SEISMIC ANALYSIS OF SOFT STORY BUILDING

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ABSTRACT

Soft first storey is a typical feature in the modern multi-storey constructions in urban India. Though multi-storeyed buildings with soft storey floor are inherently vulnerable to collapse due to earthquake, their construction is still widespread in the developing like India. Functional and Social need to provide car parking space at ground level and for offices open stories at different level of structure far out-weighs the warning against such buildings from engineering community. In present study, Multi-storey regular buildings with 3 stories have been modeled using software package SAP 2000 for seismic zone II in India. In this paper an investigation has been made to study the seismic behavior of soft storey building with different arrangement in soft storey building when subjected to static loading. This analysis is with consideration of infill strength and stiffness in the upper storey and with and without consideration of braces in the ground storey. While analyzing the soft storey building linear and nonlinear analysis methods are used. In present study for Linear analysis Equivalent static method is used and For Nonlinear analysis Pushover analysis is used. From the study it is observed that, providing braces in the Ground storey with infill walls in the upper storey improves resistant behavior of the structure when compared to soft storey provided without braces.

INTRODUCTION

Earthquakes in general occur due to intense tectonic of earth. In recent times, there is a marked increase in the frequency of occurrence of earthquakes all over the world. The intensity and location of the earthquake is unpredictable even as on date. Structures designed to withstand gravity loads alone cannot be expected to resist the damages caused due to seismic effects. Structures designed for gravity loads are normally well below the elastic limiting stage and lie within the service loads. It is neither practical nor economically viable to design structures to remain within elastic limits during earthquakes. The design approach adopted in the Indian Code IS 1893(part I):2002 'Criteria for Earthquake Resistant Design of Structures' is to ensure that structures possess at least a minimum strength to withstand minor earthquakes which occur frequently, without damage; resist moderate earthquakes without significant structural damage though some non-structural damage may occur; and aims that structures withstand major earthquakes without collapse.

India has experienced many large earthquakes in the last two decades resulting in heavy loss of life and property. In fact, more than 50% area in the country is considered vulnerable to earthquake disasters. Hence there is an urgent need for seismic evaluation and retrofitting of deficient buildings. The retrofitting is more desirable as most of the structures are designed to resist gravity loads alone.

SOFT STOREY CONCEPT

Due to increasing population since the past few years car parking space for residential apartments in populated cities is a matter of major concern. Hence the trend has been to utilize the ground storey of the building itself for parking. These types of buildings having no infill masonry walls in ground storey, but infilled in all upper storey, are called Open Ground Storey(OGS) buildings. They are also known as 'Open first storey building' (when the storey numbering starts with one from the ground storey itself), 'pilotis', or 'stilted buildings'.

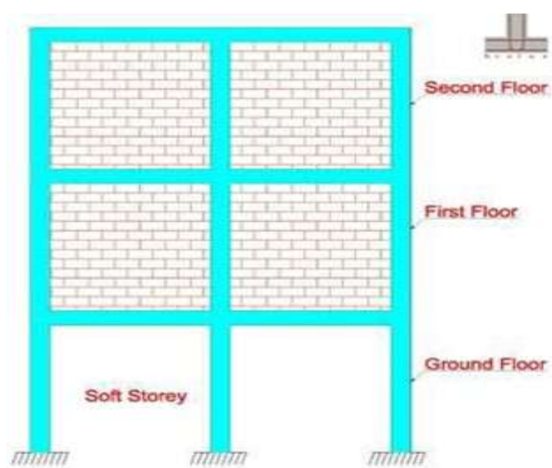


Fig. Typical Examples of soft storey building

There is significant advantage of these category of buildings functionally but from a seismic performance point of view such buildings are considered to have increased vulnerability. Due to the presence of infill walls in the entire upper storey except for the ground storey makes the upper storeys much stiffer than the open ground storey. Thus, the upper storeys move almost together as a single block, and most of the horizontal displacement of the building occurs in the soft ground storey itself. In other words, these types of buildings sway back and forth like inverted pendulum. During earthquake shaking, and hence the columns and beams are heavily stressed. Therefore it is required that the ground storey columns must have sufficient strength and adequate ductility. The vulnerability of this type of building is attributed to the sudden lowering of lateral stiffness and strength in ground storey, compared to upper storeys with infill walls.

