Seismic Planning For Irregular Structures to Avoid Torsion in First Two Primary Modes - A Literature Review

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Abstract— During strong earthquakes, it is likely that buildings with torsional irregularity in the plan have can be seriously damaged, partially collapsed or fully collapsed. This is because Torsionally Irregular Buildings may have significant aerodynamic torsion loads that increase the eccentricity between the center of mass and the center of rigidity, especially in dominant torsion modes. For this reason, torsion leads to excessive increase in lateral motions when dynamic loads excite the buildings. Torsional irregularity is one of the main failure causes during strong dynamic excitations due to earthquakes. Ignoring torsional irregularity in seismic design analysis can cause unexpected damages and losses. To enhance the safety and performance of buildings, most of the current seismic provisions address this irregularity in two main ways. The first is computing torsion-al moment at each floor by using equations provided in various current seismic code provisions. After they are applied on each floor, the seismic analysis will be performed. The second is shifting the centre of mass or stiffness to eliminate the eccentricity by putting additional masses or structural components such as braced frame systems on buildings. Recently, reports showing the damage caused by earthquakes indicate that, torsion-al effects often cause considerable damage to structures leading to their collapse. The response of asymmetric buildings towards torsion is one of the most crucial factors for their damage. Torsion in such buildings is due to irregularity in plan, mass and stiffness which may cause severe damage in structural systems. Due to various reasons structures acquire asymmetry. Asymmetric structures have irregular distribution of plan, stiffness and mass, its centre of mass and centre of rigidity do not coincide and hence cause the torsion-al effect on the structures which is one of the most important factor influencing the seismic damage of the structure. Structures with asymmetric distribution of mass and stiffness undergoes torsion-al motions during earthquake. The performance of the structures is assessed as per the procedure prescribe in IS 1893:2016. To assess the torsion-al effect on the structures in the present study, different models with irregular shapes with the different orientation of columns and other lateral load resisting elements were prepared and analyzed using E-tabs 2018 software. For the purpose of study, L shaped building of G + 30 storeys with same columns sizes subjected to gravity loads and seismic loads are analysed using linear dynamic analysis.

Keywords: Torsional Irregularity, Plan Irregularity, Sesimic Analysis, Base Shear, Drift, Displacement, IS 1893 – 2016, ETABS 2018

I. INTRODUCTION

An earthquake is a sudden and destructive shaking of the ground, resulting from released ground energy between the different layers of the earth. This released energy, called earthquake ground motion, sometimes can be brutal and unmerciful when the structures are not well-designed against a strong earthquake motion. It can leave thousands of people dead, wounded and/or homeless. For this reason, civil structures should be well-designed by taking the earthquake ground motion into account in the seismic analysis. The seismic analysis depends on two or three translational components of the earthquake ground motion in terms of design, safety and performance assessment of buildings. The rotational component of the ground motion might contribute significantly to the response and damage of these structures. However, its effect is undetermined because its intensity and frequency content are not measured by accelerographs. Therefore, an unpredictable spatial distribution of load and the effect 2 of the rotational component of the ground motion are usually ignored in seismic design practice (Moon 2012).

Earthquake Ground Motions (EQGMs) are the most dangerous natural hazards where both economic and life losses occur. Most of the losses are due to building collapses or damages. Earthquake can cause damage not only on account of vibrations which results from them but also due to other chain effects like landslides, floods, fires etc. Therefore, it is very important to design the structures to resist, moderate to severe EQGMs depending on its site location and importance of the structure. If the existing building is not designed for earthquake then its retrofitting becomes important.

Seismic requirements were not included in building codes as early as those for wind, although some experimentation had taken place in Europe and even more in Japan, which suffered from frequent seismic activity. Some of the early approaches yielded little result, but that did not stop curious minds from experimenting. The first application of Newton's first law to building codes dealing with seismic design was reportedly made in Italy following the 1911 Messina earthquake. The Present work is giving importance on the study of Seismic demands of irregular buildings using analytical techniques. There are various types of irregularities in the buildings depending upon their location and scope, but mainly, they are divided into two groups- plan and vertical irregularities. In the present paper, the irregularities are considered and described as follows:

1) Plan Irregularities: According to clause 7.1 from Sixth revision of IS 1893-2016 (Part 1). Plan irregularities are classified as torsion irregularity, re-entrant corners, floor slabs having excessive cut-outs or openings, out-of-plane offsets in vertical elements and non-parallel lateral force system.

