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COMPARATIVE ANALYSIS OF VERTICALLY IRREGULAR STRUCTURES IN DIFFERENT SEISMIC ZONES”- A LITERATURE REVIEW

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ABSTRACT

Past earthquakes in India have revealed that majority of the buildings are not designed to be earthquake resistant. Generally, buildings are designed taking into account only the gravity loads. Also, the current design seismic codes are not fully practiced while designing a building. Hence, a higher degree of damage may be expected during an earthquake if the seismic resistance of the building is inadequate. This work is concerned with the effects of various vertical irregularities on the seismic response of a structure. Study of the comparison of the results of analysis of irregular structures with regular structure was done. The scope of the project also includes the evaluation of response of structures subjected to high, low and intermediate frequency content earthquakes using response spectrum analysis. Different types of irregularities namely mass irregularity, stiffness irregularity and vertical geometry irregularity were considered. Tall structures were found to have low natural frequency hence their response was found to be maximum in a low frequency earthquake. It is because low natural frequency of tall structures subjected to low frequency earthquake leads to resonance resulting in larger displacements. If a high rise structure (low natural frequency) is subjected to high frequency ground motion then it results in small displacements. Similarly, if a low rise structure (high natural frequency) is subjected to high frequency ground motion it results in larger displacements whereas small displacements occur when the high rise structure is subjected to low frequency ground motion. The complex shaped buildings are now days 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.

***Keywords**: Mass Irregularity, Stiffness Irregularity, Geometric Irregularity, Sesimic analysis, Base Shear, Drift, Displacement, ETABS 2018.*

INTRODUCTION

In India, about 50-60% of the total area is vulnerable to the seismic activity. Past earthquakes occurrences demonstrate that, buildings with irregularity are prone to earthquake damages. In order it is essential to identify the seismic response of the structure even in low seismic zones to reduce the seismic damages in buildings. Irregularities in plan and lack of symmetry may imply significant eccentricity between the building mass and stiffness centres, giving rise to damaging coupled lateral/torsional response. Irregular structures need a more careful structural analysis to reach a suitable behaviour during a devastating earthquake. The irregularity of the structure may can classify in two types i.e. plan and vertical, these can be characterized to five different types such as torsional, re-entrant corners, diaphragms discontinuity, out of plane offset and non parallel system for plan irregularity as well as vertical irregularity such as stiffness (soft storey), mass, vertical geometric, in plane discontinuity in vertical elements resisting lateral force and discontinuity in capacity (weak storey) (IS 1893(Part I): 2016). The probable reasons for the need of proper analysis of a building may be as follows:

1. Buildings have not been designed and detailed to resist seismic forces.

2. Buildings may have designed for seismic forces, before the publication of current design seismic codes.

3. The lateral strength of the building does not satisfy the seismic forces as per the revised seismic zones or designed base shear.

4. Construction is apparently of poor quality.

5. There have been additions of change of use of building with increased vulnerability.

If all the building elements are arranged with uniformity and the earthquake striking in the familiar direction is optimal. Due to lack of availability of land in big cities, architects usually go for the irregular building structures to make the effective use of available area and to impart provision of proper light and ventilation in the structures. However, the structural irregularity is a combined state of two types that is horizontal and vertical. The horizontal irregularity may be classified on the bases of Asymmetrical plan shapes, Re-Entrant corners, Diaphragm discontinuity and irregular distribution of mass, strength, stiffness along plan etc., and the vertical irregularity may be classified on the bases of Mass, Strength, Stiffness and Setback. Adequate to most of such asymmetries, the structure's lateral resistance of earthquake is generally torsionally uneven & thus creating great amount displacement, drift and high force concentrations within the resisting elements which can cause severe damages and may lead to collapse of the structure

Vertical Irregularity: Vertical irregularity results from the uneven distribution of mass, strength or stiffness along the elevation of a building structure. Mass irregularity results from a sudden change in mass between adjacent floors, such as mechanical plant on the roof of a structure. Stiffness irregularity results from a sudden change in stiffness between adjacent floors, such as setbacks in the elevation of a building.