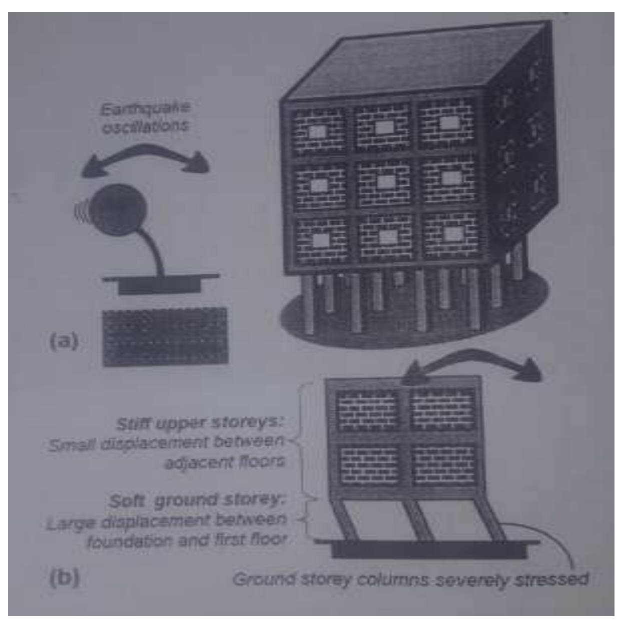


Fig. Typical Behavior of a Soft-storey structure

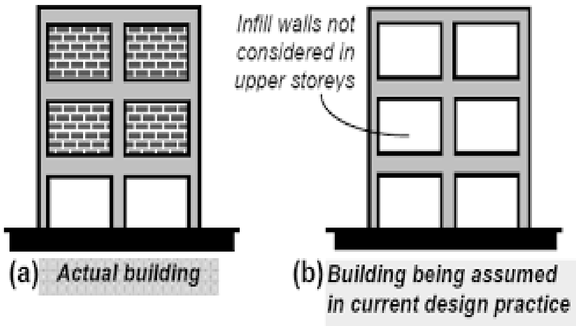


Fig. (a) Infill Frame versus (b) Bare frame

REVIEW OF LITERATURE

The behavior of RC framed OGS building when subjected to seismic loads was reported by **Arlekar et.al** (1997). A four storeyed OGS building was analyzed using Equivalent Static Analysis and Response Spectrum Analysis to find the resultant forces and displacements. This paper shows that the behavior of OGS frame is quite different from that of the bare frame.

Deodhar and Patel (1998) pointed out that even though the brick masonry in infilled frame are intended to be non-structural, they can have considerable influence on the lateral response of the building.

Davis and Menon (2004) concluded that the presence of masonry infill panels modifies the structural force distribution significantly in and OGS building. The total storey shear force increases as the stiffness of the building increases in the presence of masonry infill at the upper floor of the building. Also, the bending moments in the ground floor columns increase (more than two fold), and the mode of failure is by soft storey mechanism (formation of hinges in ground floor columns).

Ashokan (2006) studied how the presence of masonry infill walls in the frames of a building changes the lateral stiffness and strength of the structure. This research proposed a plastic hinge model for infill wall to be used in nonlinear performance based analysis of a building and concludes that the ultimate load (UL) approach along with the proposed hinge property provides a better estimate of the inelastic drift of the building.

Hashmi and Madan(2008) conducted non-linear time history and pushover analysis of OGS building. The study concludes that the MF prescribed by IS 1893 (2002) for such buildings is adequate for preventing collapse.

