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A Study on Seismic Performance of Various Irregular Structures

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ABSTRACT
The buildings constructed in the present scenario are mostly irregular in geometry and elevation for aesthetic view. These irregularities may also be due to economical feasibility, land availability and other factors. From the past earthquake, researches says that regularly configured structures stay safe in Earthquakes, but irregularly configured structures could not able to withstand effectively during an earthquake. Structures experience lateral deflections under earthquake loads. This work focuses on studying the various sorts of building irregularities possible and their behaviour during seismic forces. This study focuses on learning the parameters to be analysed while analyzing a structure for seismic force. The various structural behaviour parameters such as displacement, base shear, storey drift, stiffness, strength etc., are needed to be studied. Also to know the model analysis methods those are available for seismic analysis of a structure. Some model analysis methods are Response Spectrum Analysis, Time History Analysis.

KEYWORDS: *Irregular structures, method of analysis, torsion, displacement, base shear.*

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I. INTRODUCTION

The geographical feature of earth is such that nobody can predict the consequences. One of the natural disasters is earthquake. The destruction caused due to earth quakes are too many in the world they not only cause great destruction in terms of human loss but also have a huge economic impact on the affected area.

Irregularities are introduced in real structures for both aesthetics and utility. The magnitude of variation in response depends on the type, degree and location of irregularities present. There are basically two types of irregularities in building,

1. Plan irregularity
2. Vertical irregularity

When the center of mass doesn't coincide with the center of stiffness, eccentricity develops in the structure. Eccentricity occurs due to the irregular arrangement of structural configuration which in turn induces torsion in the structure. These torsional coupling results in damage of structures.

II. LITERATURE REVIEW

2.1 TORSIONAL COUPLING

Chandler and Hutchinson (1986), made a detailed study of the coupled lateral and torsional response of a partially symmetric single storey building model subjected to both steady state and earthquake base loadings. From their analysis it is concluded that torsional coupling induces a significant amplification of earthquake forces which should be accounted for in their design.

Mario et al. (2006), examined the effects of the over strength in element C/S on the seismic behaviour of multi-storey asymmetric buildings. Torsional provisions, which aim at reducing ductility demands of single-storey asymmetric systems to those of the corresponding torsionally balanced systems, should be re-checked in the behaviour of realistic multi-storey buildings.

Abd-el-rahim and Farghaly (2010), intended in the study to evaluate the performance of gravity loaded irregular buildings in plan under earthquake excitation. A time history analysis with a peak ground acceleration of 0.25g was carried out using finite element program SAP2000. It is found that the induced base shear perpendicular to the earthquake direction is sensitive to the torsional eccentricity and increases by about 80%, 65%, and 40% of the base shear in earthquake direction for T, L, and U shape respectively.

Gokdemir et al. (2013), studied the effects of torsional irregularity on structures. Under excessive torsion, structural elements may reach to their torsional moment capacity or the whole structure may be forced to deflect beyond its lateral deflection limit. Therefore, torsional irregularity may cause failure of any structural system.

Hassballa et al. (2013), analysed the multistorey building by response spectrum method by using STAAD.Pro software**.** They consider the static load and siesmic load for the anlysis of multistoried building. It is found that drift is obtained from this analysis is about 2 to 3 times the allowable drift. Results in large displacement due to combination of static load and seismic load.

McCrum and Broderick (2013), in this investigation, the seismic torsional response of a multi-storey concentrically braced frame plan irregular structure is evaluated numerically and experimentally through a series of hybrid tests. Results indicate that torsionally stiff structures perform well and the stiff side of the structure is subjected to a greater ductility demand compared to the flexible side of the structure.

Ozmen et al. (2014), performed parametric studies on six buildings with varying shear wall positions. Based on the floor rotations, a torsional irregularity coefficient was proposed. According to their findings, as the number of storey decreases, the torsional irregularity coefficient increases and the maximum storey rotations occur for the top storeys.

Mohamed & Abbass (2015), this paper is to discuss the determination of the effects of torsional irregularity on seismic response in accordance with ASCE 7–10. Torsional irregularity of building diaphragms leads to amplified structural responses including bending moments and drifts must be accounted in the computational model to avoid structural failures and building pounding effects.

Uzun et al. (2018), in this study, the different number of story and the different located shear wall in plan were handled. When the coefficients of torsional irregularity are examined, it is seen that the coefficient of torsional irregularity increases while number of storey decrease. The torsional irregularity coefficient increase about 50% in the EL method.