Plan Irregularity: Plan irregular structures are those in which seismic response is not only translational but also torsional, and is a result of stiffness and/or mass eccentricity in the structure. A regular structure may actually be asymmetric if the structure has masonry infill walls or stiffer lateral resisting systems on one side of the structure that has not been taken into consideration in the analysis. Asymmetry may in fact exist in a nominally symmetric structure because of uncertainty in the evaluation of centre of mass and stiffness, inaccuracy in the measurement of the dimensions of structural elements.

In the past several major earthquakes have expose the shortcomings in buildings which had caused them to damage or collapse. It has been found that regular shape buildings perform better during earthquakes. The structural irregularities cause non- uniform load distribution in various members of a building. There must a continuous path for these inertial forces to be carried from ground to the building. A gap in this transmission path results in failure of the structure at that location. The vertical irregularities are considered and described as follows.

STIFFNESS IRREGULARITY

SOFT STOREY; A soft story is one in which the lateral stiffness is less than 70 % of that in the storey above or less than 80% of the average lateral stiffness of three storeys above.

EXTREME SOFT STORY: An extreme soft storey is one in which the lateral stiffness is less than 60% of that in the storey above or less than 70% of the average stiffness of the thee storeys above.

MASS IRREGULARITY

Mass irregularity is considered to exist where the effective mass of any storey is more than 150% of the effective mass of an adjacent storey. The effective mass is the real mass consisting of the dead weight of the floor plus the actual weight of partition and equipment. Excess mass can lead to increase in lateral inertial forces, reduced ductility of vertical load resisting elements, and increased tendency towards collapse. Irregularities of mass distribution in vertical and horizontal planes can result in irregular response and complex dynamics. The central force of gravity is shifted above the basic in the case of heavy masses in upper floors resulting in the large bending moments.

VERTICAL GEOMETRIC IRREGULARITY

Geometric irregularity exists when the horizontal dimension of the lateral force existing system in any storey is more than 150% of that in an adjacent storey. The setback can also be visualized as a vertical re-entrant corner. The general solution of a setback problem is the total seismic separation in plan through separation section, so that the portion of building is free to vibrate independently.

The purpose of this hypothetical study is to evaluate the seismic properties and characteristics for regular & vertical geometry 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.

OBJECTIVES OF THE STUDY

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. In metro cities like Pune, Mumbai or developing cities like Kolhapur and Sangli there is scarcity of land for separate parking area. To overcome this situation buildings are being designed with various parking floors in the same building as well as in luxurious buildings there are facilities like swimming pool and gym etc. are provided. Due to this modern provisions the Earthquake parameters of the structure changes. This type of structure is called as Vertical Irregular structure.

We have done literature survey on vertical irregular structures by various engineers and we found that most of cases are from EQ zone IV and V .So in this project we are going to design vertical irregular structure in all EQ zones as per IS 1893 by ETABS 2018 for better and accurate results than manual. So the objectives of the study are,

1. To calculate the Base Shear by the use of ETABS 2018

2. To study vertical irregularities in structures namely mass, stiffness irregularities.

3. To carry out ductility based earthquake resistant design as per IS 13920.

4. Dynamic analysis of the building using response spectrum method.

5. To analyse the building as per code IS 1893-2002 part I criteria for earthquake resistant structure.

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.

Irregularities of mass, stiffness, strength and geometry along building height may be termed as vertical irregularity. These irregularities may be present singly or in combination. Different types of vertical irregularities have different effects on seismic response. The effect of these irregularities should be considered and incorporated in current seismic design codes.

The research works concerned with vertical irregularities started in early 1970s with **Chopra and Kan (1973)** who studied the seismic response of series of eight storey shear buildings subjected to the earthquake motion data. The main objective was to determine the effect of yielding of first storey on upper storeys. From the results of analytical study it was found that an ideal plastic mechanism and a low yield force are required in the first storey for safety of higher floors of the structure. The irregularities of mass, stiffness and strength were represented by parameters of mass ratio (Mr), stiffness ratio (Sr), strength ratio (STr) which may be defined as the ratio of mass, stiffness and strength of storey under consideration to that of the adjacent storey.

