A Study On Non-Linear Behaviour For Static Analysis of RC Framed Structures With Set Backs

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Abstract -Analysis of the structure shall be conducted to determine the distribution of forces and deformations induced in the structure by the design ground shaking and other seismic hazards corresponding with rehabilitation objectives. The analysis shall address the seismic demands and the capacity to resist these demands for all the elements in the structure that either are essential to the lateral stability of the structure (primary element) or to the vertical load carrying integrity of the building. Major structural collapses occur when the building is under the action of dynamic loads which includes earthquake loads. In these modern days most of the structures are involved with architectural importance and hence many structures in the present scenario have irregular configurations both in plan and elevation. This in future may subject to devastating earthquakes. Hence, it is necessary to identify the performance of the structures to withstand against disaster for both new and existing one. This study aims at evaluating and comparing the response of G+10, G+15, G+20 systems with vertical irregularities as described by the ATC-40 and the FEMA-273 using nonlinear static procedures, with described acceptance criteria. The methodologies are applied to G+10, G+15, G+20 systems with vertical irregularity with bracings and with masonry struts. The non linear response of structure with vertical irregularity has been done using SAP2000 16 with intent to evaluate importance of several factors in the non linear static analysis which includes time period, displacement, base shear etc. Performance may relate the strength level achieved in certain members to the lateral displacement at the top of the structure, or bending moment may be plotted against plastic rotation. Results provide insight into the ductile capacity of the structural system, and indicate the mechanism, load level, and deflection at which failure occurs.

Keywords: Time history analysis, Pushover analysis, Base shear, Inter-Storey drifts, Drifts ratio %

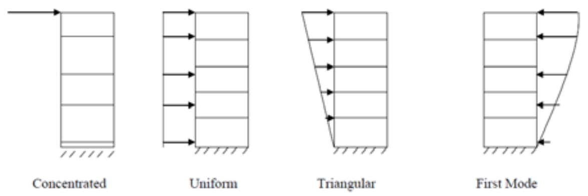
I. INTRODUCTION

The behaviour of multi- storied framed structure basically depends on the shape and size of the structure which may vary in mass, stiffness and strength in both horizontal and vertical directions. The most general type of vertical geometrical irregularity is due to the provision of setbacks which can be sudden change in the lateral dimension of the structure along the height at certain levels. These types of structures can be classified as setback structures or structures 2 with vertical geometrical irregularities. Height wise change in the mass and stiffness alters the dynamic characteristics of the structure and it has been observed that higher mode participation and inter storey drifts in upper floors are quite significant. The performance based analysis ability to predict the performance of structure to acceptable level makes it one of the more followed methods. Performance-based design differs from repressive design in that designers can use alternative solutions as long as they reach the stated goal of the performance-based code. The goal of a performance-based code is usually very broad and usually differs from prescriptive codes which give out exact steps that have to be followed to reach the objective. Recent advances in the performance based design have brought the non linear static analysis in the forefront. Static Pushover analysis is an attempt by the structural engineering profession to evaluate the real strength of the structure and it promises to be a useful and effective tool for performance based design. Non linear static analysis has become widely used performance based design tool for seismic evaluation of existing and new structures. It is assumed that non linear static analysis will provide adequate information on seismic demands induced by the design ground motion on the structural system and its components. The aim of the non linear static analysis is to estimate the expected performance of a structural system by evaluating its strength and deformation demands under the action seismic loads by developing a plot between spectral displacement and spectral acceleration which obtained by using the conversion of ADRS format. These are compared to available capacities at the targeted performance levels.

