Influencing Parameters on the Seismic Behavior of Steel Frames from Pushover Analysis

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***Abstract*—** Soft storey collapse is one of the major reasons for failure of framed structures during earthquake. Lack of stiffness due to the absence of infill in one of the floors generally makes that floor relatively soft compared to the rest of the floors. Steel building frames are becoming popular in recent times, owing to the speed of construction, low maintenance requirements, strength and durability. Pushover analysis is a nonlinear static approach for the seismic analysis of structures subjected to permanent vertical load and gradually increasing lateral load at very large strains up to failure. Considering these aspects, in the present work, an attempt is made to describe the performance of soft storey steel frames against lateral seismic loads up to failure from Pushover analysis. For this purpose, ETABS, finite element software has been used. Typical Three dimensional steel frames are modeled and their seismic performance with soft storey at different storey levels having varying stiffness ratios is evaluated using pushover curves. Base shear carried status of performance point and number & status of hinges formed are the parameters used to quantify the performance of building frames. Sensitivity analysis of several factors such as floor position of soft storey, relative stiffness of soft storey with respect to other floors etc. is made. It is inferred that structures with soft storey are most vulnerable to earthquake forces. They possess lower lateral load carrying capacity and experience increased roof displacement. In the present study an attempt is also made to study the influence of bracings and connections on steel structures.

***Keywords*-** *Stiffness;Soft storey; Base shear; Performance point; Sensitivity analysis; Pushover analysis,bracings.*

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I. INTRODUCTION

Earthquake is defined as the vibration of the earth surface as a result of release of energy in the earth curst. This release of energy can be caused by dislocation of segments of the curst, volcanic eruptions or even explosions created by humans. The sudden slip at the fault causes the earthquake. Earthquake causes shaking of the ground. So a building resting on it will experience motion at its base. The behavior of a building during earthquakes depends critically on its overall shape, size and geometry, in addition to how the earthquake forces are carried to the ground. Structural steel is a category of steel used as a construction material for making structural steel shapes. The immense strength of steel is of great advantage to buildings. Flexibility is the other important feature of steel framing. Steel building can flex when it is pushed to one side by say, wind, or an earthquake and also can bend without cracking, which is another great advantage, the third characteristic of steel is its plasticity or ductility. This means that when subjected to great force; it will not suddenly crack like glass, but slowly bend out of shape. It gives warning to inhabitants to escape as this property allows steel buildings to bend out of shape, or deform. Failure in steel frames is not sudden, a steel structure rarely collapses. Steel in most cases performs far better in earthquake than most other materials because of these properties. A soft story building is a multi-story building in which one or more floors have large unobstructed commercial spaces, windows, wide doors or other openings in places where a shear wall would normally be required for stability as a matter of earthquake engineering design. Due to increasing population and the limited areas for construction of structures as well as limited areas for car parking space for residential apartments in populated cities the constructions of multi-storied buildings with open first story has become a common practice in world. Buildings are classified as having a "soft story" according to Indian seismic code IS 1893 (Part1): 2002 if the floor level is less than 70% as stiff as the floor immediately above it, or less than 80% as stiff as the average stiffness of the three floors above it. In a phenomenon known as soft story collapse, soft story buildings are vulnerable to collapse in a moderate to severe earthquake. Different nations have experienced the poor and devastating performance of such buildings during earthquakes and have always seriously discouraged construction of such a building with a soft ground floor.

II. LITREATURE REVIEW

Santosh Kumar (2002) made an attempt to compare the existing experimental results with that of pushover analyses results for corresponding models. Different existing analytical models for computing stiffness, strength and deformation characteristics of infill panels are compared with published experimental data for ten specimens. From the results, a good match was found between the predicted responses with the experimental response.