Mehana et al. (2019), this paper addresses the effect of the ratio Ω between (ω_Θ) to (ω_x) or (ω_y), on the torsional behaviour of the structure. The study shows that structures with ratio $\Omega > 1.0$ are torsionally stiff. Structures with ratio $\Omega < 1.0$ are torsionally flexible and displacements values are sensitive to increases in eccentricity ratio. It is also observed that when $\Omega = 1.0$, no significant increase in torsional response occurs.

Neelavathi et al. (2019), considered the 20 storey building of RC structure which includes 5 models of different regular and irregular shaped structures which are subjected to earthquake load and are modelled by using ETABS version 9. Reduction of 23% was observed in RSA compared with ESA in both displacement and drift. On the basis of stiffness, the regular models are more flexible than the L shape models with provision of shear wall.

2.2 DUCTILITY REQUIREMENT

Aranda (1984), made a comparison of ductility demands between set-back and regular structures by using ground motions recorded on soft soil. He observed higher ductility demands for set-back structures than for the regular ones. Found this increase to be more observed in the tower portions.

Athanassiadou (2008), studied on two ten-storey two-dimensional plane frames with two and four large setbacks in the upper floors respectively. From his study it is found that DCM frames were found to be stronger and less ductile than the corresponding DCH ones. The over strength of the irregular frames was found to be similar to that of the regular ones, while DCH frames are found to dispose higher over strength than DCM ones.

Hirde et al. (2016), the author made an attempt to study the building models with plan irregularities. The author says that, in retrofitted building the hinges developed in beams are at Life safety which is acceptable criteria for the building. After retrofitting with X steel bracing it is observed that performance level of building is changed to life safety level from collapse level.

Babu (2017), in this paper the response is investigated for G+7 building structures by using STAAD PRO designing software. In this study of the G+7 building, seismic load dominates the wind load under the seismic zone –II. From this study it can be observed that, in the earthquake resistant design of G+7 RC framed building the steel quantity increased by 1.517% to the convention concrete design.

2.3 VERTICAL IRREGULARITY

Valmundsson and Nauhave (1997), studied the seismic behavior of multistoried buildings having vertical structural irregularities and concluded that 30% decrease in stiffness have increased the storey drift in the range of 20-40%.

Inel and Ozmen (2008), investigated the soft story behavior due to increased story height, absence of infill amount at ground story. It is observed that, soft story due to infill walls may be as damaging as soft story due to increased story height. Also soft story due to increased height and due to lack of infill walls have close values to each other. Soft story may arise because of abrupt changes in amount of infill walls which are not thought to be a part of structural system.

Magliulo and Ramasco (2008), presents the results of a research study concerning the seismic response and design of RC frames with strength discontinuities in elevation. The seismic response of frames characterised by the assigned overstrength is not very different with respect to the “regular frame” one; this demonstrates that the sensitivity of frames, designed according to High Ductility Class, to overstrength vertical variations is low.

Mohod and Karwa (2014), made an effort to understand the earthquake response of setback structures, an analytical study was undertaken. Critical setback ratio RA=0.25 and RH=6/5 shows the variation in story drift which signifies the jumping of the forces due to unequal distribution of mass along the plan as well as along the height. The optimum value of critical setback ratios mainly RA and RH comes out to be RA=0.75 and RH=6/5. From the results it may be concluded that the irregular structures have to be treated with proper understanding.

Pradeep and Jacob (2014) studied the seismic behaviour of reinforced concrete framed structures with varying height of column within one storey. The results shows that the short column in the ground storey fails very easily on a sloping terrain. Shear cracks also found on the beam column joint of short column. Due to higher ductility in the long column, it attracts lesser lateral force which results the more stable to the long column.

Rana and Raheen (2015), has shown the performance, behavior of regular and vertical geometric irregular RCC framed structure under seismic motion. It is concluded that as the amount of setback increases the shear force also increases. The fluctuation of critical shear force from regular to vertical geometric irregular is very high.

Imranullahkhan and Roa (2017), the main intension of this study is to understand irregularity and to analyze L-shape building under earthquake forces. Story drift response along the height of the building shows that the middle stories are more affected than Lower and upper stories. Displacements gradually increase from ground storey to top storey.

Pushkar and Rahul (2017), aims to study the consideration of type of structures under earthquake areas. The results obtained from the models showed that storey stiffness increases until certain storey and thereafter it starts to decrease. Storey shear inversely varies with increase in storey height.