II. System ANALYSIS

Single mode load vectors: Figure 3.5 shows the distribution of different types of loads on to structure as shown below i. Concentrated Load: The Simplest assumption for the load vector is a single concentrated load normally at the top of the structure. ii. Uniform: A uniform load vector assumes that the acceleration is the MDOF

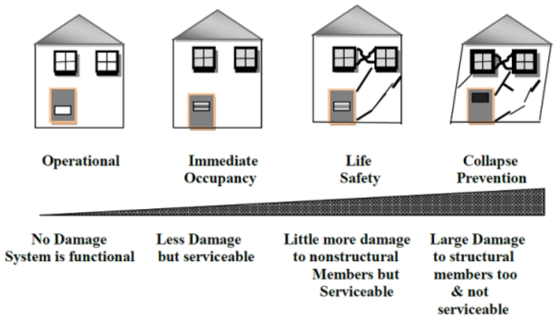
model is constant over its height. This alternative is sometimes termed as rectangular. iii. Triangular: A triangular shaped vector assumes that the acceleration increases linearly from zero at the base to a minimum at the top of the MDOF model. iv. First Mode: The first mode technique applies accelerates proportional to the shape of the first mode of the elastic MDOF
model



Types Of Load Vectors

Limited Safety Performance Range (S-4)

Structural Performance Range S-4, Limited Safety, means the continuous range of damage states between the Life Safety and Collapse Prevention levels. Design parameters for this range may be obtained by interpolating between the values provided for the Life Safety (S-3) and Collapse Prevention (S-5) levels. The following figure 4.3 displays various Structural performance levels after the earthquake.



Performance point

As explained that the performance is obtained by overlapping of demand spectrum and capacity spectrum into one graph. The intersection point of these curves is called as the performance of the structure which is said to be the initial trial point of the performance and it is checked for the acceptability criteria, if it is acceptable it is called as performance point or else another trial point is selected and is continued till the performance point in the acceptability range is obtained.

There are three procedures described in ATC-40 to find the performance point.

Procedure A: This uses a set of equations described in ATC-40.

Procedure B: It is also an iterative method to find the performance point, which uses the assumption that the yield point and the post yield slope of the bilinear representation, remains constant. This is adequate for most cases; however, in some cases this assumption may not be valid.

Procedure C: This graphical method that is convenient for hand as well as software analysis. SAP2000 uses this method for the determination of performance point.

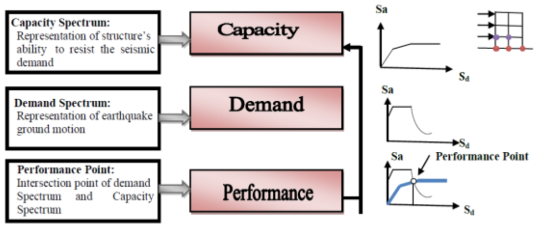


Fig. 2.1 Name of Figure(9pt, Normal)

III. LITERATURE REVIEW

- Based on Vertical Irregularities

Ramesh et al (2014)

In this study they have considered buildings with vertical irregularities and analyzes it under earthquake and wind load basically called as linear static analysis using STAAD as platform for computer based analysis. The buildings under consideration were one regular building and other with vertical geometrical irregularity with first ten floors as 6X6 bay and later ten floors as 2X2 bay at different location (center, corner and left edge of the building). The roof displacement at all corners of the regular frame is same and even no torsional effect has been observed due to symmetry. In case of irregular vertical building the responses are less at bottom floors and more at top floors than in regular building. For a vertical irregular building frame, where corners bays at top floor, the response in positive direction of the corner column is more than in negative direction. Hence the torsion effect is more in positive direction than in negative direction. In vertical irregular building there is a sudden increase in drift from tenth floor to eleventh floor. But maximum drift is observed between eleventh and twelfth floor.

Madhsudhan et al (2014)

Pushover analysis has been used as a method of analysis in this paper for vertically irregular building. Six models of 4-Bay, 4-Storey2D RC frame have been considered and one model is treated as regular building and the frames were designed according to Indian standard located in zone III for analysis and design for the study. Pushover analysis was carried out considering displacement controlled analysis. It was found that structure became venerable with increase in vertical irregularity. The percentage of plastic hinges crossing elastic limit increase, rendering the structure more venerable. Most of the structures were found to lie in elastic state to life safety level.

