Analysis & Design of Irregular Building with Re-entrant Corner using Pushover Analysis: A Review

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***Abstract*: In structure engineering nowadays it is essential to have knowledge on seismic behaviour of irregular buildings. Irregularities are unavoidable in construction due to many reasons such as aesthetic, architectural demands i.e., lights, ventilation etc. Therefore, study of design and behaviour of buildings with these irregularities during an earthquake analysis is needed. The buildings with irregularities are more affected to earthquake forces than buildings with regular configuration. The types of irregularity considered were Horizontal Irregularity as "Re-entrant corner" and Vertical Irregularity as "Mass Irregularity". In study the seismic analysis of the asymmetrical building in which building consists of two different shapes i.e. T and L shape. Re-entrant corners in buildings affect stress concentration and cause torsion related problems during earthquake. Buildings will be analysed using pushover analysis. The main objective is to study different irregularity in buildings while earthquake forces acts and to calculate additional shear due to torsion al response in columns and provide curved beams at every re-entrant corners and shear walls as Stiff Resisting Elements.**

Keywords: Additional shear in columns, curved beams, shear walls, pushover analysis, response spectrum, ETAB etc.

I. INTRODUCTION

Advancement of human mankind where a lot of development has been accounted, technology is rapidly inducing the lifestyle leading to rising in the demand for workable development, in perspective with earthquake engineering of workable development earthquake resistant structures play a significant role. At the same time, as technology is growing rapidly, people are giving special interest to stay in urban areas rather than in rural areas. Constructions can suffer various damages when they are put under seismic activity. Earthquake Engineering allows designing and building a structure in such a way that the damage to the structure and its structural components during an earthquake is reduced. The study includes a thorough understanding of the seismic response of the building. The seismic response relies on a seismic zone, importance factor, ground type, behaviour factor and on the magnitude as well as the distribution of stiffness and masses of building. In urban areas the utilization of space nowadays has caused many alterations in the buildings we want more functionality in less space which makes buildings asymmetric, this may lead to buildings with irregular distributions in their mass, stiffness and strength along with the height of building and cause interruption of force flow and stress concentrations. Whereas regular building arrangements are nearly symmetrical about the axis and ensure uniform distribution of the lateral force-resisting structure elements which deals a constant load path for both gravity and lateral loads. Some studies have focused on assessing the response of "regular" structures.

Regularities in Structures

The following conditions are required for a building to categorize as a regular structure

- The building means to be nearly symmetrical in plan with respect to two orthogonal axes.
- Plan outline shall be compacted. Any current set-backs should not distract the floor stiffness and their area should not exceed 5% of the floor area.
- The in-plan stiffness of a floor shall be adequately large compared to the lateral stiffness of the vertical elements (columns).
- All lateral load resisting vertical elements (columns) mean to run without break from the top of the building (or top of setback) to the foundations.
- The lateral stiffness and mass of floors shall remain constant or decrease gradually from the base to the top.
- The actual storey resistance should not vary excessively between adjacent storeys, etc.

Irregularities in Structures

As per IS 1893, the irregularity in the building structures may be due to irregular distributions in their mass, strength and stiffness along with the height of the building. When such buildings are constructed in high seismic zones, the analysis and design become more complicated. Irregularities are categorized in two types.

Vertical Irregularities

- Vertical Discontinuities in Load Path.
- Irregularity in Strength and Stiffness.
- Mass Irregularities.
- Vertical Geometric Irregularity.
- Proximity of Adjacent Buildings.

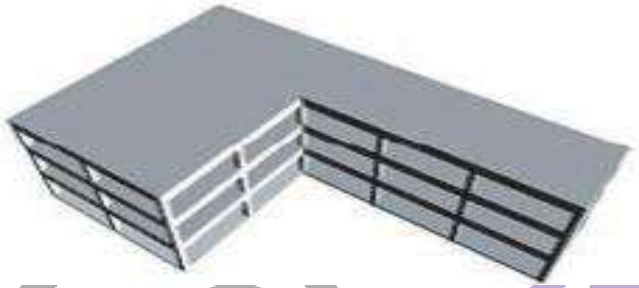
Horizontal Irregularities

- Torsion Irregularities
- Re-entrant Corners
- Non-parallel Systems
- Diaphragm Discontinuity