Humar and Wright (1977) studied the seismic response of multistorey steel building frames with and without setback irregularity using one ground motion data. Based on analytical study it was concluded that, in case of building frames with setbacks, the storey drift was found to be greater at upper portion of setback and smaller in the base portion. Also, the drift of building frames with setbacks was found to be less as compared to their regular counterparts.

This approach was extended by **Aranda (1984)** who determined the seismic response of structure with and without setback irregularity founded on soft soil. From the results of analytical studies it was confirmed that the ductility demand and its increase in upper portion of setback was higher as compared to the base portion and structures with setbacks experienced higher ductility demand as compared to their regular counterparts.

Fernandez (1983) determined the elastic and inelastic seismic response of multistorey building frames with irregular distribution of mass and stiffness. Reduction in storey stiffness resulted in increased storey drift and structures with constant variation of mass and stiffness in vertical direction showed better seismic performance as compared to the structures with abrupt variations.

Moelhe (1984) determined the seismic response of R.C structures with irregularities. For analytical study, nine storey building frames with 3 bays with structural walls were modeled. The irregularity in building models was created by discontinuation of structural walls at different storey heights. Based on the analytical results it was found that the seismic response not only depended on extent of structural irregularities but also on the location of irregularities.

Experimental studies are necessary to verify the accuracy of analytical results and researchers like **Moehle and Alarcon (1986)** performed experimental tests on two small prototype R.C. building frames subjected to the ground motion data. The tests were performed using shake table. The two small scale R.C. building models used for the study were named as „FFW" and „FSW". The „FFW" model had two frames of nine storey having 3 bays each and the third frame was also of 9 storey but had prismatic wall, this model represented the building systems without any irregularity. The vertical irregularities were introduced in the building models by discontinuation of shear wall at first storey and this building model was designated as „FSW" Rest of the features in both „FFW" and „FSW" were same. The displacements of top floor were computed for all these building models using elastic and inelastic dynamic analysis. From the analytical study it was concluded that in case of „FSW" ductility demand increased abruptly at the vicinity of discontinuity of shear wall and this increase was found to be 4 to 5 times higher as compared to the „FFW" models. Further the inelastic dynamic analysis was found to be more efficient as compared to the elastic analysis in determining the effect of structural discontinuities.

Barialoa and Brokken (1991) determined the effect of strength and stiffness variation on nonlinear seismic response of multistorey building frames. For analytical study 8 storey buildings with 5 bays were modeled. The building frames were subjected to three different category of time periods namely low, medium and high. Each building category was further subdivided into two more categories based on base shear namely weak and strong. In the weak building the base shear was 15 % of total seismic weight whereas in strong building the base shear was 30 % of total weight of the structure. The results of analytical study showed that the time period of structure increased during seismic excitation and this increase was more pronounced in case of weaker structures.

Ruiz and Diederich (1989) conducted analytical studies on five and twelve storey building models with strength irregularity. The strength irregularity in the building model was created by modeling first storey of the structure as the weak storey in the first case. In the second case the infill walls in top storey were modeled as brittle and in the third case the infill walls were modeled as ductile. From results of analytical study it was found that the yielding, failure and formation of plastic hinges in infill walls was greatly influenced by time period of seismic excitation.

Shahrooz and Moehle (1990) determined the seismic response of building systems with vertical setbacks. The authors conducted both experimental and analytical tests to improve previous design methodologies for design of setback buildings. For performing the experimental study a six storey RC frame having setback at mid-height was prepared. From results of experimental study it was found that there was no abrupt variation in the displacement along the building height. The interstorey drifts were found to be largest with increased damage and abrupt reduction in lateral force at location of setbacks. The variation of lateral displacement and force along building height suggested that the translational seismic response of the building parallel to direction of setback was influenced by fundamental mode of vibration. For performing analytical study six storey building frames with six different patterns of setbacks were modeled and designed in accordance with UBC code of practice. For all of these frames the floor plan dimensions and mass ratios were varied from 3 to 9 times as suggested by UBC 1988 code of practice which differentiated symmetric and setback structures on the basis of plan dimensions and mass ratios. The analyses of these frames were carried out by modal analysis procedure as prescribed by UBC 1988 code of practice. From results of analytical study it was concluded that all these frames experienced similar magnitude and distribution of ductility demand. The frames with similar mass ratios and floor plan dimensions but with different setback heights experienced different amount of damage which contradicted the approach of UBC 1988 code.

