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Seismic Behavior of RC Buildings with Re-entrant Corners and Strengthening

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ABSTRACT : *The disastrous effects of earthquake on the structures are magnified by the presence of irregularities in the structures. Presence of re-entrant corners in buildings is one of the major deficiencies in buildings causing stress concentration and torsion related problems in the event of an earthquake. The present work focuses on the behavior of buildings with irregularities in the form of re-entrant corners and its strengthening. A four storey L - shaped building is analyzed using response spectrum and pushover analysis methods. Subsequently analysis was also carried out on structures strengthened by the introduction of shear walls and bracings. Results of analysis confirmed the improvement in base shear carrying and roof drifts capacity of the frames by the introduction of retrofitting methodologies.*

Keywords - *Base Shear, Pushover Analysis, Re-entrant corners, Response Spectrum Analysis, Roof Top Displacement.*

1. INTRODUCTION

Building Plans with re-entrant corner forms are a most useful set of building shapes for urban sites, particularly for residential apartments and hotels, which enable large plan areas to be accommodated in relatively compact form, yet still provide a high percentage of perimeter rooms with access to air and light. L and C shaped buildings with re-entrant corners are also common for school buildings to accommodate spaces for play grounds and assembly areas. But these configurations pose a great deficiency in the seismic behavior of the structure.

Most of the building codes recognize re-entrant corners as one of the serious irregularities in buildings and recommends proper evaluation of such structures and incorporation of retrofit strategies [1]. Damages to West Anchorage High School, Alaska, during the 1964 earthquake clearly illustrate the damages to buildings with re-entrant corners (Fig.1). The photo shows damage to the notch of this splayed L-shape building.

Fig 1. Damages Caused to the Roof Diaphragm at the Re-entrant Corner of West Anchorage High School, Alaska, during the 1964 earthquake

The analytical work carried out by Sujay Deshpande and Chandradhara G. P. [2] has illustrated the effect of irregular plan configurations on the seismic behavior of structures from pushover analysis. Naresh Kumar.B.G and Avinash Gornale [3] presented an overview of the seismic performance of torsionally balanced and unbalanced RC framed buildings (also called as symmetric and asymmetric buildings) subjecting them to pushover analysis. However, there is a need to establish specifically the challenges posed by the buildings with re-entrant corners in seismic behavior and evaluate the effectiveness of retrofit strategies. Present works aims at demonstrating the deficiencies of a frame with re-entrant corner and to review the retrofitting strategies analytically.

2. DEFICIENCIES OF FRAMES WITH RE-ENTRANT CORNERS

Basically, any irregularity causes an abrupt change in strength or stiffness of the structure which is not desirable in an earthquake resistant system. Buildings with simple and regular configurations are likely to perform better in the event of an earthquake. Presence of re-entrant corners are one the serious plan irregulars that results in poor seismic performance of buildings. Fig. 2 shows some of the configurations that results in the formation of re-entrant corners.