2.4 MASS IRREGULARITY

Padol et al. (2015), studied the seismic analysis of multistoried RCC building with mass irregularity at different floor level are carried out. They suggest that whenever structure has different irregularity the effect of earthquake on structure can be minimize by providing shear wall, base isolation etc.

Soni (2015), studied the effect of irregularities in building and their consequence. In this study the author used the response spectrum method for the analysis of G+10 building. Buildings with soft storey and heavy mass at top storey suffered maximum displacement. Storey drift is maximum, which change abruptly when heavy loaded.

Sweetlin et al. (2016), studied a comparison of displacement between regular and irregular building for the zone 2. The displacement have direct co relation with mass of building so displacement in regular building is more than irregular building and story drift is also more in regular building because they consider only the geometric irregular building.

Choudhary et al. (2018), addressed the difference between a building without diaphragm discontinuity and a building with diaphragm discontinuity. The study shows that variation in the slab thickness reduces the performance of the buildings during earthquakes. It is found that the slab openings in a building having shear wall gives better performance during earthquakes.

2.5 PLAN IRREGULARITY

Guevara et al. (1992), focused on the effect of floor plan on the seismic behavior of structures. Study includes the dynamic analysis of H and L shaped buildings. The paper suggests that buildings having H and L shaped plan should be divided into rectangular blocks separated by seismic joints.

Kabir et al. (2015), this paper is to assess the seismic vulnerability and response of regular and irregular shaped multi-storey building of identical weight in context of Bangladesh. It is concluded that C- shaped and L- shaped multi-storey buildings are more susceptible to static, dynamic seismic load and wind load compared to the rectangular and irregular shaped buildings. With a constant mass, rectangular and irregular shaped building acts alike.

Rizwan and Peera (2015), his work involved four 15 storied building of totally different configuration rectangular shape, L shape, H shape and C shape building. It was found out that results yielded more deformation in plan irregularity buildings than regular plan.

Momen et al. (2016), have studied the effect of seismic response of L shaped buildings. Equivalent static and response spectrum methods were performed using ETABS software. They observed that the response of L shaped building is higher than that of the regular frame due to torsion.

Singh et al. (2016), the response is investigated for G+10 building structures by using STAAD Pro software. This building is safe for area coming under earthquake zone II. The maximum drift in the building is 2.077 cm which is safe as per IS 1893-2002. The maximum beam displacement of 3m span beam is 0.044mm and allowable displacement is 12mm.

Dhananjay (2017), analysed G+25 storey rectangular shape, L shape and I shape building using STADD pro software in zone III and zone IV for hard and medium soils. It was found out that L shape had less maximum bending moment and maximum displacement in z direction.
Reena Sahu et al. (2017), made an attempt to know the difference between a building with diaphragm discontinuity and without diaphragm discontinuity. From the results, base shear, shear force, bending moment and axial force 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. The increase in the opening percentage, increase the storey drift in all the models.
Upendra (2017), designed and analysed on G+12 storey building having rectangular shape, T shape, C shape and O shape using ETABS software. It was found that minimum drift in x direction was found to be more in C shape while in Y direction, O shape building was found to have less drift.
Ahirwal et al. (2019), in this study an attempt has been made to know the difference in seismic response of two building having diaphragm discontinuity and without diaphragm discontinuity. Base shear for regular diaphragm building is more than irregular diaphragm building. Due to the reduction in floor area dead load of the regular structure is more than irregular structure which leads to increase in base shear of regular diaphragm building. Joint displacement in regular diaphragm building is 15% more than irregular diaphragm building.
Naik and Shetty (2019), this research paper involves the modeling and analysis of G+10 storied building of Rectangular shape, L shape snd C shape structure using ETABS 2016. The L shape structure and C shape structure has less shear force carrying capacity. The storey overturning moment is also more in rectangular shape which indicates that more moment is required to overturn the storey.
Patil et al. (2019), this paper is an attempt to evaluate and compare seismic performance of G+14 Storey with 7 bays X 9 bays plan irregular and Regular building using ETABs. The building is analyzed in the region of earthquake zone IV on a medium soil. Storey Displacement & Storey drift is maximum for Plan irregular building compare to plan regular building. As the plan irregularity increases both storey displacement and storey drift increases.