2) Torsion Irregularity: A building is said to be torsionally irregular, when maximum horizontal displacement of any floor in the direction of the lateral force at one of the floor is more than 1.5 times its minimum horizontal displacement at the far end in that direction.
3) Vertical Irregularities: According to clause 7.1 from Sixth revision of IS 1893-2002 (Part 1). Vertical irregularities are classified as mass irregularity, vertical geometrical irregularity, stiffness irregularity, In-plane Discontinuity in Vertical Elements Resisting Lateral Force and Mass Irregularity:
4) Mass irregularity shall be considered to exist, when the seismic weight of any floor is more than 150 percent of that of its adjacent floors. This provision of 150 percent may be relaxed in case of roofs.
5) Vertical Geometric Irregularity: Vertical geometric irregularity shall be considered to exist, when the horizontal dimension of the lateral force resisting system in any storey is more than 125 percent of that in its adjacent storey.

The purpose of this hypothetical study is to evaluate the seismic properties and characteristics for regular and plan irregular structures. The main aspect of this analysis is to obtain the sustainability of the building regarding the performance of the buildings by using the aid of capacity and the demand of the structure for a designed strong motion earthquake characteristics using the different method of analysis.

II. Objectives of the Study

Structural eccentricity is a useful parameter which is responsible to co-relate the seismic elastic response of asymmetric structures. When the structural system is excited into the inelastic range, yielding of the resisting elements complicates the behaviour. Therefore there is a need to study this parameter that captures the inelastic response of the structure. As a part of civil engineering work or as being a civil engineer it's our duty to design such a structure which will sustain in severe earthquakes in various earthquake prone zones and which will lead to reduce the harm of catastrophic as well as economic losses.

III. Literature Review

There were various studies been conducted on the static and dynamic analysis and design of such regular and irregular structures. The studies also suggests about the difficulties arise for the seismic design of high rise building where such situation occurs. Few of the data from previous studies have been discussed here along with the methodology adopted and conclusions. Many research investigations have been carried out regarding the torsional effect of the multi-storey structures.

1) Salunkhe and Kanase (2021) investigated that response of mass irregular structure need to be studied for the earthquake scenario. In this paper researcher deal with RCC framed structure in both regular and mass irregular manner with different analysis methods.
2) Oman Sayyed (2021) focused his study on the effect of infill and mass irregularity on different floor in RC buildings. The results were concluded that the brick infill enhances the seismic performance of the RC buildings and poor seismic responses were shown by the mass irregular building, therefore it should be avoided in the seismic vulnerable regions.
3) Sagar et al. (2020) analysed the performance on various type of irregularity Considered i.e. (a) Horizontal Irregularity-plan irregularity (b) Vertical Irregularity - Mass Irregularity. To achieve objective of the project Time history Analysis & Response spectrum analysis method were carried out.
4) Ramesh Konakalla (2020) analysed four different 20 story building for effect of vertical irregularity under Dynamic Loads Using Linear Static Analysis. Response of all cases is compared and concluded that in regular structure there is no torsional effect in the frame because of symmetry. The response for vertically irregular buildings is different for the columns which are located in the plane perpendicular to the action of force. This is due to the torsional rotation in the structure.
5) Bansal, and Gagandeep (2019) studied ductility based design is carried considering vertical irregular building and methods used are RSA and THA. Three types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered.
6) Himanshu Bansal (2019) analysed vertical irregular building with Response spectrum analysis and Time history Analysis. Irregularities considered are mass irregularity, stiffness irregularity and vertical geometry irregularity. The storey shear force was found maximum for the first storey and it decreases to minimum in the top storey in all cases.
7) S.Varadharajan et al. (2018) reviewed existing works regarding plan irregularities and justified the preference of multistory building models over single storey building models.
8) Aijaj and Rahman (2018) tried to analyse the proportional distribution of lateral forces involved in earthquake for individual storey due to changes in stiffness of vertically irregular structure.
9) Poncet, L. And Tremblay (2018) proposed the impact and effect of mass irregularity considering case of an eight-storey concentrically braced steel frame structure with different setback configurations. Methods used in present paper are equivalent static load method and the response spectrum analysis method.
10) Devesh P. Soni (2016) considered several vertical irregular buildings for analysis. Various criteria's and codes have been discussed and reviewed in this paper. Vertical irregular structure performance and response is reviewed and presented. The studies suggested that for combined stiffness and strength irregularity large seismic demands are found.
11) Vipin Gupta and Dr. P.S. Pajgade [2015] presented a review about the investigation done on torsional behaviour of multistory buildings with plan as well as vertical irregularities. It also focuses on codal provision made for torsion. From their investigation on reviews they concluded that the torsion is the most critical factor leading to major damage or completes collapse of building; therefore, it is necessary that symmetric

buildings should also be analyzed for torsion. As result the buildings should be designed by considering the design eccentricity & accidental eccentricity. It was observed that the irregular profile buildings got larger forces and displacement as compared to regular one. Structures are never perfectly regular and hence the designers routinely need to evaluate the likely degree of irregularity and the effect of this irregularity on a structure during an earthquake.