Sattar and Abbie (2010) in their study concluded that the pushover analysis showed an increase in initial stiffness, strength, and energy dissipation of the infilled frame, compared to the bare frame, despite the wall's brittle failure modes. Likewise, dynamic analysis results indicated that fully-infilled frame has the lowest collapse risk and the bare frames were found to be the most vulnerable to earthquake-induced collapse. The better collapse performance of fully-infilled frames was associated with the larger strength and energy dissipation of the system, associated with the added walls. There are numerous research efforts found on the seismic behavior OGS buildings and on the modeling infill walls for linear and nonlinear analysis. However, no published literature found on the design criterion given in IS

1893:2002 (part-1) for OGS low rise buildings. This is the primary motivation behind the present study.

Durgesh c. rai gave the guidelines for seismic evaluation on and strengthening of buildings. This document was developed as part of project entitled –Review of Building Codes and Preparation of Commentary and Handbooks, awarded to Indian Institute of Technology Kanpur by the Gujarat State Disaster Management Authority (GSDMA), Gandhinagar through World Bank finances. This document was particularly concerned with the seismic evaluation and strengthening of existing buildings and it was intended to be used as a guide.

The accuracy and reliability of nonlinear time history analysis is simulating the actual behavior of structure under seismic action has been widely accepted since 1960. However, the time required for proper modeling. Input preparation, computation time, computer costs and the effort for the interpretation of voluminous output make use of such analysis impractical. This led researchers to propose simplified nonlinear analysis procedures and structural models to estimate inelastic seismic demands. The proposed simplified nonlinear analysis procedures and structural models are usually based on the reduction of MDOF model of structures to an equivalent SDOF system.

Mahaney et al(1993) introduced the ADRS format that the spectral accelerations are plotted against spectral displacements with radial lines representing the period, T. The demand (inelastic) response spectrum accounting for hysteretic nonlinear behavior of structure is obtained by reducing elastic response spectrum with spectral reduction factors which depend on effective damping. A performance point that lies on both the capacity spectrum and the demand spectrum (reduced of nonlinear effects) is obtained for performance evaluation of the structure. The dependence of spectral reduction factors on structural behavior type (hysteretic properties) and ground motion duration and the approximations involved in determination of the main weaknesses of the method.

Capacity Spectrum Method is one of the most popular methods utilized for a quick estimate to evaluate the seismic performance of structures. The method is recommended by ATC-40 (1996) as a displacement-based design and assessment tool for structures. The method was developed by Freeman and it has gone through several modifications since then. The most recent three versions (Procedures A,B and C) of Capacity Spectrum Method are presented in detail AtC-40(1996), The method requires construction of a structural capacity curve and its comparison with the estimated demand response spectrum, both of which are expressed in Acceleration- Displacement Response Spectrum (ADRS) FORMAT

Newmark and Hall (1982) and Miranda(2000) proposed procedures based on displacement modification factors in which the maximum inelastic displacement demand of MDOF system is estimated by applying certain displacement modification factors to maximum deformation of equivalent elastic SDOF system having the same lateral stiffness and damping coefficient as that of MDOF system.

Chopra and Goel(1999) have proposed and improved capacity-demand diagram method that uses constant ductility demand spectrum to estimate seismic deformation of inelastic SDOF system.

LINEAR ANALYSIS

Broadly we can say that linear analysis of structures to compute the earthquake forces is commonly based on one of the following three approaches.

1. An equivalent lateral procedure in which dynamic effects are approximated by horizontal static forces applied to the structure. This method is quasi-dynamic in nature and is termed as the Seismic Coefficient Method in the IS code.
2. The Response Spectrum Approach in which the effects on the structure are related to the response of simple, single degree of freedom of the time history of varying natural periods to earthquake shaking.
3. Response History Method or Time History Method in which direct input of the time history of a designed earthquake into a mathematical model of the structure using computer analyses.

Equivalent Static Analysis

This is a linear static analysis. This approach defines a way to represent the effect of earthquake ground motion when series of forces are act on a building, through a seismic design response spectrum. This method assumes that the building responds in its fundamental mode. The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces. In the equivalent static method, the lateral force equivalent to the design basis earthquake is applied statically. The equivalent lateral forces at each storey level are applied at the design 'centre of mass' locations. It is located at the design eccentricity from the calculated 'center of rigidity (or stiffness)'.

