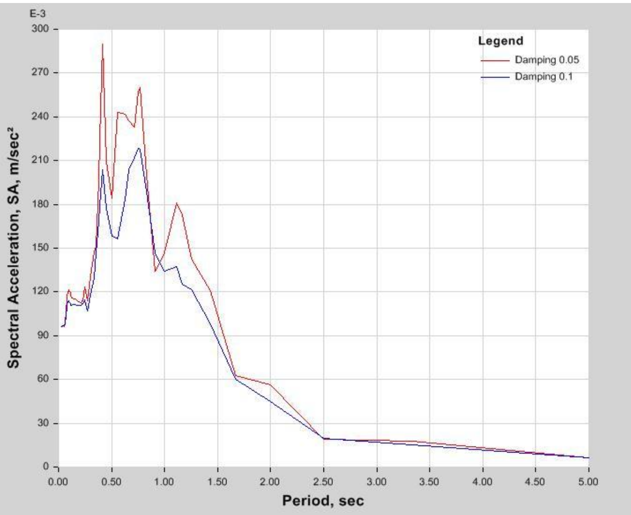



Fig. 18 - floor acceleration response spectrum of re-entrant building to Bhuj earthquake.

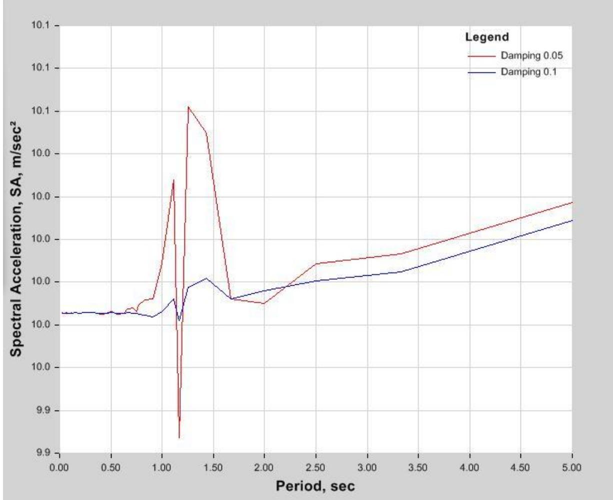



Fig. 19 – floor acceleration response spectrum of re-entrant building to El – Centro earthquake.

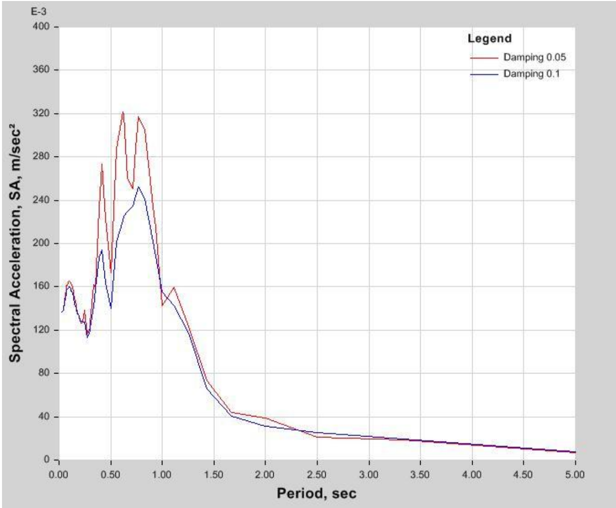



Fig. 20 - floor acceleration response spectrum of regular building to Bhuj earthquake.

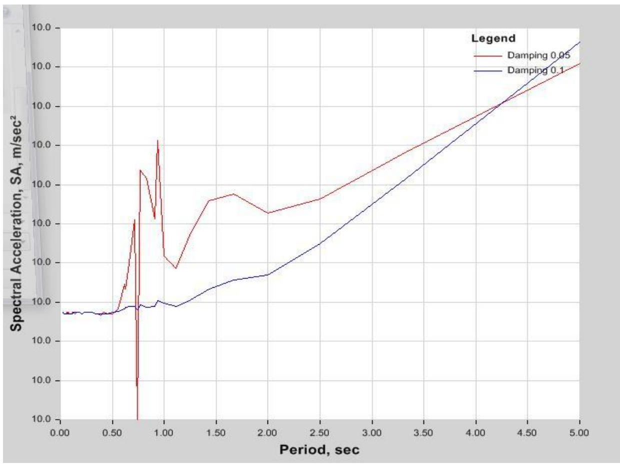



Fig. 21 – floor acceleration response spectrum of regular building to El centro earthquake.