Nassar and Krawinkler (1991) conducted parametric study on multistorey (3, 5,10,20,30, 40 storey) SDOF and MDOF systems (with strength irregularity) with different periods of seismic excitation ranging from 0.217s – 2.051s. The models used are described in Table 1.9. In case of SDOF models the strength demand was represented in terms of strength reduction factor which represents the reduction in strength of structural elements. In case of MDOF systems it was found that strength demand and displacement demand depend on failure mechanisms developed and the presence of weak first storey increased the ductility demand and overturning moments.

Esteva (1992) evaluated the seismic response of building frames with soft first storey by using non-linear analysis. For simplification of analytical study the shear beam model was used to represent the building systems. The first main purpose of analytical study was to observe the bilinear hysteric behavior of the building systems with and without consideration of P-Delta effects. The second main purpose of the analytical study was to determine the effect of influence ratio r (which was defined as the ratio of average value of lateral shear safety factor for upper storeys to the bottom storeys) on ductility demand.

Wood (1992) observed that presence of setbacks did not affect the dynamic seismic response which was more or less similar for symmetrical structures.

Wong and Tso (1994) used elastic response spectrum analysis to determine seismic response of structures with setback irregularity and it was observed that buildings with setback irregularity had higher modal masses causing different seismic load distribution as compared to the static code procedure.

Duan and Chandler (1995) conducted analytical studies on building systems with setback irregularity using both static and modal spectral analysis and based on the results of analytical studies, it was concluded that both static and modal analysis procedures were inefficient in predicting the concentration of damage in structural members near level of setbacks.

Valmudsson and Nau (1997) evaluated seismic response of multistorey buildings with vertical irregularities. For analytical study two dimensional shear beam building models with five, ten and twenty storeys were prepared. The structural irregularities were introduced in the building models by varying the mass, stiffness and strength. From analytical studies it was found that introduction of mass and stiffness irregularity resulted in minor variation in the seismic response. The storey drifts were increased in range of 20% - 40 % for 30 % decrease in the stiffness of the first storey, with constant strength. The strength reduction of 20 % doubled the ductility demand.

Al-Ali and Krawinkler (1998) evaluated the effect of mass, stiffness and strength and their combinations on seismic response of a 10 storey structure. Elastic and inelastic dynamic analyses were used for the analytical study. Based on the results of analytical study it was observed that, when irregularities were considered separately; the strength irregularity had the maximum impact on roof displacement and mass irregularity had the minimum impact on the roof displacement. When combination of irregularities was considered, the combination of stiffness and strength irregularity had the maximum impact on roof displacement.

Kappos and Scott (1998) made comparison between static and dynamic methods of analysis for evaluating the seismic response of R.C frames with setback irregularity. On comparison between results of both methods it was concluded that dynamic analysis yielded results different from that of static analysis. In the analytical study, other forms of irregularities like mass, stiffness and strength irregularity were not included.

Magliulo et al. (2002) conducted parametric studies on multistorey RC frames (5, 9 storey) with mass, stiffness and strength irregularity designed for “low ductility class” as per EC 8 provisions. The authors evaluated the seismic response of the irregular frames and compared it with the seismic response of building frames without any irregularity. From the analytical study it was found that mass irregularity does not affect plastic demands. In case of strength irregularity, irregular distribution of strength in beams increased the seismic demand. However, seismic demands were not affected due to irregular strength distribution in columns. Finally the authors concluded that the parameter of storey strength (define) as prescribed by EC8 and IBC codes was ineffective in predicting strength irregularity.

Chintanpakdee and Chopra (2004) evaluated the effects of strength, stiffness and combination of strength and stiffness irregularity on seismic response of multistorey frames. For analytical study, different 12 storey frames were modeled based on strong column – weak beam theory. The irregularity in strength and stiffness were introduced at different locations along height of the building models. The building models were analyzed using time history analysis by subjecting the building model to 20 different ground motion data. From analytical study it was concluded that irregularities in strength and stiffness when present in combination had the maximum effect on the seismic response. Further maximum variation in the displacement response along height was observed when irregularities were present on the lower storeys.