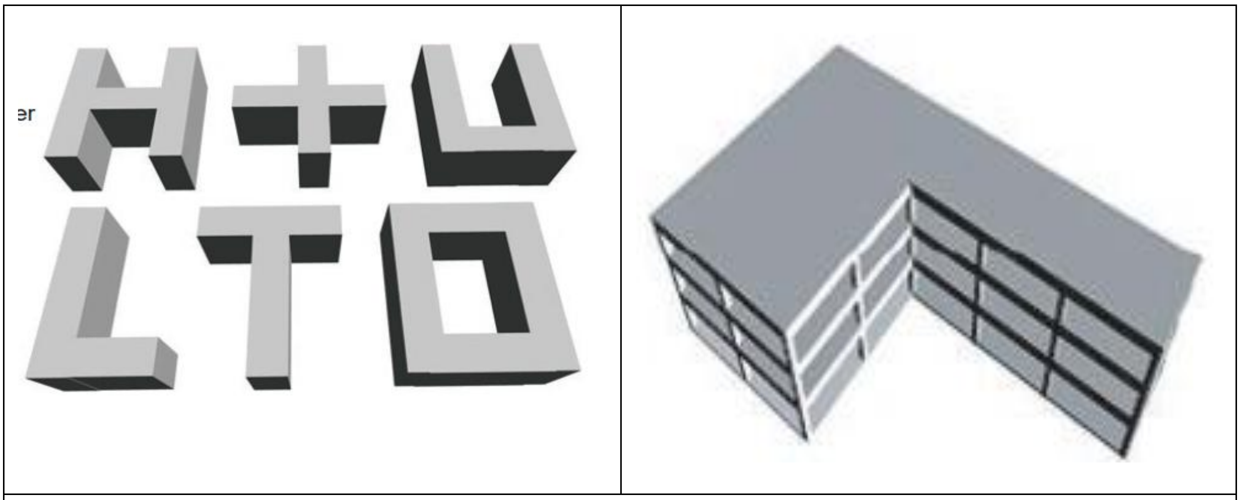


Fig 2. Configurations of Buildings with Re-entrant corners

There are two problems created by these shapes. The first is that they tend to produce differential motions between different wings of the building that result in local stress concentrations at the re-entrant corner, or “notch.” The second problem of this form is torsion which is caused because the center of mass and the center of rigidity in this form cannot geometrically coincide for all possible earthquake directions. The result is rotation. The resulting forces are very difficult to analyze and predict.

The stress concentration at the “notch” and the torsional effects are interrelated. The magnitude of the forces and the severity of the problems will depend on:

- The characteristics of the ground motion
- The mass of the building
- The type of structural systems
- The length of the wings and their aspect ratios (length to width proportion)
- The height of the wings and their height/depth ratios

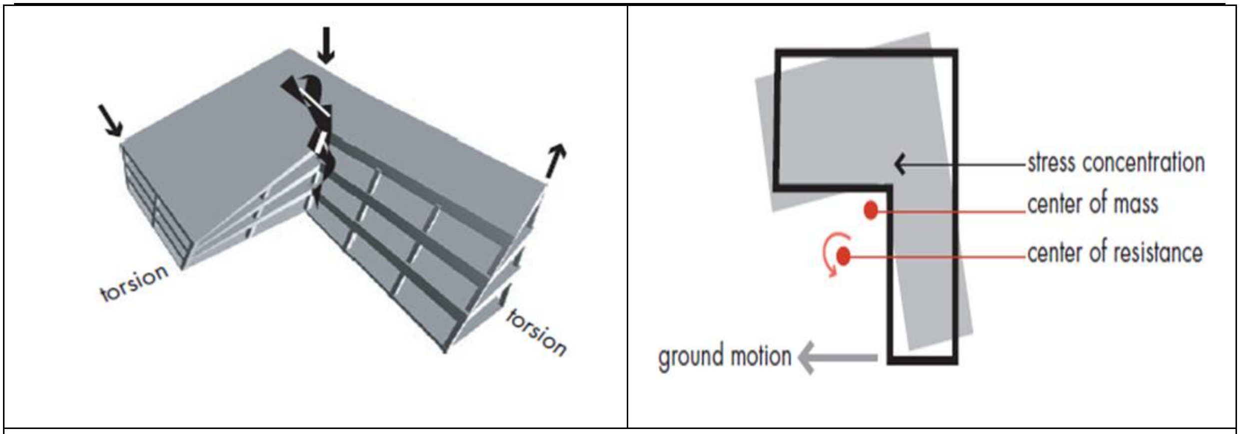
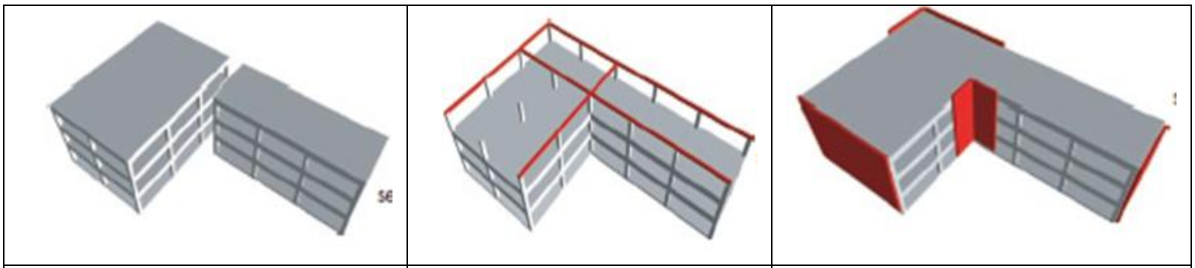


Fig 3. Problems Caused by a Building with Re-entrant corners

3. SOLUTIONS

One of the simplest methods of relieving the structures of the deficiencies caused by the re-entrants corners is to separate the structures at the notches and converting them into smaller blocks of regular configurations. Separation of buildings needs to take into account the functional requirements. The separated structures should be located far apart so as to avoid ponding effects during earthquakes.