- Based on Masonry Infill Wall

Saraswathy et al (2014)

A twelve storey RC framed building with masonry infill wall is considered in the present study. The building has overall dimension of 24m × 12m, with 8 bays in the larger direction and 3 bays in the smaller direction. Fig. 3 shows the 3D view of building models with and without setbacks, generated using SAP 2000-12. Set back ratios were maintained as 0.27 and 0.40. Fundamental time period of setback buildings are found to be always less than that of similar regular buildings and it is found to depend on the setback ratio and storey level at which irregularity is introduced. The top storey drift increases with setback ratio; maximum storey drift is found for the building with greatest setback ratio, near to the storey where irregularity is introduced. It was found that the performance point changes due to the presence of irregularity. The base shear is found to decrease with increase in setback ratio. Roof top displacement depends on setback ratio of the buildings but it is found to be independent of the storey level where irregularity is introduced.

Anwaruddin et al (2013)

The performance of a structural system can be evaluated resorting to non-linear static analysis. This involves the estimation of the structural strength and deformation demands and the comparison with the available capacities at desired performance levels. The study aimed at evaluating and comparing the response of five reinforced concrete building systems by the use of different methodologies namely the ones described by the ATC-40, using nonlinear static procedures, with described acceptance criteria. The methodology is applied to a 3 storey frames system with and without vertical irregularity, designed as per the IS 456-2000 and in the context of Performance Based Seismic Design procedures. Bare frame without vertical irregularity as more lateral load capacity. However, the lateral displacement of the building is reduced as the vertical irregularity is increased. There is not much variation in the story shear values which is between 2% to 5%.

Ravikumar et al (2012)

This work is focused on the study of Seismic demands of different irregular R.C buildings using various analytical techniques for the seismic zone V (hard rock) of India using ETABS 6.0 methods of analyses being pushover. The Layout of plan having 5X4 bays of equal length of 5m. The buildings considered are Reinforced concrete ordinary moment resisting frame building of three storeys with different irregular configurations. Here stiffness of the infill is neglected in order to account the nonlinear behavior of seismic demands. The performances of all the models except two on sloping ground lies in between life safety and collapse prevention. This shows the buildings resting on sloping ground are more vulnerable to earthquake than rest of the models.

Kumar et al (2012)

Four distinct building models were considered namely, G+2, G+5, G+8 & G+9. The overall procedure of analysis as explained above remains same for G+8 & G+9. Entire analysis has been carried out by considering Zone – II, III, IV & V with soil type - I & III of IS 1893- 8 2002 (Part-1). For the case of G+5, soil type III and Zone V were considered. Entire modeling, analysis and design were carried out by using ETABS 9.6 nonlinear version software. The methods followed in this paper were equivalent static and response spectrum method. Time period does not change, when the zones and soil stratum is changed for individual model respectively. Base shear will increase when the zones changes from II to V and soil stratum III to I in equivalent Static method as well as response spectrum (dynamic analysis) method. Maximum story displacement increases for individual model as the zone increase from II to V as well as soil type from I to III. Maximum story drift increases for individual model as the zone increase from II to V as well as soil type from I to III. Max story drift and story displacement increases as the vertical irregularities increase in models respectively. The study as a whole identifies the influencing parameters, which can regulate the effect of vertical irregularities on time period, base shear, drift and displacement of building frames.

- Based on Steel X Bracings

Khoshnoudian et al (2008)

This paper investigates the accuracy of the modal pushover analysis to estimate the seismic performance of high rise buildings. The effects of structural irregularities in stiffness, strength, mass and combination of these factors are considered. In other words reliability of the modal pushover analysis (MPA) has been verified by defining a referenced regular structure for comparison between MPA and nonlinear dynamic analysis. In the study, onebay, hypothetical sixteen-story steel moment resisting frame selected as reference frame. A story height, of 3.5 m was assigned at all floors. Hence, the structures with the height of 56 m studied herein are potentially active for inelastic seismic response. Modal pushover analysis is the method used to analyze the models under study. The MPA procedure seems to produce results that are somewhat more reliable than those obtained from single load vectors in FEMA. However, it is readily apparent that the accuracy of these depends upon the parameter of interest (e.g., drift, plastic hinge rotation) 9 the characteristics of the structure and the details of the specific procedure. It is also possible that future development of the basic MPA procedure may improve predictions further. The effects of mass irregularities, stiffness irregularities, and strength irregularities are evaluated for seismic demands. Vertical Mass irregularities have known to be in smaller degree of attention due to change at upper stories. Effects of vertical irregularities generally increased when irregularity conducted to base or lower stories.