12) Amin Alavi et al., [2015] made an attempt to realise the seismic response of the structures, for various location of shear walls on RC building having re-entrant corners on high seismic zones. They studied a five storey building with six different shear wall locations They considered the accidental torsion of both negative and positive X and Y directions. The results proved that the structures are more vulnerable when they are more irregular, and also the eccentricities between centre of mass and centre of resistance are more significant to the torsional behaviour of structures during an earthquake.
13) Gunay ozmen [2015] explained the conditions which cause torsional irregularity coefficient to exceed the upper bound value of 2 are investigated. A series of eight walled and framed sample structures with different structural shear wall configurations was chosen and their behaviour under earthquake loading were considered. It was found that torsional irregularity coefficient was maximum when the number of axes and number of stories are low. Also when structural walls are placed as close as possible to the gravity centres without coinciding them, the coefficient were found to be maximum.
14) R.Riddell and J.Vasquez [2015] discussed the existence of centre of resistance as origins of eccentricity are restricted to a particular class of structures, and concluded that for a general multi-storey building such concepts are physically meaningless. They created a pseudo model and torsional uncoupling had been carried out. They found that the definition of centres of resistance as origins for measuring eccentricity must be associated to the possibility of torsion free dynamic response. Also, concluded that the centres of resistance must be such that if the eccentricity is zero in all stories then the modes of vibration of the building uncoupled into purely torsional modes and purely translational modes. When centres of resistance do exist, they all lie in a vertical line and torsion free vibration is achieved when all storey centres of mass lie in that same line.
15) O. A. Mohamed and O. A. Abbass (2015) [4] explains review about the Consideration of torsional irregularity in Modal Response Spectrum Analysis. The motivation behind their work is to determine the impacts of torsional irregularity on seismic reaction as per ASCE 7–10, when MRSA is utilized for count of seismic forces and drifts. They discussed about why torsional irregularity must be represented, notwithstanding when MRSA is utilized. From their investigation on reviews they concluded that the torsional irregularity of building diaphragm or floor frameworks prompts increased structural reactions including bending moments and drift and should be represented in the computational model to maintain a strategic distance from structural failures and building pounding effects.
16) Turgut Ozturk , Zubeyde Ozturk and Onur Ozturk (2015) [2] presented a review about the seismic behavior analysis of multi-story reinforced concrete buildings having torsional irregularity. The purpose of their work is to understanding of the characteristics of an earthquake and correct determination of the behavior of buildings under earthquake excitation turn out to be the most important requirement to build earthquake resistant buildings. In their study torsional effects that occur during earthquake excitations are analyzed in multi-story reinforced concrete buildings. In that manner the behavior of reinforced concrete structures under earthquake loads are examined and by the way the behaviors of structures having torsional irregularities are enlightened and clarified. From the results they explains that the torsional irregularity can occur in the buildings that have regular geometrical shape and regular rigidity distribution. The reason of this irregularity which is called hidden torsional irregularity, is due to lack of rigidity along the extern axes. In certain cases, torsional irregularity can be lowered or totally removed as a result of decrease shear wall rigidity at central zone. torsional irregularity is more related to the rigidity distribution than the geometrical plan of the building. For this reason, determination of the load carrying system of a structure is the most important issue at the planning stage of the project. It is essential that shear wall locations and cross-sectional areas must be properly selected, and the shear walls must be symmetrical in the plan in order to prevent torsional irregularity.
17) Arvindreddy and R.J.Fernandes (2015) [3] presented a review about the Seismic analysis of RC regular and irregular frame structures. They considered 2 types of reinforced concrete structures with regular and irregular 15 story structures and analysed for static and dynamic methods. For time history examination past seismic earth ground movement record is taken to think about reaction of the considerable number of structures. Directly they taken six models. One is of general structure and remaining are unpredictable structural models. From their investigation on reviews they concluded that, the static analysis strategy demonstrate lesser story displacements when compared with response spectrum analysis. This variation may be because of nonlinear distribution of force. In diaphragm irregularity, story displacement and story drift observed to be less when compared with normal structures in both static and response spectrum analysis.
18) Han Seon Lee, Dong Woo Co (2013) studied Seismic response characteristics of high rise RC wall buildings having different irregularities in lower stories. They studied the seismic response of high rise RC wall buildings with different irregularities. In this study they have consider three models with three different cases. First model has a symmetrical moment resisting frame, second has infilled shear wall at the central frame and third one is with infilled shear walls in most exterior frames at the bottom two storey. The model testing is done on shake table. The comparison of all models is

done on the basis of base shear, storey drift and axial forces in columns of each model. The failure mode and crack pattern of all models are studied.