The story displacement of both the building models have been compared for both the ground motions as shown in table 3. The storey displacement of re-entrant buildings is higher than that of the regular building, irrespective of the ground motion.

| TABLE 3: STOREY DISPLACEMENT (mm) | | | | |
|---|---|---|---|---|
| | *re-entrant* | | *regular* | |
| | *Bhuj* | *El Centro* | *Bhuj* | *El Centro* |
| *storey 5* | 25.062 | 788.714 | 5.985 | 328.011 |
| *storey 4* | 22.374 | 690.228 | 5.202 | 258.278 |
| *storey 3* | 17.805 | 558.232 | 4.049 | 184.062 |
| *storey 2* | 11.696 | 387.807 | 2.602 | 109.016 |
| *storey 1* | 4.806 | 181.505 | 1.069 | 41.637 |

Also, the story drift of both the models has been compared in table 4. However, the storey drifts have responded quite differently when compared to displacement. Both the building models subjected to El Centro have shown maximum drift with re-entrant building showing highest response among the two.

| TABLE 4: STOREY DRIFT | | | | |
|---|---|---|---|---|
| | *re-entrant* | | *regular* | |
| | *Bhuj* | *El centro* | *Bhuj* | *El centro* |
| *storey 5* | 0.0009 | 0.0328 | 0.0003 | 0.0233 |
| *storey 4* | 0.0015 | 0.0440 | 0.0004 | 0.0247 |
| *storey 3* | 0.0020 | 0.0568 | 0.0005 | 0.0250 |
| *storey 2* | 0.0023 | 0.0688 | 0.0005 | 0.0225 |
| *storey 1* | 0.0016 | 0.0605 | 0.0004 | 0.0139 |

Joint displacement at the re-entrant corners is as shown in fig. 22. Similar to the drift behaviour, joint displacements are maximum for El centro time history.

These joints undergo larger displacement when subjected to El Centro ground motion.

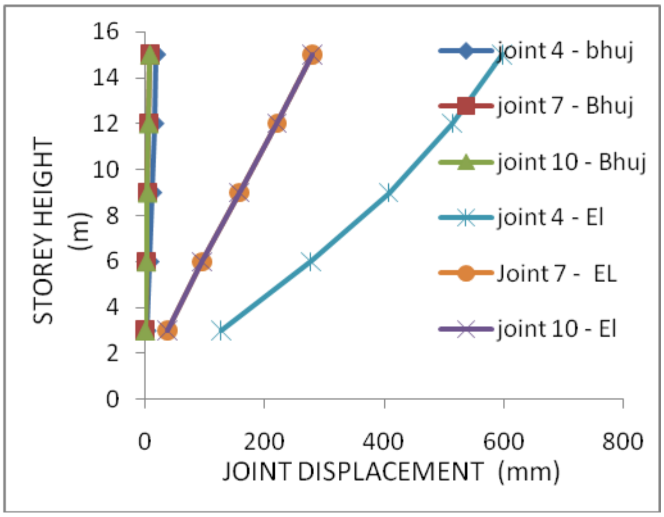
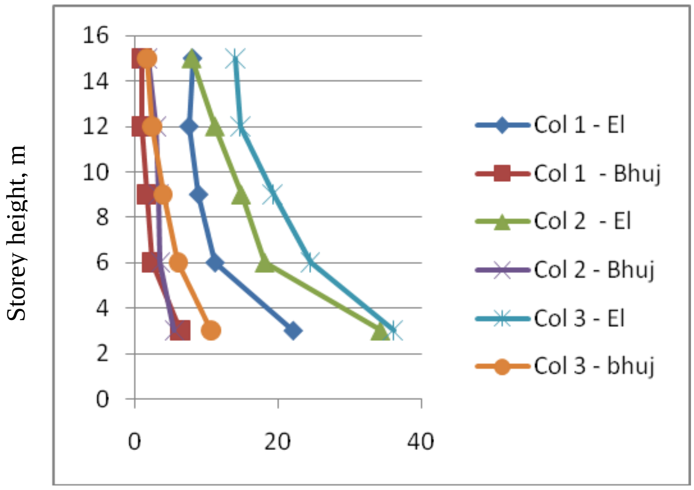



Fig. 22 - joint displacement at the re-entrant corner

The moment distribution in various columns located near re-entrant corners varying over the height of the building is shown in fig. 23. It is evident from this graph that the columns possess considerably higher moments when subjected to El – Centro than Bhuj. Also the moment is maximum at the base and decreases as the height increases, which is in agreement with the conceptual understanding of the moment developed in columns over the height of the building.




Moment (kN – m)

Fig. 23 - moment envelope along the height of the building.

## V. CONCLUSION

In the present study, an attempt has been made to compare an irregular building consisting of re-entrant corner 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 drifts and maximum storey displacement undergone by a re – entrant building is highest when located in zone V and least in zone II.
4. 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.
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. As observed from table 3 and 4, re-entrant buildings undergo larger displacements and drifts when compared with regular buildings.
8. Maximum drift is observed in case of El Centro earthquake in both the type of building models when compared with Bhuj ground motion.
9. Building model with higher percentage of re-entrant corner undergo larger joint displacements.
10. Moment to which a column is subjected to is greater in case of El Centro earthquake when compared with Bhuj earthquake.

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