Soni et al (2006)

This study summarizes state-of-the-art knowledge in the seismic response of vertically irregular building frames. A review of studies on the seismic behavior of vertically irregular structures along with their findings was presented. Most of the studies have focused on investigating two types of irregularities: those in set-back and soft and/or weak first story structures. Conflicting conclusions have been found for the set-back structures; most of the studies, however, agree on the increase in drift demand for the tower portion of the set-back structures. For the soft and weak first story structures, increase in seismic demand has been observed as compared to the regular structures. For buildings with discontinuous distributions in mass, stiffness, and strength (independently or in combination), the effect of strength irregularity has been found to be larger than the effect of stiffness irregularity. And the effect of combined-stiffness-and strength irregularity has been found to be the largest.

Chatpan et al (2004)

This study compares the seismic demands for vertically irregular frames determined by MPA procedure and the rigorous nonlinear response history analysis (RHA), due to an ensemble of 20 ground motions. Forty-eight irregular frames, all 12-story high with strong-columns and weak-beams, were designed with three types of irregularity—stiffness, strength, and combined stiffness and strength—introduced in eight different locations along the height using two modification factors. The MPA procedure has ready been evaluated for “regular” frames of six different heights each designed for five different strength levels. The second 10 phase of the overall investigation concerned irregular frames, which was the subject of this paper. To focus on the issue of height-wise irregularity, the frame height was fixed at 12 stories, a mid-rise frame for which pushover analyses are appropriate. In spite of the larger bias in estimating drift demands for some stories in different cases, the MPA procedure identifies the stories with largest drift demands and estimates them well, detecting the critical stories in such frames. The MPA procedure provides usefully accurate seismic demands also for irregular frames, except for those with a strong first story or strong lower half. 2.5 Conclusion From the above literature it is noted that the irregularity in elevation of building reduces lateral forces resisting capacity of the structure which in turn reduces the performance of the building and there is also decrease in deformation or displacement of the building. The assessment of non linear behavior of the structure is difficult as they have relied on the empirical formulas. A structure cannot be made earthquake proof as the intensity and the direction of the earthquake is guaranteed, it can’t even be predicted precisely; but it can be strengthened to such a level that it can withstand with minimum damage. Therefore different type of bracings are considered and analyzed to find the minimum damage.

IV. PROPOSED METHODOLOGY

Equivalent Static Analysis

Seismic analysis of most of the structures are still carried out on the basis lateral(Horizontal) force assumed to be equivalent to the actual(Dynamic) loading. The base shear which is the total horizontal force on the structure is calculated on the basis of structural mass and fundamental period of vibration and corresponding mode shapes. Base shear is distributed along the height of the structure in terms of lateral force according to the 12 code formulae. The method is usually conservative for low to medium height buildings with a regular conformation. The equivalent lateral force procedure is the simplest method of analysis and requires less computational effort which is very suitable for manual calculations because, the forces depend on the code based fundamental period of structures with some empirical modifications. However, software programs are also available to accelerate results computation. The design base shear is computed as a whole, then be distributed along the height of the building based on simple formulas appropriate for buildings with regular distribution of mass and stiffness. The procedure basically constitutes of two steps first one being calculation of seismic weight of the building and second one calculation of base shear of building. Computation of base shear includes some code based formulae by which the horizontal acceleration of building is obtained through which the base shear of building is obtained, later distributed as lateral force along the height of the building using a formula mentioned in the code.