Rajeshwari Kammar et al (2007) studied the performance based seismic evaluation of non-ductile RC multi-storied buildings. The study investigates the performance based seismic evaluation of non-ductile RC Multi-storied buildings by varying the storey stiffness above the soft ground storey located in zone-III constructed on medium soil. The results of the study concluded that the stiffness of masonry infill walls increases the lateral stiffness of the building for different models and methods of analysis as compared to the stiffness of bare frame model. Elimination of the masonry infill walls in the upper storey reduces the stiffness irregularity only marginally. The analytical natural period of the building models decreases with the removal of masonry wall in upper storey. Compared to low rise building the analytical natural period of midrise building and high rise building is 1.5 and 2 time more. The inter storey drift demand is largest in the first storey for model with soft ground storey. This implies that the ductility demand on the columns.

Savita Athani et al (2007) studied the performance based seismic evaluation and retrofitting of multi-storied buildings. The study investigates performance based seismic evaluation of building models namely: bare frame, soft storey, retrofitted buildings with unreinforced masonry infill and increased stiffness of columns at different locations in open ground storey for G+2, G+5 and G+8 stories located in seismic zone III, constructed on medium soil are considered. They concluded drawn from the study that the buildings analyzed and designed for gravity load combination as per IS: 456-2000 are inadequate for seismic load combination as per IS: 1893 - 2002. Bare frame idealization is an overestimation of fundamental natural period and also the lateral displacement profiles are linear, which is an unrealistic modeling of an open ground storey infill walls in upper storey RC buildings. Fundamental natural period from seismic codal empirical formula is an underestimation of actual period, leading to overestimation of design base shear. The storey drift of soft storey is effectively minimized by adding masonry infill walls in the ground storey.

Hardik Bhensdia and Siddharth Shah (2015) made an attempt to reveal the effects of soft storey in different zones of earthquake by using pushover analysis. This study concluded that with the increase of mass and number of storey of the building, base shear increases. Base shear obtained from pushover analysis is much more as compared to base shear obtained from the equivalent static analysis. As the magnitude of intensity will be more for higher zones, displacement and drift of building will be more compare to lower zones.

Akshay V.Raut and Prasad (2014) conducted a nonlinear pushover analysis of G+3 reinforced concrete building with soft storey. The present study highlights the importance to prevent the soft first storey used in buildings by adopting immediate measures and also to reduce the irregularity due to open first storey by alternate measures for stiffness balance of open first storey and the storey above. The results of real behavior of structures are obtained in terms of pushover demand, capacity spectrum and plastic hinges.

Nivedita et al (2013) investigated the seismic performance and partial seismic damage of masonry in filled R/C frames under strong ground motion using nonlinear static pushover analysis. For architectural, economic or aesthetic reasons large number of multi storey reinforced concrete (R/C) framed building structures with masonry in fills are being constructed in urban India. The result of this study showed that severe hinges are formed more in beam than column and the seismic performance of multistoried building if the infill panels are discontinued in the ground storey referred as open storey will be affected significantly and adversely.

Mohd Mubeen et al (2015) carried out the nonlinear pushover analysis with different patterns of eccentric bracing systems for high rise steel frame building. This analysis showed that ISMB section compare to angle section gives better base shear. In order to control the displacement of the steel bare frame model, special moment resisting frame as lateral load resisting system such as steel bracing can be used.

Misam A and Mangulkar Madhuri.N (2012) presented study on structural response of soft storey high rise buildings under different shear wall location. In this paper, in order to reduce structural seismic response due to soft story effect shear wall has been added in different arrangement. Four models with different condition, such as bare RC frame of G+14 storied building and others with different shear wall arrangement has been analyzed using software SAP (2000) V15, situated in seismic zone 5. The following are the conclusion drawn from this study:

1) By using shear wall, horizontal and vertical movement of building are reduced compare to other models during earthquake.
2) Compare to frame system, dual type structure considerably reduces shear force, bending moment and if the shear wall is properly located, dual type structure resists earthquake forces more effectively than the moment resisting frame system.
3) When shear walls are placed at corners of the structural plan, storey drift, and displacement and in model 3, maximum force reduction is found to be less.