2.6 COMBINED IRREGULARITIES

Al-Ali and Krawinkler (1998), carried out evaluation of the effects of vertical irregularities. Studied a 10-story building model designed by strong-beam-weak-column philosophy. The effect of mass irregularity is the smallest, the effect of strength irregularity is larger than the effect of stiffness irregularity, and the effect of combined-stiffness-and-strength irregularity is the largest. Roof displacement is not affected by the vertical irregularity.
Bansal and Gagandeep (2012) carried out RSA and THA of vertically irregular RC building frames and to carry out the ductility based design using IS 13920. The storey shear force was found to be maximum for the first storey and it decreases to minimum in the top storey in all cases. The mass irregular structures were observed to experience larger base shear than regular structures. Lower stiffness results in higher displacements of upper stories.
Akhare and Maske (2015), in this work performance based seismic design of buildings with plan irregularity is studied using Standard pushover analysis and Modal pushover analysis. The results shows that the Standard pushover analysis gives same results as compare to Modal pushover analysis and THA for regular building, but for irregular buildings modal pushover analysis gives better results due to consideration of higher mode effects. It is also concluded that torsion produced in irregular buildings are almost 20% more than the regular building so it is necessary to take the effects due to torsion for irregular buildings.
Dubule (2018), considered the residential building of G+ 13 storied structure for the seismic analysis and it is located in zone III. Mass irregularity, stiffness irregularity and stiffness & mass irregularity were considered. From observation, the storey shear force was found to be maximum for the first storey and it decreases to minimum in the top storey in all cases. The mass irregular structures were observed to experience larger base shear. The stiffness irregular structure experienced lesser base shear and has larger inter-storey drifts.
Naveen et al. (2019), the present study addresses the seismic response of RC structures possessing various combinations of irregularities. It is observed that irregularity considerably affects the seismic response. Out of various types of single irregularities analyzed, stiffness irregularity is found to have maximum influence on the among the cases having combinations of irregularities, the configuration with mass, stiffness and vertical geometric irregularities has shown maximum response.
Raj and Devi (2019), in this study seismic performance of G+15 irregular buildings of re-entrant corner irregularity, vertical geometric irregularity and stiffness irregularity is modelled and analyzed. The seismic response of stiffness irregular structure is far better. The lateral displacement is found very high for re-entrant corner structure this is due to change in geometry of the structure and the inertial forces are more and hence displacement is more.

2.7 EXPERIMENTAL STUDIES

Humar and Wright (1977), studied seismic response of steel frames with set-backs by using one ground motion. They found story drifts to be larger in the tower parts of set-back structures than those for the regular structures. Smaller story drifts were found in the base parts of set-back structure as compared to the regular structures. Most notable observations were altered displacements and high ductility demands in the vicinity of the irregularities.

Moehle and Alarcon (1986), done an experimental response study on two small scale models of RC frame-wall structures subjected to strong base motions by using shake table. The main advantage of dynamic methods is that those are capable of estimating the maximum displacement response. Also inferred that the inelastic static and dynamic methods are superior to the elastic methods in interpreting the structural discontinuities.

Sarno et al.(2003), this paper assesses the feasibility of the application of stainless steel in the seismic design of regular and irregular framed structures. The results of the analyses shows that for regular frames and frames with setbacks the use of stainless steel columns enhances the energy absorption and leads to large spread of plasticity.

Asgarian et al. (2010), comparative studies on the seismic performance of different types of structure are performed in this study. Results show that Immediate Occupancy performance level is not exceeded for all frames but the Collapse Prevention performance level is not met for Ordinary Moment Frame considering the level of seismicity of the site and incapability of OMF connections to withstand significant inelastic deformations and rotations.

Chunyu et al. (2012), an office building with height of 112.4m scaled to 1/20 scaled test model was designed to have very irregular plan and elevation. Shaking table test was carried out on the structure to investigate its seismic performance. The structural irregularities, including plan reduction, little top tower and discontinuous columns, cause some obvious damage under large earthquakes. The little top tower has obvious whipping effect.

Kazantzi et al. (2014), a quantification of the model parameter uncertainty effects on the seismic performance has been presented for a 4- story steel moment-resisting frame designed for Western USA. The comparison of the interstory drifts obtained with and without the consideration of model parameter uncertainties revealed that their effect can be safely ignored for the examined case, i.e., for regular low-rise capacity-designed steel frame buildings, as long as one is interested in the global behavior.

Ferraioli (2015), the manuscript reports the comprehensive study on the seismic vulnerability of an irregular RC building: the hospital building of Avezzano (L'Aquila Italy). The results from the pushover analysis suggest the sensitivity of the capacity curve to the controlled point, especially when the accidental eccentricity has the same sign of the structural eccentricity.