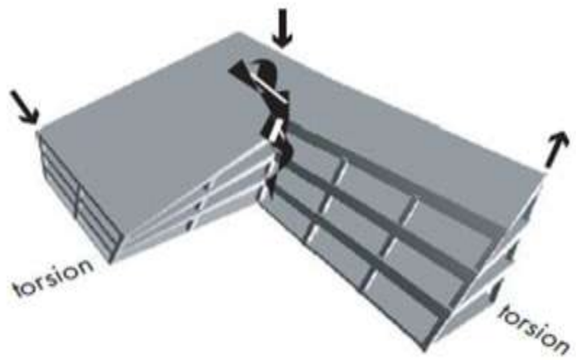
The present scenario has irregular configurations both in plan and elevation, which in future may subject to devastating earthquakes. However, a collective assessment of the effect of vertical and horizontal irregularities on the seismic demand of building structures is needed. The T, L shape consists of both Horizontal Irregularity as Re-entrant corner and Vertical Irregularity as Mass Irregularity. The irregularity causes a sudden change in strength or stiffness of the structure which is not desirable in an earthquake-resistant system. Buildings with simple and regular configurations perform better in the event of an earthquake.
The re-entrant corner is the common characteristic of building configurations that occurs due to lack of tensile capacity and force concentration. Presence of re-entrant corners results in poor seismic performance of buildings. Some of the configurations that result in the formation of re-entrant corners are H, T, U, +, O, L shapes of buildings.

Problem occurs with re-entrant corner

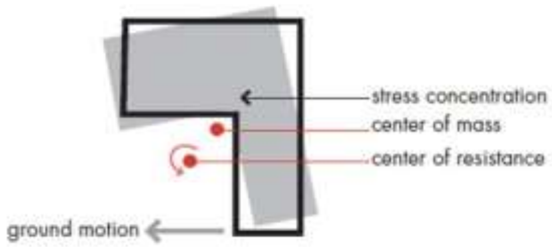
As per IS 1893 Part 1: 2016 plan configurations of a structure and its lateral resisting system contain re-entrant corner is subjected to two types of problems the first is resulting in a local stress concentration at the notch of the re-entrant corner and the second problem is torsion. The resulting forces are very difficult to study. The stress concentration and torsion al effects are interrelated. The magnitude of the forces will depend on characteristics of the ground motion, a mass of the building, type of structural systems, length and height of the wings and their aspect ratios.



Building with re-entrant corner



Torsional Effects Problem



Local Stress Concentration at the Notch

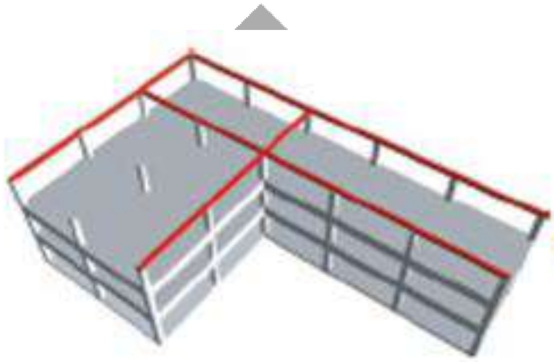
Prevention for re-entrant corner

There are many possible options for strengthening and preventing the structure to overcome the harsh effects of horizontal irregularity. Some of them are as follows.

- **Separation**: The simplest methods are to separate the structures at the notches and converting them into smaller blocks of regular configurations. Separation of buildings should be located far apart to avoid ponding effects during earthquakes.

Separation of building

- **Strengthening the Notch:** The providing curved beam is one way to strengthening the notch, purpose of providing curve beam is to reduce the main torsion at corner because storey overturning moment is maximum at the base and if the torsion is also maximum at the base then maximum chances to produce the crack at the re-entrant corner of the building.



Strengthening the Notch

- **Using Stiff Resisting Elements:** The stiff elements such as shear walls, bracings or mild steel splays can be used, nowadays shear wall and bracings are commonly used. In this paper, we study shear wall which are vertical members provided in the buildings to resist the lateral loads.