Suchita Hirde and Ganga Tepugade (2014) attempted to study soft storey buildings at different level as well as in ground level, their seismic performance and results of retrofitting the building with shear wall. This study concludes that building with soft storey at different level and at ground level performs poorly during earthquake. In ground level soft storey plastic hinges are developed which is not safe for buildings. Lateral displacement is reduced due to addition of shear wall. Retrofitting of all the models with shear wall increase base shear carrying capacity by 8.45% to 13.26% and in any column of the building hinges are not developed.

III. METHODS OF ANALYSIS FOR SEISMIC VULNARABILITY ASSESMENT

Pushover analysis is a technique by which a structure is subjected to an incremental lateral load of certain shape. The sequence of cracks, yielding, plastic hinge formation and failure of various structural components are noted and the structural deficiencies are observed and rectified. Pushover analysis is one of the analysis methods recommended by Euro code and FEMA 273. This analysis provides a series of sequential elastic analyses, superimposed to approximate a force-displacement curve of the overall structure

Pushover analysis is a static, nonlinear analysis which used to determine seismic structural deformations. Pushover Analysis is basically the analysis which is to be carried after modeling, analysis and concrete steel check. It is an incremental static analysis used to determine the base shear-displacement relationship, or the demand capacity curve, for a structure or structural element. In order to carry out pushover analysis, the linear model created for gravity analysis is converted into a non-linear model by assigning frame non-linear hinges. Various pushover parameters such as type of analysis (Force of deformation controlled), Target displacement, Lateral load Pattern and geometric non-linearity are defined and the pushover analysis is then run. The demand curve is then generated by providing the C_a and C_v values for the corresponding zone and type of soil.

IV. MODELLING

The 3-story and 6-story steel structure has been modeled and analyzed using ETABS software. The structure is made up of steel beams and columns with RC slabs on decking sheets. Rolled I-sections are used as beams and columns. The loads considered for analysis are as per IS-800 and IS1893:2002.The cladding and roofing for the building is using GI sheets. The details of the buildings are shown in Table 1. The building model created is designed for Dead, Live and Earthquake loads using ETABS. The most sections considered have an interaction value of 0.50- 0.70 for the steel design according to Indian code.

Table 1: Details of model considered for analysis

DESCRITION	**VALUES CONSIDERED**
Total area of building	5X3.65 m (18.25 m^2)
No of stories	3
Total height	10.95 m
Grade of steel	Fe 410 (fy= 250 MPa)
Column section	ISWB 250
Beam section	ISWB 400
Loads considered	
Finishing load	1.5 kN/m^2
Live load	3 kN/m^2
Earthquake parameters	
Zone	5
Soil	Medium

Fig 1: Plan of a model considered for analysis

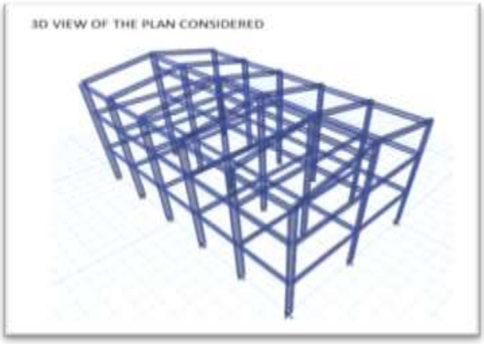

Fig 2: 3-D view of a model considered for analysis

V. RESULT AND DISCUSSIONS

In the present study, non-linear pushover analysis of steel building with soft storey and the influence of location of soft storey along the height of structure using ETABS under the loading have been carried out. The objective of this study is to see the variation of load- displacement graph and check the maximum base shear and displacement of the frame at different height of soft storey structures.