Homaei et al. (2017), the probabilistic seismic performance of vertically irregular steel buildings, considering soil–structure interaction effects, is evaluated. In comparison to the regular structure, the irregularity caused considerable reduction of the seismic capacity in most performance levels. The foundation flexibility increased damage potential at the bottom floor, irregularity augmented the displacement demand of the lowest floor and raised the vulnerability of the irregular structures.

Avila (2018), presents the experimental validation and analyses of a structural constructive system based on concrete block masonry. The reinforced building attained an input acceleration twice the unreinforced building on the weak direction. The structure developed important in-plane and out-of-plane damage mainly at the first level including detachment of units, structural components and failure of horizontal reinforcement. The damage observed on the unreinforced building was more distributed along the height of the building.

2.8 METHODS OF ANALYSIS

Tremblay and Poncet (2005), tested an eight - storey concentrically braced steel frame with different setback configurations resulting in sudden reductions in plan dimensions and seismic weight along the height of the structure. The performance of irregular structures exhibiting lower performance could be improved by using the dynamic analysis method in design, but not to the level achieved by the reference regular structure.

Bahador et al. (2012), studied Multi-storey irregular buildings with 20 stories have been modeled using software packages ETABS and SAP 2000 v.15 for seismic zone V in India. Time history analysis is an elegant tool to visualize the performance level of building and static analysis is not sufficient for high rise building. The result of equivalent static analysis are uneconomical because values of displacement are higher than dynamic analysis.

Bhagwat et al. (2014), studied dynamic analysis of G+12 multistoried practiced RCC building considering for Koyna and Bhuj earthquake is carried out. The value of base shear for Bhuj earthquake is 49.11% more than the Koyna earthquake and Response Spectrum method gives 50% more result than Time History Analysis.

Harshita et al. (2014), studied the dynamic behavior of multistoried symmetrical building frame using IS1893-2002 code recommended response spectrum method and time history method. Result shows that the base shear obtained from time history analysis is slightly higher compared to response spectrum analysis, this may be due to variation in amplitude and frequency content of the ground motion.

Arvind and Fernandes (2015), worked on reinforced regular and reinforced irregular structures in zone IV and zone V. The results found out from the analysis included lesser storey displacement values in static analysis method as compared to dynamic analysis method.

Dubey et al. (2015), a multi-story irregular buildings with 20 stories have been modeled using software STAAD PRO for seismic zone IV in India. It is concluded that storey drift in time history analysis is 2 to 8% higher than RSA. The base shear value obtained in case of RSA are more as compared to Time history analysis as its depends on the frequency content of the earthquake data. Time history method is better and more economical for designing.

Kulkarni and Tatikonda (2016), in this paper El Centro earthquake occurred in 1940, data is used. It is observed that the time period Vs displacement graphs obtained were similar to that of Time Vs acceleration graph obtained from earthquake data. As the time period increases displacement of each floor also increases.

Mindaye (2016), studied the seismic response of residential G+10 RC frame building is analyzed by the linear analysis approaches. Concludes that dynamic story shear is less than story shear for all cases. Equivalent static lateral force method gives higher value of force and moments which make building uneconomical hence consideration of response spectrum method is also needed.

III. OBSERVATIONS

- Torsional coupling induces a significant amplification of earthquake forces.
- Eccentricity between center of mass and center of rigidity cause torsion in structures and a magnitude of torsional moment.
- To improve the performance of earthquake resistant structure the ductility of the structure should be increased appropriately.
- As the amount of setback increases the shear force also increases.
- The middle stories of high rise structures are more vulnerable to earthquake forces than lower and top stories as the responses are higher.
- Structures with heavy mass at top suffers maximum displacement.
- As the Plan Irregularity Increases both Storey Displacement and Storey drift increases.
- When a structure is stiff enough it is able to withstand seismic force.
- Structures with re-entrant corners showed worst behaviour during earthquake.
- Time history analysis is more precise and best suited for seismic analysis and design.

IV. CONCLUSION

- The behaviour of building during the earthquake is depend upon many conditions like stiffness, strength, ductility and most probably on configuration of structure.
- Irregularities in buildings causes eccentricity between the building mass and stiffness centers, give rise to damaging effect on building.
- Structures with plan irregularities quite often suffer severe damage in earthquake events.
- Plan asymmetric building structures subjected to lateral input ground motions are affected by torsional coupling
- To overcome this, structures should be designed considering the seismic loads and improve the seismic behavior of the building.
- Response spectrum analysis is the generally used method for analysis and design of earthquake resistance structures.

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