Tremblay and Poncet (2005) evaluated the seismic response of building frames with vertical mass irregularity designed according to NBCC provisions by static and dynamic analysis. Based on the analytical study it was concluded that both static and dynamic method of analysis (as prescribed by NBCC provisions) resulted in similar values of storey drifts and hence they were ineffective in predicting the effects of mass irregularity.

Fragiadakis et al. (2005) determined the seismic response of building systems with irregular distribution of strength and stiffness in vertical direction. After conducting the analytical study it was concluded that seismic performance of the structure depended on type and location of irregularity and on intensity of seismic excitation. Modal pushover analysis (MPA) procedure is an important analytical tool to evaluate the seismic performance and several researchers like Lignos and Gantes (2005) investigated the effectiveness of Modal pushover analysis procedure (MPA) in determination of the seismic response pf multistorey steel braced frame (4, 9 storey) with stiffness irregularities. Based on the results of analytical study it was concluded that MPA procedure was incapable of predicting failure mechanism and collapse of the structure.

Khoury et al. (2005) designed a 9 storey steel framed structure with setback irregularity as per Israeli steel code SI 1225(1998). The height and locations of setback were varied for the analytical study. Results of analytical studies confirmed that higher torsional response was obtained in tower portion of setbacks.

Ayidin (2007) evaluated the seismic response of buildings with mass irregularity by ELF procedure (as prescribed by Turkish code of practice) and by time history analysis. The researcher had modeled multistorey structures ranging from 5 to 20 storey height. The mass irregularity was created by variation in mass of one storey with constant mass at other storeys. Based on the analytical study author concluded that the mass irregularity affects the shear in the storey below and ELF procedure overestimates the seismic response of the building systems as compared to the time history analysis. Some researchers preferred dynamic analysis over MPA procedure to evaluate seismic response due to its accuracy.

Fragiadakis et al. (2006) proposed an IDA (Incremental dynamic analysis) procedure for estimating seismic response of multistorey frame (9 storeys) with stiffness and strength irregularity contrary to Lignos and Gantes (2005), Alba et al. (2005) who used MPA procedure to evaluate the seismic response of building frames with stiffness irregularity Based on the analytical results the authors concluded that the proposed method was effective in predicting effects of irregularity in building frames. Finally, the authors concluded that the effect of irregularity is influenced by location and type of irregularity and building systems subjected to unidirectional seismic excitation underestimate the seismic demand significantly.

Basu and Gopalakrishnan (2007) developed a simplified method of analysis for determination of seismic response of structures with setbacks and torsional irregularity. The assessment by the proposed method was made by applying it on four building models. In case of building models with scattered positions of CM the proposed method evaluates seismic response considering average value of position of CM whereas perturbation analysis considered the exact location of CM at different floor levels to evaluate the seismic response. Results of analytical study showed that for building systems with vertically aligned CM. The frequencies obtained by proposed procedure and perturbation analysis were observed to be in close agreement. However, the results of frame shear forces differed by 7%. In case of second example, the modal response obtained by proposed method and perturbation analysis was similar, but difference in frame shear force was found to be 4% for upper storeys and 1% for base storeys. In case of third building model, the frequencies obtained by proposed procedure and perturbation analysis were in close agreement, but difference of results in case of frame shear forces as 10 % at ground storey level and 4% at first storey level. In case of fourth example the difference of results in estimation of frame shear forces as high as 50%, Thus, it was concluded that the proposed position is not applicable to the building models where the prescribed limit of scattering of CM was exceeded.