Stiff Resisting Element

II. OBJECTIVE

The main objective of this research is to study various seismic responses of regular and irregular structure and to analyze the behavior of the structures by adopting the methodology such as pushover analysis, response spectrum etc. to minimize the effects caused by seismic forces.

Moreover, the objective is figured out as follows:-

- To identify additional shear due to tensional response in columns.
- Study effects curved beams at every re-entrant corner.
- Understanding behavior of shear walls as Stiff Resisting Elements.
- To identify the suitable building configuration from this study.
- To analysis change in parameters such as displacement, Bending moments, and shear forces, storey drift etc. in L-shaped and T-shaped building structure.
- To study the response of these structures with varying stiffness subjected to gravity loads and seismic loading using ETAB.

Comparison between Model is analyzed using code IS: 456-2000 & IS: 1893-2016 Part1. The various seismic parameters such as soil conditions, seismic zone, importance factor etc would allow us to propose the best suitable building configuration.

III. DIFFERENT RESEARCH WORK

[SK Abid Sharief, M Shiva Rama Krishna et al.,2019] The results of reconnaissance studies regarding the seismic response of the college building located in Andhra Pradesh (falling under seismic zone III) are presented, this scenario indicates that the seismic effect depends upon type irregularity and site hazards but the seismic effect is going to be more in irregular structure instead of in regular structure. Three-types of study are performed for the buildings to know the seismic response of the structure in an efficient manner. Linear static method, linear dynamic analysis & non-linear time history analysis has done. It is observed in the analysis performed that factors like storey drift and storey displacement are more sensitive for higher storeys. Major Mode shapes identified have a modal mass contribution of greater than 90% to total mass of the structure.

[**Ratnesh Pathak et al.,2019]** Every re-entrant corner provided curved beam with slab in every model of asymmetrical building of T, L and plus shape to reduce the torsion at corner because storey overturning moment is maximum at the base and if the torsion is also maximum at the base then maximum chances to produce the crack at the re-entrant corner of the building. The analysis of the six models (zone 5) is done with the help of the ETABS software by using two different IS Code such as IS CODE 1893 part1: 2016 for the earthquake resistant design of the structure and IS CODE 456:2000 for design and analysis of the reinforced concrete structure. Study includes the variation of torsion of frame at corner, storey overturning moment, base shear, etc due to provide the curved beam and without curved beam.

[**Vaishnavi Vishnu Battul et al.,2018]** The irregularity is due to the reason the stiffness center and mass center of the building is not at the same location. Hence it is needed to study behavior of such structures during earthquake. The study understands plan irregularity and analyze the seismic performance of the irregular frame using nonlinear static analysis in SAP2000. The study includes identification and measure of the irregularity level due to the irregular plan and improvement of the structural system considering seismic behavior. Irregularity in plan is unavoidable. Due care is needed while designing such structures. Study observed that fore-entrant corner columns need more attention than the other columns. These columns should be designed properly. After proper modifications the bending moment capacity of re-entrant corner column is increased by 1.5 and twice in case of IS456 and IS13920 respectively. Base Shear for regular structures is more than that of irregular structures. Base shear for modified structures is more than the original structures.

[**Reena Sahu, Ravi Dwivedi et al.,2017]** The effect of diaphragm openings on the seismic response of multi-storeyed buildings reduces the base shear, hence attract lesser seismic forces. The study makes a humble effort to portrait the behaviour of multi storied buildings with diaphragm openings under earthquake static analysis and response spectrum analysis, to achieve these objective various models with varying percentages of diaphragm openings were analysed and compared for seismic parameters. It can be seen from the results that base shear in the buildings calculated from the earthquake static analysis is higher than the response spectrum analysis. Provision of the diaphragm opening alters the seismic behaviour of the buildings. Models with a symmetrical opening in both directions expressed similar response for all the parameters while models with change in the symmetry behaved differently. The increase in the opening percentage, increase the storey drift in all the models. It can be seen from the results that storey drift in the buildings calculated from the earthquake static analysis is higher than the response spectrum analysis. Shear force, bending moment and Axial Force obtained from the earthquake static analysis is higher as compared to response spectrum analysis.