OBJECTIVE 1: INFLUENCE OF LOCATION OF SOFT STOREY ALONG THE HEIGHT OF THE STRUCTURE

Following are the graphs drawn for the soft storey at different floor of structure using nonlinear pushover analysis.

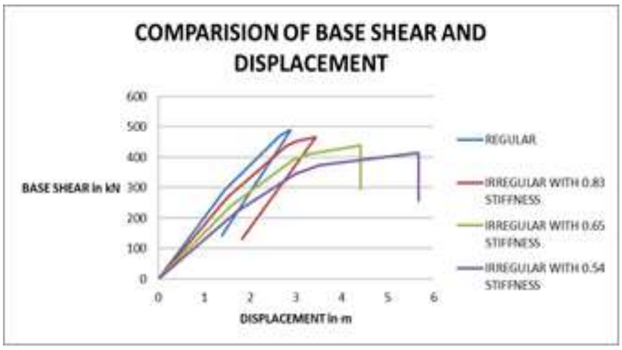

Fig 3: Comparision of base shear and displacement for different structures

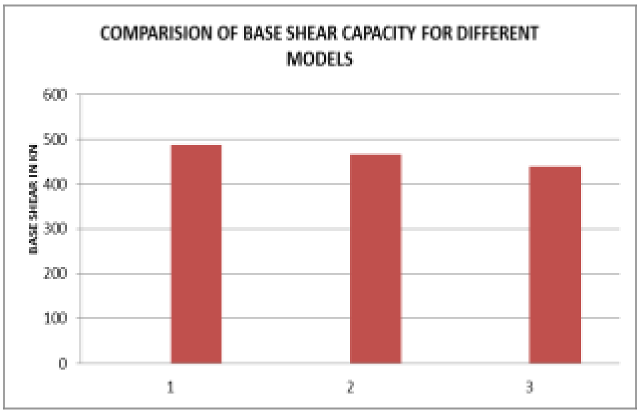

Fig 4: Comparision of base shear and stiffness ratio for different structures

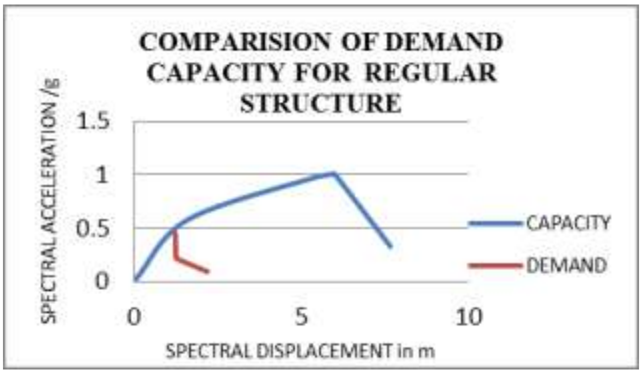

