Seismic analysis of plan irregular RC building frames

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Abstract. The presence of irregularity in buildings is a matter of concern when it is subjected to devastating earthquakes. A sudden change in vertical or plan configuration in buildings tends to weaken the structure. To prevent failure and minimize the hazard potential of irregular buildings, the responses of such buildings to lateral loads have to be studied in detail. In this paper, the responses of irregular buildings are analyzed using Pushover analysis. 10 re-entrant corner models are analyzed to study their effect as per IS 1893 (Part 1): 2016 codal provisions. The analytical tools used include ETABS v 16.2.0 software and SeismoMatch 2018 software. The parameters considered in this study are storey displacement, stress concentration and performance levels. Strengthening techniques to strengthen vulnerable models are also discussed. The results obtained are compared with that of a regular structure.

Keywords: Re-entrant corner irregularity; Pushover analysis; Strengthening techniques.

1. Introduction
Earthquake is one of the most devastating natural hazards that claim great losses, most important of them being collapse of structures that leads to loss of life and livelihood. During an earthquake, failure of structure starts at points of weakness. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structures having these discontinuities are termed as irregular structures.

Irregular structures contribute a large portion of urban infrastructure. When such structures are in high seismic zones, the analysis and design becomes more complicated. These irregularities may cause interruption of force flow and stress concentrations. Asymmetrical arrangement of mass and stiffness of elements may cause a large torsional force where the centre of mass does not coincide with the centre of rigidity. Height-wise changes in stiffness and mass render the dynamic characteristics of these buildings different from the regular building.

Several attempts were made in the past to study the behavior of irregular buildings during seismic excitation. Rofooei and Mirjalili [1] proposed a simple Dynamic-based Pushover analysis for Plan Asymmetric buildings (DPPA) with the aim of properly considering the effects of torsional behavior as well as the higher modes in the applied lateral load pattern. A new multimode pushover procedure is developed by Manoukas [2] for the approximate estimation of the seismic response of asymmetric in plan buildings under biaxial seismic excitation. Strategies to improve the performance of the vulnerable models were also developed. Kadidla and Yahiaoui [3] found that among the retrofitting techniques available, steel braces can be considered as one of the most efficient solution for seismic performance upgrading of RC frame structures. It is found to enhance the global capacity of the
buildings in terms of strength, deformation and ductility compared to the case with no bracing, and the X and Zipper bracing systems performed better depending on the type and size of the cross section. A displacement-based design procedure is proposed by Mazza [4] for proportioning hysteretic damped braces (HYDBs) in order to attain, for a specific level of seismic intensity, a designated performance level of a reinforced concrete in-elevation irregular framed building which has to be retrofitted.

The present study is regarding the response of plan irregular (re-entrant corner) buildings subjected to various Time History Data. An attempt is made to find out the most vulnerable case of re-entrant corner irregularity. Suitable methods for strengthening existing vulnerable structures are also discussed. 15 storeyed Reinforced Concrete building frames without plinth beam, basement and shear walls are considered for analysis. Column ends are assumed to be fixed at the foundation. The contribution of infill wall to the stiffness is not considered. The effect of soil structure interaction is ignored.

2. Structural modelling
According to IS 1893:2016, a building is said to have re-entrant corner in any plan direction, when its structural configuration in plan has a projection of size greater than 15% of its overall plan dimension in that direction.

2.1. Description of the problem
Several buildings in the present scenario have irregular configurations both in plan and elevation. These buildings in future may be subjected to devastating earthquakes. So it is essential to identify the performance of the structures to withstand against disaster. Re-entrant corner irregularities are introduced on the buildings as per IS 1893:2016. In the present study ten 15-storeyed buildings with re-entrant corner irregularity (T-shape, L-shape and + shape) are analyzed using Pushover method of analysis. Stress concentration, Performance levels and Hinge formation for all structures are obtained.

2.2. Model description
The structural details of regular building model are given in Table 1. The loading and earthquake details are given in Table 2.

| Terms                        | Data     |
|------------------------------|----------|
| No. of Stories               | 15       |
| No. of Bays in X direction   | 5        |
| No. of Bays in Y direction   | 4        |
| Spacing of frame in X direction (m) | 4   |
| Spacing of frame in Y direction (m) | 4   |
| Dimensions of Beam (mm)      | 400 * 500 |
| Dimensions of Column (mm)    | 500 * 500 |
| Thickness of Slab (mm)       | 150      |
| Thickness of Outer Wall (mm) | 230      |
| Thickness of Inner Wall (mm) | 150      |
| Density of Infill (kN/m^2)   | 20       |
| Height of each floor (m)     | 4        |
Table 2. Loading and Earthquake Details

| Description                        | Value |
|------------------------------------|-------|
| Dead Load (kN/m$^2$)               | 3     |
| Live Load (kN/m$^2$)               | 4     |
| Earthquake Zone                    | V     |
| Importance Factor                  | 1.5   |
| Type of Soil                       | Medium|
| Response Reduction Factor          | 5     |

The plan configuration consists of

MODEL R – Building without irregularity.

MODEL L1 – Re-entrant corner L shape in which Projections provided are 20% in X direction and 50% in Y direction.

MODEL L2 – Re-entrant corner L shape in which Projections provided are 40% in X direction and 50% in Y direction.

MODEL L3 – Re-entrant corner L shape in which Projections provided are 60% in X direction and 50% in Y direction.

MODEL L4 – Re-entrant corner L shape in which Projections provided are 80% in X direction and 50% in Y direction.