Response Spectrum Method

Methods of Analysis For seismic performance evaluation, a structural analysis of the mathematical model of the structure is required to determine force and displacement demands in various components of the structure. Several analysis methods, both elastic and inelastic, are available to predict the seismic performance of the structures.

Response Spectrum is the plot between time period and the response quantity (which may vary depending upon the study). According to the Indian code response spectrum method is applied to those regular building higher than 40m in height in Zones IV and V, and those higher than 90m in height in Zones II and III. Irregular buildings higher than 12m in Zones IV and V, and those higher than 40m in height in Zones II and III.

The procedure of dynamic analysis of irregular type of buildings should be based on 3D modeling of building that will sufficiently represent its stiffness and mass distribution along the height of building so that its response to earthquake could be predicted with sufficient accuracy. The procedure involves calculation of mode shape using characteristic equation also called as Eigen equation. Modal participation factors are obtained and 13 according to the prospects of the code mass participation of the building in the first mode must be greater than 90%. And lateral forces for different mode shapes are calculated using formulae which is combined to represent the peak response using three approaches mentioned below. i. Maximum Absolute Response ii. Square Roots of the Sum of Squares (SRSS) iii. Complete Quadratic Combination (CQC) The result of a response spectrum analysis using the response spectrum from a ground motion is typically different from that which would be calculated directly from a linear dynamic analysis using that ground motion directly, since phase information is lost in the process of generating the response spectrum.

Non Linear Analysis

Structures suffer significant inelastic deformation under a strong earthquake and dynamic characteristics of the structure change with time so investigating the performance of a structure requires inelastic analytical procedures accounting for these features. Inelastic analytical procedures help to understand the actual behavior of structures by identifying failure modes and the potential for progressive collapse. It provides better insights to assess the risk of a building during earthquake. This in turn leads to economical design and retrofitting of building. Non linear analysis procedures basically include inelastic time history analysis and inelastic static analysis which is also known as pushover analysis. The inelastic time history analysis is the most accurate method to predict the force and deformation demands at various components of the structure

Time History Analysis

Time history analysis provides response of structure under loading which might vary according to the specified time function. The forces that are included in time history analysis are inertia, elastic and damping. In time history analyses the structural response is computed at a number of subsequent time instants. In other words, time histories of the structural response to a given input are obtained ad a result. In response spectrum analyses the time evolution of response cannot be computed. Only the maximum response is estimated. Time history analysis is perhaps the most fulfilling analysis which is required to analyze the performance of a structure during a dynamic event. However, the use of inelastic 15 time history analysis is limited because dynamic response is very sensitive to modeling and ground motion characteristics. It requires proper modeling of cyclic load deformation characteristics considering deterioration properties of all important components. Also, it requires availability of a set of representative ground motion records that accounts for uncertainties and differences in severity, frequency and duration characteristics. Moreover, computation time, time required for input preparation and interpreting voluminous output make the use of inelastic time history analysis impractical for seismic performance evaluation.

- Push Over Analysis

The most basic inelastic analysis method is the complete non linear time history analysis, which at time is considered overly complex and impractical for general use. An available simplified nonlinear analysis method, referred to as nonlinear static analysis procedures, includes the capacity spectrum method that uses the intersection of capacity curve and a response spectrum to estimate maximum displacement. The pushover analysis of a structure is a static non linear analysis under permanent vertical loads and gradually increasing lateral loads. The equivalent static lateral loads approximately represent earthquake induced forces. A plot of the total base vs top displacement in a structure is obtained by this analysis that would indicate any premature failure (or) weakness. The analysis is carried up to failure, and then it enables determination of collapse load and ductility capacity. The seismic design can be viewed as a two step process. The first and usually most important one, is the conception of an effective structural system that needs to be configured with due regard to all important seismic performance objectives, ranging from serviceability considerations. This step comprises of seismic engineering. The rule of thumb for the strength and stiffness targets, based on fundamental knowledge of ground motion and elastic and inelastic dynamic response characteristics, should suffice to configure and rough size an effective structural system.