Fig 5: Demand vs. Capacity for regular G+ 3 structure with 3.65m height

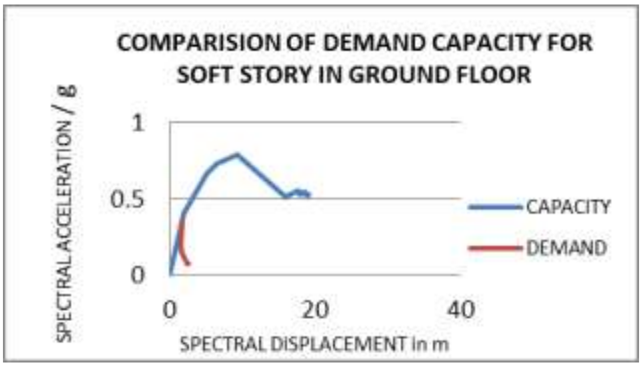

Fig 6: Demand vs. Capacity for soft story G+ 3 structure at ground floor

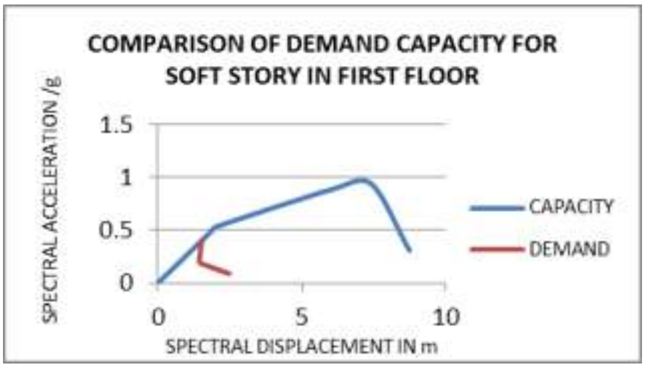

Fig 7: Demand vs. Capacity for soft story G+ 3 structure at first floor

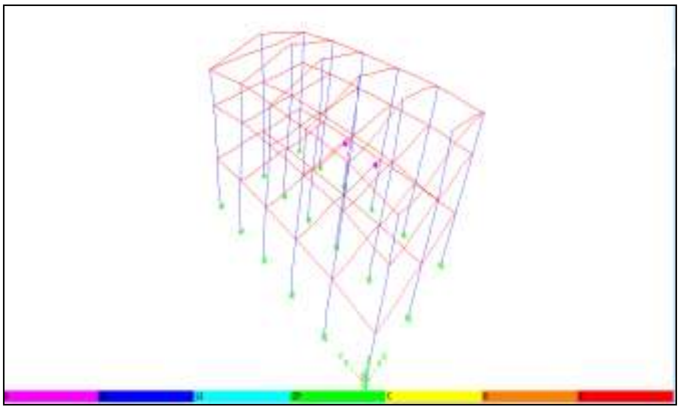

Fig 8: Hinged form of regular structure

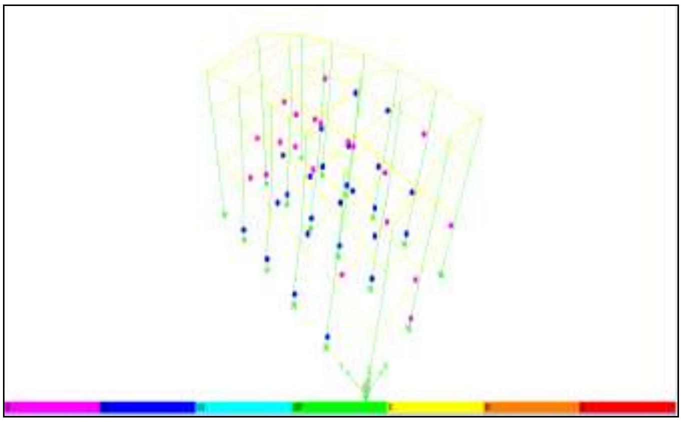

Fig 9: Hinged formed at ground floor.

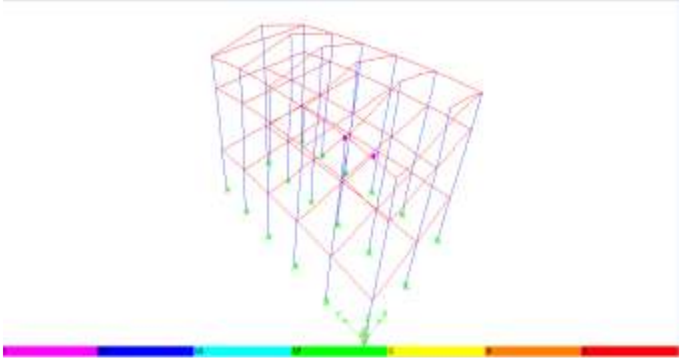

Fig 10: Hinged formed at first floor.