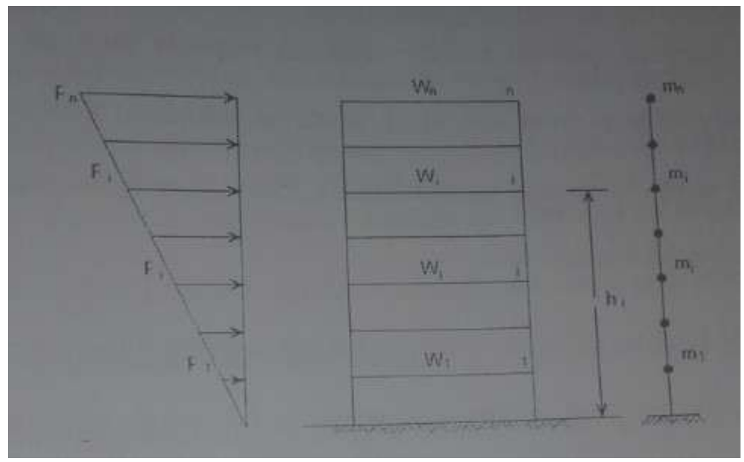


Fig. Equivalent Lateral Loads for Seismic analysis

NON LINEAR ANALYSIS

In general, linear procedures are applicable when the structure is expected to remain nearly elastic for the level of ground motion or when the design results in nearly uniform distribution of nonlinear response throughout the structure. As the performance objective of the structure implies greater inelastic demands, the uncertainty with linear procedures increases to a point that requires a high level of conservatism in demand assumptions and acceptability criteria to avoid unintended performance. Therefore, procedures incorporating inelastic analysis can reduce the uncertainty and conservatism. Nonlinear analysis of structures to compute the earthquake forces is commonly based on one of the following two approaches.

1. Pushover Analysis –A pattern of forces is applied to a structural model that includes non-linear properties (such as steel yield), and the total force is plotted against a reference displacement to define a capacity curve. This can then be combined with a demand curve (typically in the form of an acceleration–displacement response spectrum (ADRS)). This essentially reduces the problem to as single degree of freedom (SDOF) system.
2. Nonlinear Dynamic Analysis- Nonlinear Dynamic analysis utilizes the combination on of ground motion records with relatively low uncertainty. In nonlinear dynamic analysis, the detailed structural model subjected to a ground-motion record produces estimates of component deformations for each degree of freedom in the model and the modal responses are combined using schemes such as the square-root-sum-of squares. In non-linear dynamic analysis, the non-linear properties of the structure considered as part of a time domain analysis. This approach is the most rigorous, and is required by some building codes for buildings of unusual configuration or of special importance.

In the present study, pushover analysis is comprehensively elaborated in the following chapters as it has been used for performing non linear analysis.

PUSH OVER ANALYSIS

The existing building can become seismically deficient since seismic design code requirements are constantly upgraded and advancement in engineering knowledge. Further, Indian buildings built over past two decades are seismically deficient because of lack of awareness regarding seismic behavior of structures. The widespread damage especially to RC buildings during earthquakes exposed the construction practices being adopted around the world, and generated a great demand for seismic evaluation and retrofitting of existing building stocks. This led to the necessity of non-linear static pushover analysis.

The static pushover analysis is becoming a popular tool for seismic performance evaluation of existing and new structures. The expectation is that the pushover analysis will provide adequate information on seismic demands imposed by the design ground motion on the structural system and its components.

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 shear versus roof displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity. On a building frame, moment and plastic rotation is monitored. And lateral inelastic forces versus displacement response for the complete structure are analytically computed **(**Fig 5.1**)**.This type of analysis enables weakness in the structure to be identified. The decision to retrofit can be taken in such studies.

However retrofitting is not the scope of this study. Having retrofitted all the vulnerable members of the building frame, the building cam be anticipated to perform at its maximum capacity. Thereby the method suggests a suitable procedure for strengthening the existing building structures against seismic effects.