For an existing structure, there are many possible options of strengthening the structure to overcome the ill effects of irregularity. One of the viable methods is to strengthen the notch part of the re-entrant corner using stiff elements such as shear walls, bracings or mild steel splays. In the present study, two of these retrofitting methods in the form of shear walls and bracings are used for the retrofitting.



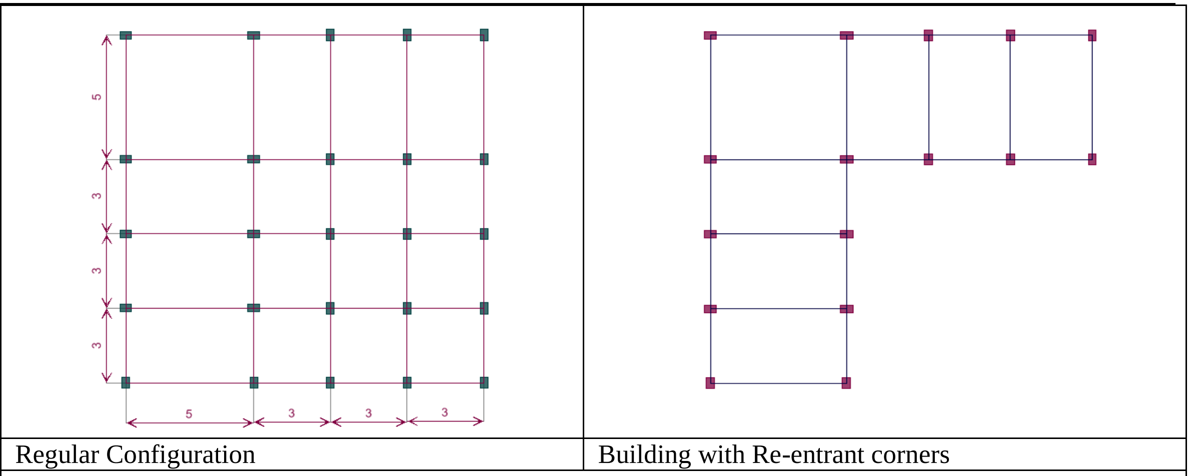
Separation | Strengthening the Notch | Using Stiff Resisting Elements

Fig 4. Solutions to Re-entrant Corners

4. Modeling

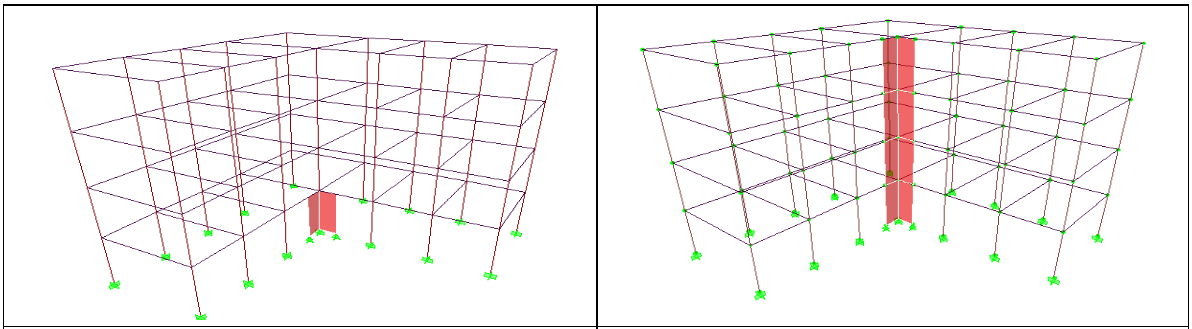
In the present work a typical 4-storey building of regular and irregular (with re-entrant corner) have been chosen for the comparison of their seismic performance. Fig 5 shows the plan view of the structure modeled using ETABS software [4]. In order to evaluate the retrofitting strategies, two type of retrofitting strategies namely, use of shear walls and bracings are considered. For the purpose of modeling 4 different types of retrofitted models are modeled using ETABS.

Retrofit S1 – Buildings provided with shear walls at the notches at bottom storey only
Retrofit S2 – Buildings provided with shear walls at the notches at all storey
Retrofit B1 – Buildings provided with bracings at the notches at bottom storey only
Retrofit B2 – Buildings provided with bracings at the notches at all storey