Table 2: Performance point of regular and soft story G+ 3 structures at different floor

STRUCTURAL TYPES	PERFORMANCE POINT		PERFORMANCE POINT	
	Sa	Sd	V	D
Regular structure	0.450	1.240	227.862	1.129
Soft story at 1st floor	0.438	1.396	226.745	1.264
Soft story at 2nd floor	0.403	1.517	189.20	1.329

OBJECTIVE 2: EFFECT OF BRACING

In the present study, an attempt is made to study the seismic performance of building with regular and braced structure. Following are the graphs drawn for the regular and braced 3 storey buildings using nonlinear pushover analysis.

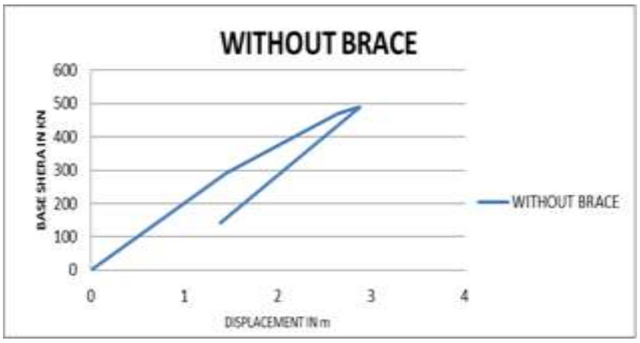

Fig 11: Comparision of base shear and displacement for regular structure

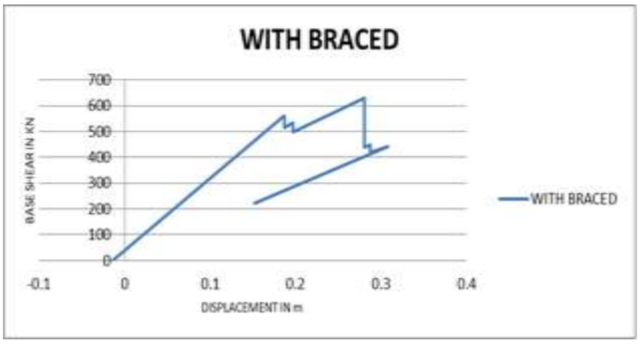

Fig 12: Comparision of base shear and displacement for braced structure

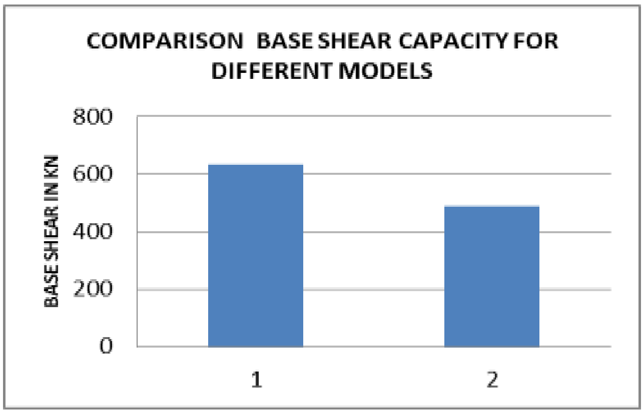