19) H. Gokdemir, H. Ozabasaran, M. Dogan, E. Unluoglu, U. Albayrak (2012) studied Effects of torsional irregularity of structures during earthquakes. They have studied the behavior of torsional irregular structures. In this paper they have considered models with irregular plans like T-shaped, L-shaped, U-shaped, cruciform plan. Different building models with different floor area and number of floors are modeled in SAP2000 software for analysis. Also the articles in Turkish code and different earthquake codes related to torsional irregularities are compared. The calculations are made for the safe distance between adjacent buildings to avoid pounding effect. They concluded that eccentricity between centre of mass and centre of rigidity cause torsion in building and magnitude of torsion moment is function of eccentricity ratio. It is observed from their results that increasing strength of structural elements on the weak direction or decreasing strength of structural elements on strong direction can prevent effects of torsion on structures.
20) Semih S. Tezcan, Cenk Alhan (2011) studied parametric analysis of irregular structures under seismic loading according to the Turkish Earthquake Code In this paper they have investigated the effect of torsion moment and shear values of vertical structural elements. Three cases are considered with different center of rigidity with 1, 5 and 10 storey buildings. The modeling and analysis of all models is done in SAP90 software. The analysis is done by both the methods dynamic analysis and equivalent earthquake loading. The detailed study of model of 5 storey building with shear wall at different location i.e. one non orthogonal and two orthogonal shear walls. Each case is analyzed with different directions of earthquake.
21) Emrah Eeduran (2010) studied Assessment of current nonlinear static procedures on the estimation of torsional effects in low rise frame buildings. In this paper two types of eccentricity are considered. To do so two models are studied, one with uni-directional eccentricity and second with bi-directional eccentricity. The response history analysis is carried out on both models. It is observed from the results that nonlinear static procedures proposed for asymmetric buildings are more effective to get torsional effects. This also concluded that for the uni-directionally eccentric system, the underestimation of torsional rotations results in traditional displacement demand estimates for the torsionally stiff side.
22) Mr. Sandesh N. Suryvanshi, Prof. S. B. Kadam, Dr. S. N. Tande (2010) studied Torsional behavior of asymmetric buildings in plan under seismic force. They have studied the torsional behavior of irregular structure. They worked on three types of structures with symmetric plan, T shaped plan, L shaped plan. Two models of each case with G+3 and G+6 floors are analyzed. The modeling and analysis is done with the help of SAP2000 software. The conclusions are made by comparison of all models on the basis of base shear, time period and torsion moment.

IV. CONCLUSION

With requirement of high infrastructure increasing day by day, more amounts of high rise structures have been designed and analyzed. The research works were undertaken with various issues related to seismic analysis of such structures in different seismic zones. From all the previous studies, following points have been concluded:

- To understand the behavior of irregular building subjected to lateral loading with the help of time period, frequency, modal mass participating ratio and the magnitudes of stress resultants.
- To study the structural response for torsional irregularities.
- To determine the structural response under seismic loading using shear walls with the same cross sectional area in different models.
- To determine optimum position of shear walls by taking irregular building plan.
- To calculate the design lateral forces on regular and irregular buildings using response spectrum analysis and to compare the results of different structures.
- To calculate the response of buildings subjected to various types of ground motions namely low, intermediate and high frequency ground motion using Response spectrum analysis and to compare the results.
- To accomplish a comparative knowledge on the various seismic parameters for the different forms of reinforced concrete moment resisting frames (MRF) with varying number of stories, configuration and types of irregularity.
- This is not sufficient to study the nonlinear behaviour of the structure. A great amount of research in nonlinear static analysis i.e., push over analysis is in progress and at the same time a great focus is also in the direction of nonlinear dynamic analysis.
- Now a day, complex shaped buildings are getting popular, but they carry a risk of sustaining damages during earthquakes. Therefore, such buildings should be designed properly taking care of their dynamic behaviour.
- As Response Spectrum Method, used for seismic analysis, it provides a better check to the safety of structures analyzed and designed by method specified by IS code.

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