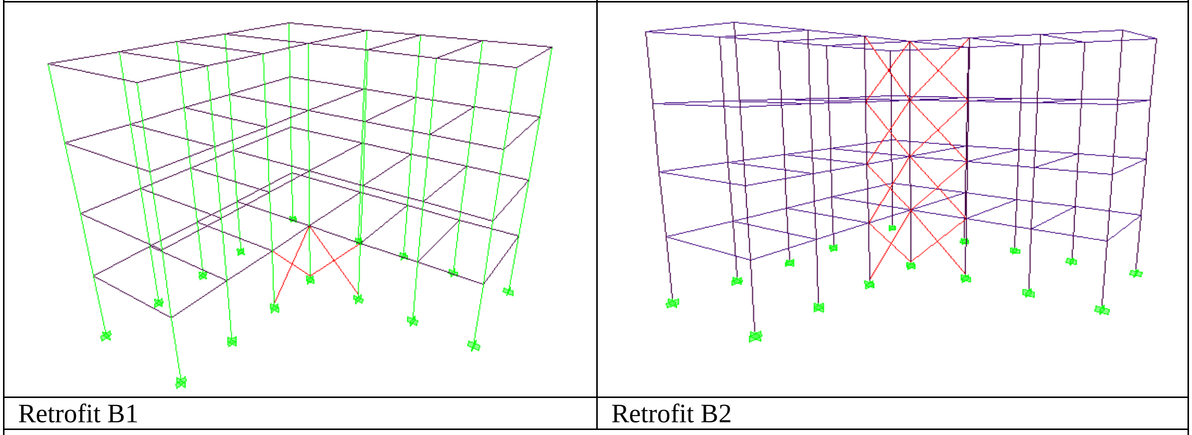


Regular Configuration | Building with Re-entrant corners

Fig 5. Models Considered for the Study



Retrofit S1 | Retrofit S2



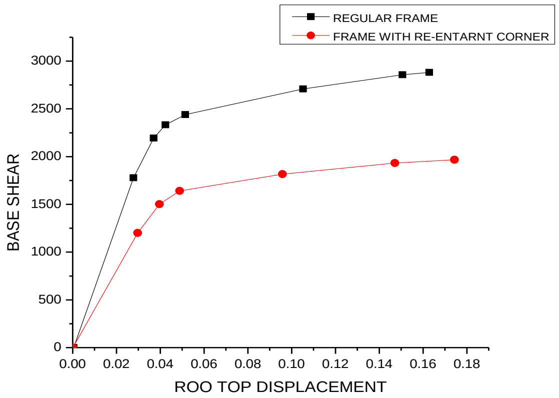
Retrofit B1 | Retrofit B2

Fig 6. Retrofitted Models

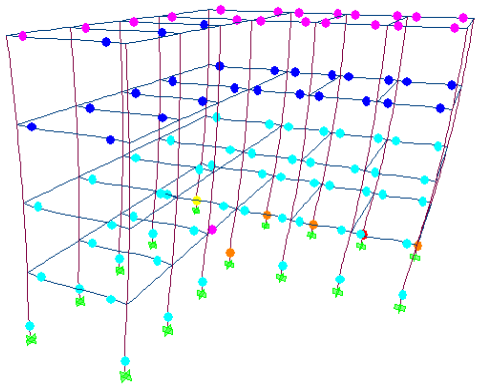
5. Analysis and Results

Structures listed above are subjected to Pushover analysis as per the recommendations of ATC 40 [5] and response spectrum analysis as per IS1893:2001 [1] using ETABS software. The resultant Pushover curves and hinge status formations are as in fig.7. Comparison of the Pushover curves (Base Shear in kN v/s Roof Top Displacement in meters) for these two cases clearly illustrates the higher base shear carrying capacity of regular frame. Also, the hinge status formation at failure confirms the stress concentration at the notch of the re-entrant corner.

Results of response spectrum analysis (fig.8) also shows that irregular frame experiences much higher roof drifts compared to regular frame. Also, in case of irregular frame there is a shift of centre of mass from centre of rigidity which could result in the origin of torsion in the structure.



Pushover curve

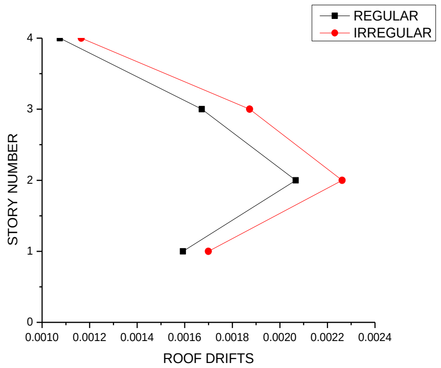


Status of Hinges Formed at Failure

Fig 7. Results of Pushover Analysis

	REGULAR	IRREGULAR
CENTRE OF MASS	(7.251,6.748)	(5.413,8.587)
CENTRE OF RIGIDITY	(7.251,6.748)	(5.613,8.892)
T (SEC)	1.0062	0.9653
BASE SHEAR (X –DIR)	879.82 kN	614 kN