Fig 13: comparisons of base shear capacity for G+ 3 regular and braced structure

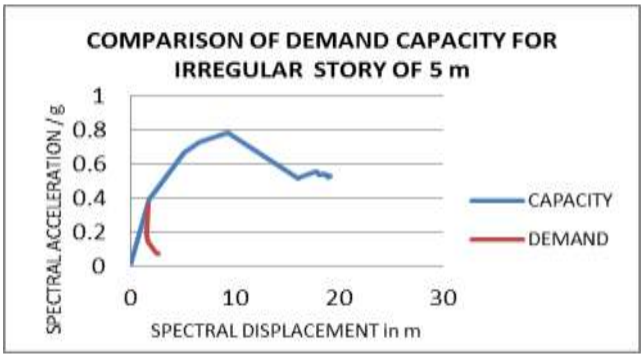

Fig 14: Demand vs. Capacity for regular G+ 3 structure with 3.65m height

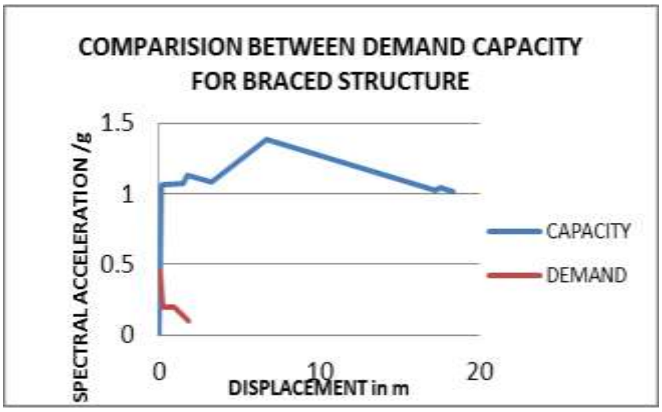

Fig 15: Demand vs. Capacity for G+ 3 braced structure

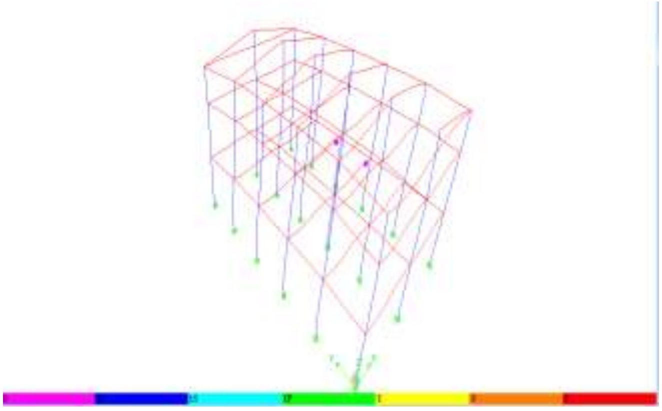

Fig 16: Hinged form of regular structure

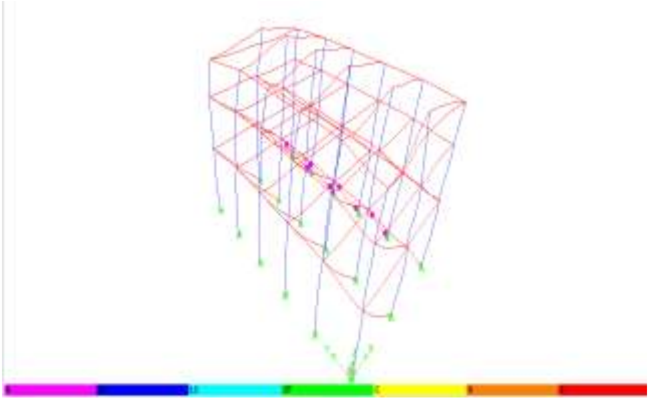

Fig 10: Hinged form at braced structure

OBJECTIVE 3: EFFECT OF RIGID, SEMI RIGID AND MOMENTLESS CONNECTIONS ON G+3 STRUCTURES

In the present study, an attempt is made to study the seismic performance of building with connections from pushover analysis. For this purpose, a typical three storey and six storey buildings are modeled and analyzed using ETABS software. Following are the results of the study.