[B K Raghuprasad, Vinay S et al.,2016] The effects of torsion on buildings are investigated and the inelastic seismic behaviour of symmetric and asymmetric single & multi-storied buildings is studied. There is an increase in shear in columns and the rotation of columns need some special attention. The natural frequencies of an asymmetric spring model are greater than those of symmetric spring model while the rotations about the vertical axis through the mass centre of an asymmetric model are lesser than those of symmetric model.Similarly, maximum displacement of an asymmetric spring model due to an earthquake is greater than that of symmetric spring model.

[Sharath IrrappaKammar et al.,2015] Study proposed that the base shear of the building increase with the addition of the shear wall as the load resisting capacity increases. The addition of shear wall significantly reduces the displacement in the structures when compared with the structures without shear wall. The performance point of the models without shear wall will have base shear less compared to model with shear wall as the shear wall resists the earthquake forces to greater extent. The model is analysed using SAP2000 software, hinge properties are applied by default method as per cod al provisions in FEMA 356 and pushover analysis procedure is followed as per the prescriptions in ATC-40. From results, it is observed that the buildings with re-entrant corners are more prone to earthquake damage causing Torsion effect.

[Neha P Modakwar et al.,2014] Effect of torsion is much more when diaphragms at some level are removed, so in re-entrant corner building it is better to avoid irregularity in diaphragm ,the re-entrant corner columns are needed to be stiffened for shear force in the horizontal direction perpendicular to it as significant variation is seen in these forces ,from the torsion point of view the re-entrant corner columns must be strengthen at lower floor levels and top two floor levels and from the analysis it's observed that behavior of torsion is same for all zones. Equation generated from the graph shall be used for calculating values of shear forces, moments and displacements in various zones. Study was initiated to quantify the effect of various degrees of irregularity on Structures designed for earthquake using simplified analysis.

[Dr. S.K. Dubey et al.,2012] Study proposed that buildings with irregularities are prone to earthquake damage as observed in many earthquake occurrences. Since current codes fall short of providing simplified analytical tools for irregular structures. It is necessary to develop an easy analytical procedure supported rigorous computations and experiments on the seismic response of irregular structures. To calculate additional shear due to torsion in the columns, additional shear due to torsion al moments needs to be considered because this increases shear forces which causes columns to collapse.

[Diyvyashree M et al.]The study confirmed improvement in base shear carrying and roof drifts capacity of the frames by the introduction of retrofitting methodologies. Comparison of the Pushover curves for 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. While the results of response spectrum analysis also show 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 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.

IV. NEED OF THE STUDY

The intention of this study is to have a collective knowledge of the effect of vertical and horizontal irregularities on the seismic demand of a building. The study will include analysis of curved beam and shear wall together at the re-entrant corner. This analysis and design will be carried out by latest IS cod al provision such as IS 1893:2016 Part1, IS 456:2000 and as required design need. In this study, we also are going to analyse causes for column collapse at re-entrant corner during the seismic forces. The study contributes in future research of seismic analysis of irregular structure at the re-entrant corner and the outcome of the study may lead to the development of the classical approach in understanding behaviour and prevention of structure of re-entrant corner locations during seismic forces.

V. CONCLUSION

The above literature review gives information on different irregularities in building and problem occurred while design and detailing such buildings under seismic forces. In previous studies, it is shown that in inelastic seismic behavior of symmetric and asymmetric building, the storey drift and storey displacement are more sensitive in irregular buildings. The base shear, ductility ratio and response reduction factor for a regular structure is more than that of Irregular Structure. The failure of any structure travel either top to bottom or vice-a-versa.

In the case of seismic design, it's essential to know about overcoming from this type of failures in irregular buildings. From the above studies, it is observed that the buildings with re-entrant corners are more prone to earthquake damage-causing Torsion al effect. As the cracks chance increases while the torsion is maximum at the base because the storey overturning moment is maximum. Various studies show that column and beams in a re-entrant corner need more attention than column and beam of other plan section. If there is an increase in shear in a re-entrant corner the rotation of columns needs some special attention.

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