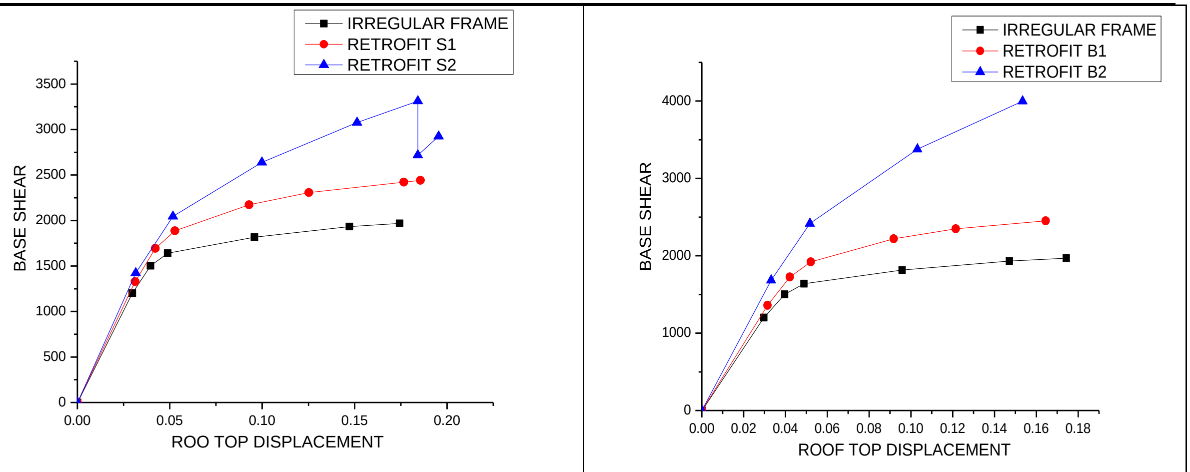
Basic Analysis Details



Comparison of Drifts

Fig 8. Results of Response Spectrum Analysis

Pushover and response spectrum analysis are also carried out on structures retrofitted with shear walls and bracings. Results confirm the increased base shear capacity of the structures retrofitted with shear walls and bracings. Response spectrum analysis also shows the decrease in roof drifts due to the incorporation of retrofitting strategies.



Buildings Retrofitted with Shear Walls

Buildings Retrofitted with Frames

Fig 9. Results of Pushover Analysis on Retrofitted Frames

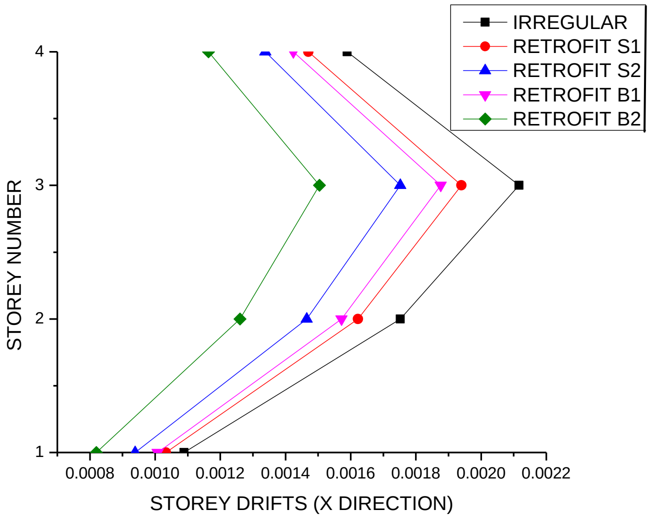


Fig 10. Storey Drifts in X-direction from Response Spectrum Analysis

6. CONCLUSIONS

- Results of both Pushover and response spectrum analysis confirmed the poor performance of frames with re-entrant corners. In the present study, building with re-entrant corners experienced about 12% more lateral drift and 22% reduction in base shear capacity compared to regular building. Also, results have confirmed their susceptibility to stress concentration at notch and torsion due to asymmetry.
- Buildings retrofitted with shear wall and bracing at notches of all storey (model S2 & B2) showed an improvement in base shear carrying capacity of 75% and 110% respectively while those retrofitted at ground level only (model S1 & B1) showed an improvement in base shear carrying capacity of 31% and 22% respectively.
- Response spectrum analysis have shown that retrofitted models S2 and B2 showed a reduction in maximum storey drifts in X-direction by 17% and 29% respectively.

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