Karavasilis et.al. (2008) performed extensive parametric study on steel frames with different types of setback irregularity designed as per European seismic and structural codes (EC 8 :2004). From analysis, the databank of output parameters corresponding to number of storeys, beam to column strength ratio, geometrical irregularity etc. was created. Based on the deformation demands four performance levels were identified and these were (a) occurrence of first plastic hinge, (b) Maximum inter-storey drift ratio (IDRmax) equal to 1.8 % ; (c) IDRmax equal to 3.2%, (d) IDRmax equal to 4.0%. The results for different types of setback structure were expressed in terms of these performance levels. From analytical study it was concluded that interstorey drift ratio (IDR) increased with increase in storey height and tower portion of setback experienced maximum deformation as compared to the base portion. Athanassiadou (2008) made the assessment of seismic capacity of the RC structures irregular in elevation. The author modeled three multistorey frames. Out of these three frames ,two ten storey plane frames were modeled with two and four large setbacks in their upper floors and the third frame was regular in elevation. These three frames were subjected to 30 different ground motions and designed as DCH and DCM frames (designed for high ductility and medium ductility) as per Euro code 8. Then non linear dynamic analysis of the frames was carried out by subjecting the frame to the ground motion data of the earthquake and parameters of rotation, base shear and interstorey drift were evaluated. Based on the analytical study it was found that the performance of both DCM and DCH frames was found to be satisfactory as per guidelines of EC 8.

Karavasilis et al. (2008) evaluated the seismic response of family of 135 plane steel moment resisting frames with vertical mass irregularities and created databank of analytical results. The authors used regression analysis technique to derive simple formulae to evaluate seismic response parameters using the analysis databank. Results of analytical studies suggested that the mass ratio had no influence on deformation demand. The results obtained from proposed formulae were found to be comparable with results of dynamic analysis.

Sadasiva et al. (2008) evaluated the effect of location of vertical mass irregularity on seismic response of the structure. A 9 storey regular and irregular (with vertical irregularity) frame was analyzed and designed as per New Zealand code of practice in two ways. Firstly, it was designed to have maximum interstorey drift at all levels (represented as CDCSIR). Secondly, it was designed to have a constant stiffness (represented by CS) at all levels. To make clear distinction between regular and irregular structure, a special notation form was used by the authors of form NS-M-L-(A), where Nno.of storeys, S-Shear beam, M- Type of model [i.e. S(Shear beam) or SFB (Shear Flexure beam), (A) – Mass ratio].The deformation was represented in the form of graphs. For the study Los Angeles earthquake records had been used and inelastic time history analysis of the structure was performed using Ruamoko software. Based on this analysis it was concluded that in case of both CS and CISDR model the interstorey drift produced is maximum when mass irregularity is present at topmost storey and irregularity increases the interstorey drift of the structure. However, this magnitude varied for both CS and CISDR type of models.

Ambrisi et al. (2009) proposed a modified pushover analysis method for determining the seismic response of building structures, and found the comparable results by both pushover and inelastic dynamic analysis for setback frames.

Dinh Van Thuat (2011) determined the storey strength demands of irregular buildings under strong earthquakes. The strength irregularity in the building models was introduced in terms of storey strength factor which represents the relative reserve strength of the storey against failure. A large number of analysis of building models ranging from 7 storeys to 19 storeys were conducted. The analysis results indicate the variation in seismic demands due to introduction of irregularity.

Kappos and Stefanidou (2010) proposed a new deformation design method based on inelastic analysis for the setback frames. From analysis results, adequate seismic performance of the setback frames designed as per the proposed method was observed.

Kim and Hong (2011) determined the collapse resisting capacity of the building models with stiffness and strength irregularity. The irregularity in the building models was created by removal of column in the intermediate storey. However, analysis results suggested minor variation in the collapse potentials of regular and irregular structures.

Lu et al. (2012) performed non-linear time history analysis of the tall setback building and found excessive damage concentration in storeys adjacent to setbacks.

Rajeeva and Tesfamariam (2012) Fragility based seismic vulnerability of structures with consideration of soft - storey (SS) and quality of construction (CQ) was demonstrated on three, five, and nine storey RC building frames designed prior to 1970s. Probabilistic seismic demand model (PSDM) for those gravity load designed structures was developed, using non-linear finite element analysis, considering the interactions between SS and CQ. The response surface method is used to develop a predictive equation for PSDM parameters as a function of SS and CQ. Result of the analysis shows the sensitivity of the model parameter to the interaction of SS and CQ.