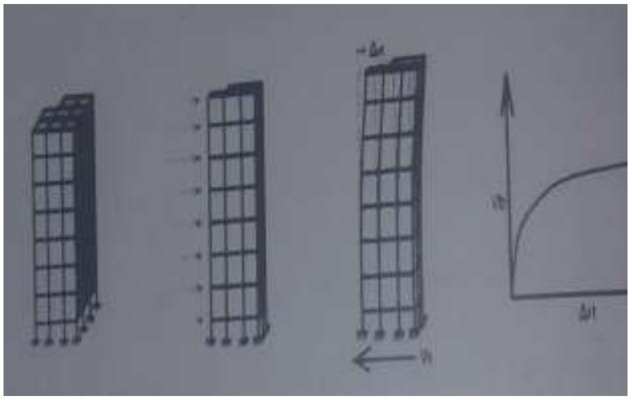


Fig. Global capacity curve for a structure

The seismic design cam 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 the art of seismic engineering. The rules 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.

Elaborate mathematical/physical models can only be built once a structural system has been created. Such models are needed to evaluate seismic performance of an existing system and modify component behavior characteristics (strength, stiffness, deformation capacity) to better suit the specified performance criteria.

The second step consists of the design process that involves demand/capacity evaluation at all important capacity parameters, as well as the prediction of demands imposed by ground motions. Suitable capacity parameters and their acceptable values as well as suitable methods for demand prediction will depend on the performance level to be evaluated. The implementation of this solution requires the availability of a set of ground motion records (each with three components) that account for the uncertainties and differences in severity, frequency characteristics, and duration due rapture characteristics distances of the various faults that may cause motions at the site. It requires further the capability to model adequately the cyclic load-deformation characteristics of all important elements of the three dimensional soil foundation structure system, and the availability of efficient tools to implement the solution process within the time and financial constraints on an engineering problem.

RESULTS AND DISCUSSIONS

RESULTS FROM LINEAR ANALYSIS

The Equivalent Static analysis was performed on the building model. Various results obtained such as storey displacements, storey drifts, drift ratios, response of building roof and base shear are presented in this section applying the ground motion in both the orthogonal directions of the building.

Equivalent Static Analysis

By using Equivalent Static analysis Results obtained are shown in Tabulated form for both the cases i.e., Infill wall without braces and with braces.