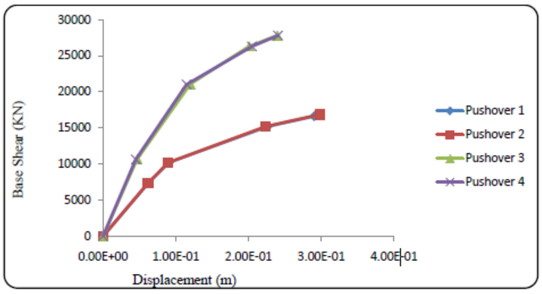


Figure: 5.1 Pushover Curves for G+ 11 Bare Frames

There are a number of options for the form of load vector used to generate the SDOF model of the structure, some are based on single vector and one uses several vectors applied to comprise a multi-modal pushover approach. In all the load forms, lateral forces are applied incrementally to a non linear structure model to generate a pushover curve representing the relationship between lateral force and global displacement at the roof or some other control point. The applied load at any level is proportional to the mass level. The various options are summarized below, as are the specifications of ATC 40 and FEMA 356 related to MDOF effects.

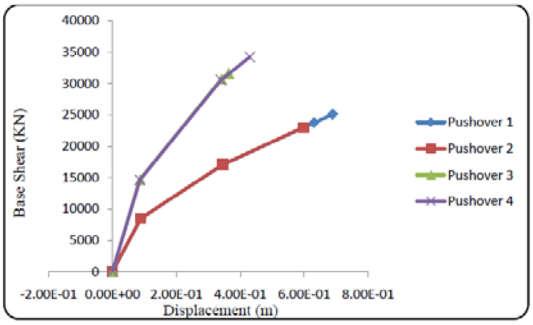


Figure: 5.3 Pushover Curve for G+ 21 Bare Frames

As from the Fig. 5.1, it can be concluded that the pushover curves for the pushover case 1 and 2 and pushover case 3 and 4 are quite identical. The structure performs better when it is subjected to acceleration load pattern as it is able resist more lateral loads than in mode load pattern.3.2

V. CONCLUSION

- Base Shear capacity of the structure increases for x masonry bracing and x steel bracing than bare frame and the percentage change in base shear is 11% & 6% with x masonry pushover cases. It increases by 224% & 189% for steel braced structure for respective pushover cases.
- Base Shear of the G+15 storied structure also increases as it did for the G+11 storied structure; the increment is seen as 4% & 4% for x masonry structure pushover cases and 227% & 198% for x steel bracing pushover cases.
- Roof displacement for G+11 x masonry and x steel braced structures the percentage changes observed were 6% & 39% • Roof displacement of the structures decreases with provision of bracings; the percentage changes observed to that of bare frame are 6% & 22% with x masonry and steel bracing respectively for G+15 storied structure.
- Time period of G+11 storied structure varies as 1.6638, 1.5895 & 1.04051seconds for bare frame, x masonry bracing & x steel bracing respectively.
- Time period of the structure decreases with increase in the stiffness, with 2.75488 seconds for a bare frame to 2.59755 & 1.96806 seconds for structure with x masonry and steel bracing for G+21 story structure respectively.

VI. FUTURE SCOPES

Pushover analysis has been extensively performed on the regular building but considerably less work has been done on structures with vertical irregularity. Response to the dynamic event is not that predictable for vertical irregular structures they don't behave as the regular structure does, so more work has to be carried on these structures to study their behavior. Study of the intricate details of the irregular structure has been the pivotal aim of this study. The study can be elaborated for the structures with irregularity by,

- Introduction of different types of lateral resisting systems with higher mode shapes accounting for its behavior.
- Applying different pushover analyses some of which could be energy based pushover analysis, adaptive pushover analyses as these are modified analyses than conventional pushover analysis.
- Considering different type of irregularities such as mass, stiffness, in plane discontinuity of lateral loads resisting members etc.

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