MODEL P1 – Re-entrant corner + shape in which Projections provided are 20% in X direction and 25% in Y direction.

MODEL P2 – Re-entrant corner + shape in which Projections provided are 40% in X direction and 25% in Y direction.

MODEL T1 – Re-entrant corner T shape in which Projections provided are 20% in X direction and 25% in Y direction.

MODEL T2 – Re-entrant corner T shape in which Projections provided are 40% in X direction and 25% in Y direction.

MODEL T3 – Re-entrant corner T shape in which Projections provided are 60% in X direction and 25% in Y direction.

MODEL T4 – Re-entrant corner T shape in which Projections provided are 80% in X direction and 25% in Y direction.

Figure 2. Model L1: Projections provided is 20% in X-direction and 50% in Y-direction

Figure 3. Model L2: Projections provided is 40% in X-direction and 50% in Y-direction
Figure 4. Model L3: Projections provided is 60% in X-direction and 50% in Y-direction

Figure 5. Model L4: Projections provided is 80% in X-direction and 50% in Y-direction

Figure 6. Model T1: Projections provided is 20% in X-direction and 25% in Y-direction

Figure 7. Model T2: Projections provided is 40% in X-direction and 25% in Y-direction

Figure 8. Model T3: Projections provided is 60% in X-direction and 25% in Y-direction

Figure 9. Model T4: Projections provided is 80% in X-direction and 25% in Y-direction

Figure 10. Model P1: Projections provided is 20% in X-direction and 25% in Y-direction

Figure 11. Model P2: Projections provided is 40% in X-direction and 25% in Y-direction
2.3. Strengthening techniques
Steel bracings are used for strengthening of vulnerable models. The different types used include V-shaped bracings, inverted V-shaped bracings, X-shaped bracings and ZX-shaped bracings.

![Figure 12. Different Types of Steel Bracings](image)

3. Results and discussions
3.1. Displacement comparison
At lower storeys, no significant variation in displacement is observed. At higher storeys, significant change in displacement is observed. The displacement is observed to increase with increase in amount of projections for L and + type re-entrant corner models. No variation in displacement was observed with increase in amount of projections for T type re-entrant corner models. L4 model has the maximum top storey displacement.

![Figure 13. Displacement comparison of various re-entrant models](image)
3.2. Stress concentration
High stress concentration is observed at all the re-entrant corners as indicated by the following figures.

![Figure 14. Stress Concentration in L-Shaped Models](image)

![Figure 15. Stress Concentration in T-Shaped Models](image)

![Figure 16. Stress Concentration in P-Shaped Models](image)

3.3. Performance levels
The performance levels of re-entrant corner models are compared with that of regular model. The performance level of regular building is Immediate Occupancy. The corner columns are observed to fail. The columns along the central lines are also observed to fail. The comparison is given by the following figures.

![Figure 17. Comparison of Hinge Formation in L Models](image)
3.4. Strengthening techniques

3.4.1. Performance levels. For re-entrant corner models, performance levels are found to be better for models with bracings as compared to models without bracings. The performance points are also shown to be within elastic limits for strengthened models. The following observations are made for re-entrant corner models.

- The columns are observed to fail for models without bracings.
- 1 column failed when V-shaped bracings were used.
- Only green hinges were formed when inverted V-shaped bracings were used.
- Green hinges were formed only on the braces when X-shaped bracings were used.
- No hinges were formed when ZX-shaped bracings were used.

3.4.2. Performance points. For re-entrant models with ZX-shaped bracings, hinges are not formed. This can be due to two reasons:

- The model has failed.
The demand curve meets the capacity curve within the elastic limit. To understand the correct behavior, the performance point has to be obtained. It is observed that for models without braces, the demand curve intersected the capacity curve in the non-linear portion. This shows that the structure behaves poorly during seismic excitations. For models with braces, the demand curve intersected the capacity curve in the linear portion which indicates good resistance to seismic excitations.

**Figure 21.** Performance Point of P2 Model Buildings with Bracings and with ZX Bracings

### 4. Conclusions

In this paper, re-entrant corner irregularity is studied. All frames analyzed are subjected to pushover methods of analysis. The responses of the irregular frames when subjected to lateral loads are studied.

- Storey displacement is observed to increase with increase in the amount of projection provided.
- High stress concentration is observed at the re-entrant corners.
- Percentage variation in top storey displacement and stress concentration of re-entrant corner models from regular model is shown in Table 3.

**Table 3.** Comparison of Results

| Model | Percentage variation in displacement | Percentage variation in shell-stress concentration |
|-------|-------------------------------------|---------------------------------------------------|
| L1    | 12.6                                | 41.4                                               |
| L2    | 15.4                                | 48.5                                               |
| L3    | 20                                  | 52.6                                               |
| L4    | 25.2                                | 43.7                                               |
| T1    | 8.9                                 | 63.3                                               |
| T2    | 11.7                                | 56.8                                               |
| T3    | 12.2                                | 52.7                                               |
| T4    | 12.6                                | 42.3                                               |
| P1    | -4.6                                | 65.2                                               |
| P2    | 6.5                                 | 52.4                                               |

- L-shaped models are observed to have large top storey displacement but less stress concentration.
P-shaped models are observed to have large stress concentration but less top storey displacement.  
L4-model is found to have maximum top storey displacement.  
P1-model showed maximum stress concentration.  
The members at the vicinity of re-entrant corners are observed to fail.  
ZX bracing system is found to be most suitable.  
The performance point of re-entrant corner models with ZX bracing system is 48% less than that without bracings.

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