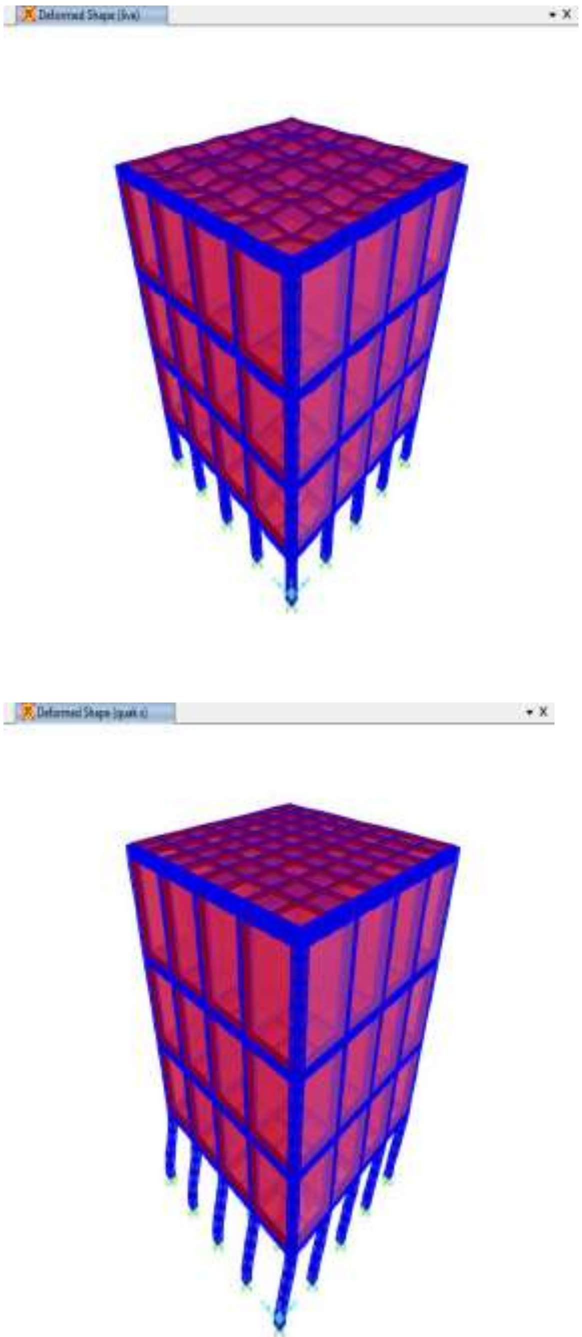


Fig. Deformed shapes of Soft storey due to different loads

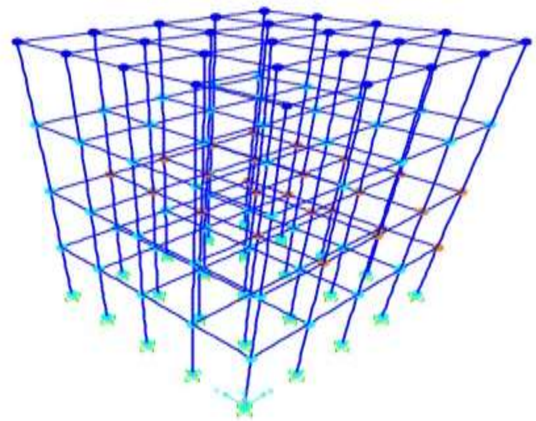


Fig (e) Hinge formations at collapse

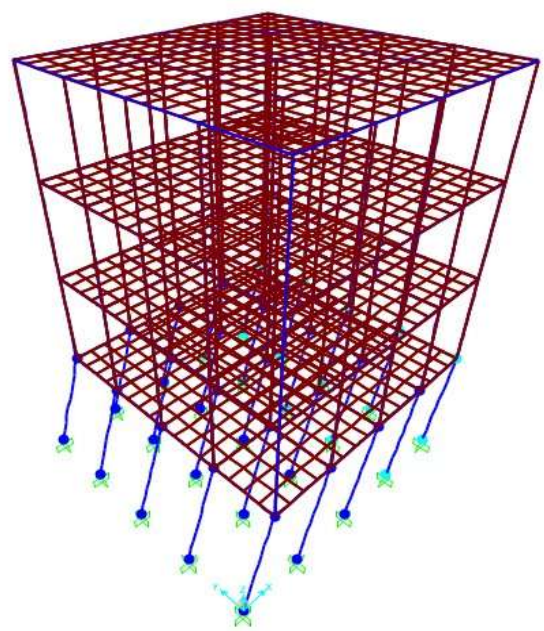
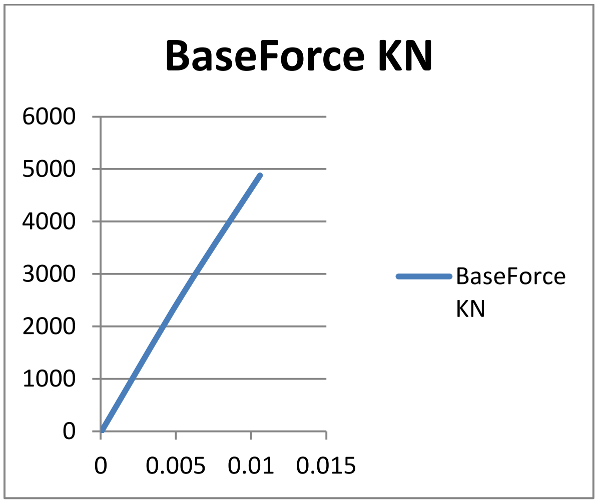
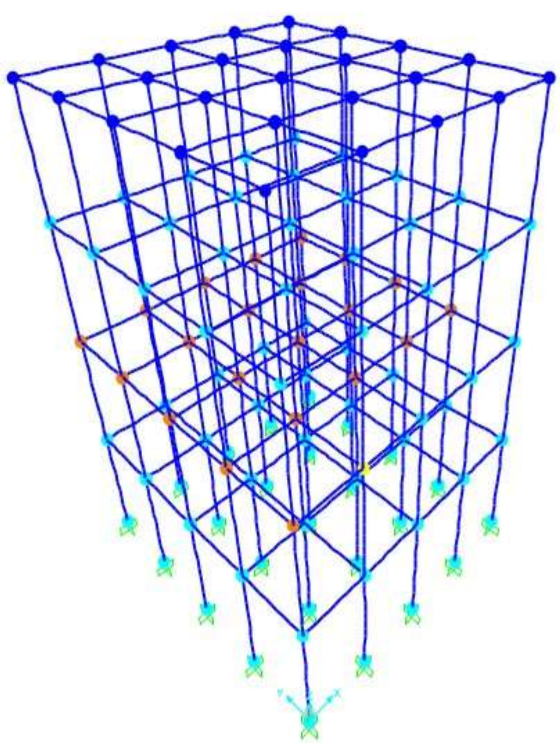