Sarkar et al. (2010) proposed a new method of quantifying irregularity in vertically irregular building frames, accounting for dynamic characteristics (mass and stiffness). The salient conclusions were as follows: (1)A measure of vertical irregularity, suitable for stepped buildings, called _regularity index‘, is proposed, accounting for the changes in mass and stiffness along the height of the building. (2) An empirical formula is proposed to calculate the fundamental time period of stepped building, as a function of regularity index.

Athanassiadou (2008) concluded that the effect of the ductility class on the cost of buildings is negligible, while performance of all irregular frames subjected to earthquake appears to be equally satisfactory, not inferior to that of the regular ones, even for twice the design earthquake forces. 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 were found to dispose higher over strength than DCM ones. Pushover analysis seemed to underestimate the response quantities in the upper floors of the irregular frames.

Lee and Ko (2007) subjected three 1:12 scale 17-story RC wall building models having different types of irregularity at the bottom two stories to the same series of simulated earthquake excitations to observe their seismic response characteristics. The first model had a symmetrical moment-resisting frame (Model 1), the second had an infilled shear wall in the central frame (Model 2), and the third had an infilled shear wall in only one of the exterior frames (Model 3) at the bottom two stories. The total amounts of energy absorption by damage are similar regardless of the existence and location of the infilled shear wall. The largest energy absorption was due to overturning, followed by the shear deformation.

Devesh et al. (2006) agreed on the increase in drift demand in the tower portion of set-back structures and on the increase in seismic demand for buildings with discontinuous distributions in mass, strength and stiffness. The largest seismic demand was found for the combined stiffness and strength irregularity. It was found out that seismic behavior is influenced by the type of model.

Kim and Elnashai (2009) observed that buildings that are seismically designed to contemporary codes would have survived the earthquake. But, the vertical motion would have significantly reduced the shear capacity in vertical members.

Duan et al. (2012)- According to the numerical results, the structures designed by GB50011- 2010 provides the inelastic behavior and response intended by the code and satisfies the inter storey drift and maximum plastic rotation limits recommended by ASCE/SEI 41-06. The pushover analysis indicated the potential for a soft first story mechanism under significant lateral demands.

Poonam et al. (2012)- Results of the numerical analysis showed that any storey, especially the first storey, must not be softer/weaker than the storeys above or below. Irregularity in mass distribution also contributes to the increased response of the buildings. The irregularities, if required to be provided, need to be provided by appropriate and extensive analysis and design processes.

Sagar et al. (2015) analyzed 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.

Shvin g. Soni et al. (2015) carried out the performance evaluation of RC (Reinforced Concrete) buildings with irregularity. Structural irregularities are important factors which decrease the seismic performance of the structures. The study as a whole makes an effort to evaluate the effect of vertical irregularity on RC buildings, in terms of dynamic characteristics and the influencing parameters which can regulate the effect on Story Displacement, Drifts of adjacent stories, Excessive Torsion, Base Shear, etc and conclude that that irregularities in buildings are harmful for the structures and it is important to have simpler and regular shapes of frames as well as uniform load distribution of load around the building.

Khan & Dhamge (2016) highlighted the effect of mass irregularity on different floor in RCC buildings with as Response Spectrum analysis using STAAD-Pro V8i software. In the project work seismic analysis of RCC buildings with mass irregularity at different floor level were carried out. Models are compared with each other for response in terms of drift and deflection.

Salunkhe and Kanase (2017) 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.

Sayyed (2017) 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.

Himanshu Bansal & Gagandeep (2018) carried out their study on the seismic analysis and design of vertically irregular RC building frames. In this study, they considered different types of vertical irregularities like Stiffness, mass and geometric. G+10 storeys have been analyzed using Staad Pro for the seismic zone IV. The results in the form of base shear, drift and displacement have been compared and concluded.

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 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.
- The aim of this research is to show the performance & behaviour of rcc framed regular & vertical geometric irregular structures under seismic motion.
- 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.
- To study the change in different seismic response parameters along the increasing height and increasing bays.
- To obtain the storey drifts & displacements at each one of the storey's using equivalent static analysis & response spectrum analysis.
- This is not sufficient to study the nonlinear behavior 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.
- To know the complete behavior of the structure with irregularity from linear stage to the collapse stage, nonlinear dynamic analysis study is done.
- 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 behavior.
- 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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