Fig (d) Hinge formations at maximum level of immediate occupancy

Pushover analysis of Braced Frame

The introduction of bracings in the ground storey improved the capacity of the structure locally as well as globally. show the capacity curve and location performance point respectively.





Hinge formations at collapse

Comparison of Performance Point parameters

Performance Point	X direction		Y direction	
Parameter	Base Shear kN	Roof Displacement m	Base Shear	Roof Displacement m
Bare Structure	537.659	0.035	527.942	0.039
Soft-Storey Structure	1178.534	0.045	1143.336	0.047
Braced structure	2833.185	0.0059	2845.832	0.0058

CONCLUSIONS

Based on the results from the linear and non-linear static pushover analysis performed on the three storey building following observations are made:

- There are god reasons for advocating the use of the inelastic pushover analysis for demand prediction, since in many cases it wil provide much more relevant information that an elastic static or dynamic analysis, but it would be counterproductive to advocate this method as a general solution technique for all cases.
- The pushover analysis is a useful, but not infallible tll for assessing inelastic

strength and deformation demands and for exposing design weaknesses.

- Its foremost advantage is that it encourages the design engineer to recognize important seismic response quantities and to use sound judgment concerning the force and deformation demands ands and capacities that control the seismic response close to failure, but it needs to be recognized that in some cases it may provide a flase feelings of security if its short comings and pitfalls are not recognized.
- AS the push was incrementally applied on a control node plastic hinges corresponding to various levels (I.O,L.S and C.P) the vulnerability of different beam and column members can be recognized.
- Depending on the degree of importance of a particular structure the retrofitting of the may be taken up.
- Since neither national building code nor any of earthquake related codes in India illustrate the categorization of the building for structural retrofitting, no generalized retrofitting procedure may be defined.
- The introduction of bracings in the ground storey was done based on the proposed car parking plan and incorporated them rationally without affecting the functionality of the open ground storey.
- The bracings proved to eliminate the soft storey failure mechanism and also brought down the global response of the structure and are recommended for preventing much damage or collapse of the building in an earthquake of higher magnitude.
- It may be concluded from the pushover analysis that there is an increase in initial stiffness and strength of the infilled frame, compared to the bare frame, despite the wall's brittle failure modes. However it fails at a relatively lower drift level thatn the bare frame (at aournd one third of the roof displacement).
- For the considered earthquake the existing building can survive collapse but may suffer little damage in the ground storey columns which show soft storey mechanism of failure.
- No retrofitting is required if design level earthquake for Zone II is considered, as the structures performance is in immediate occupancy level i.e., no structural damage is expected. Only nominal repair works may be carried out.

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