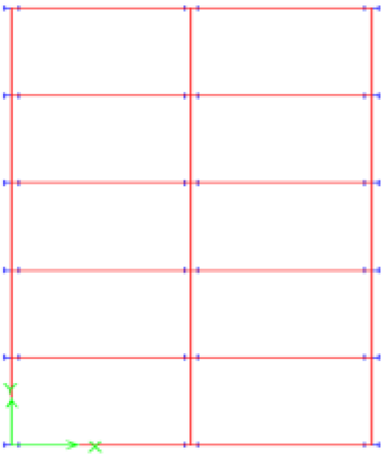

Figure 17: Structure with rigid connection

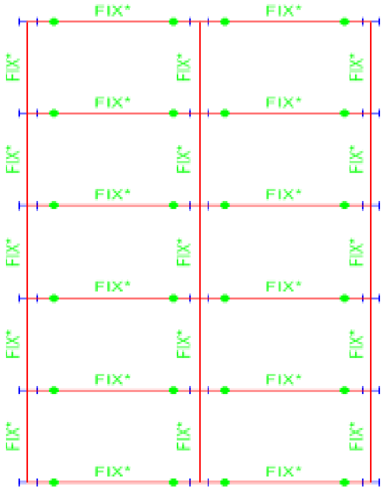

Figure 18: Structure with semi rigid connection

Figure 19: Structure with moment less connection

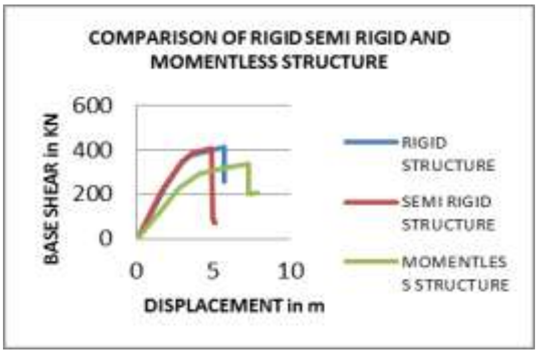

Fig. 20: Comparisons of varying connections for G+ 3 structures

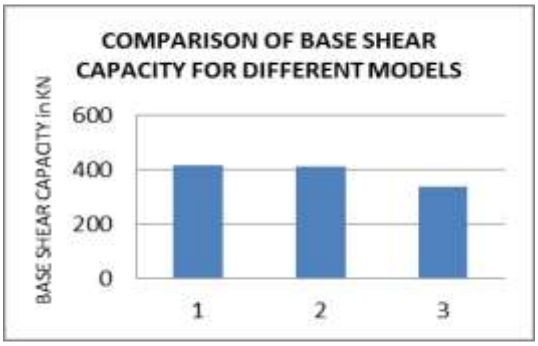

Fig. 21: comparisons of base shear capacity for G+ 3 structure with varying connection

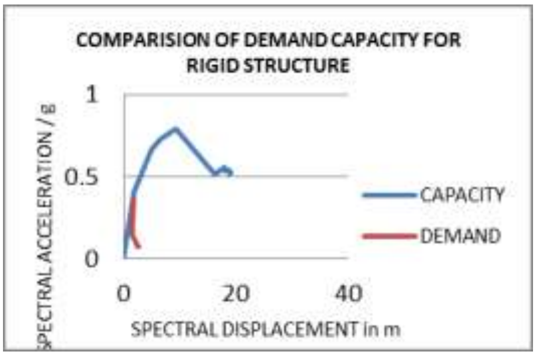

Fig 22: Demand vs. Capacity for G+ 3 rigid structure

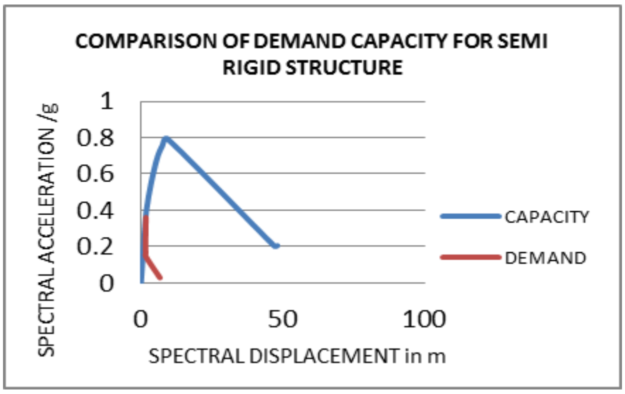

Fig 23: Demand vs. Capacity for G+ 3 semi rigid structure

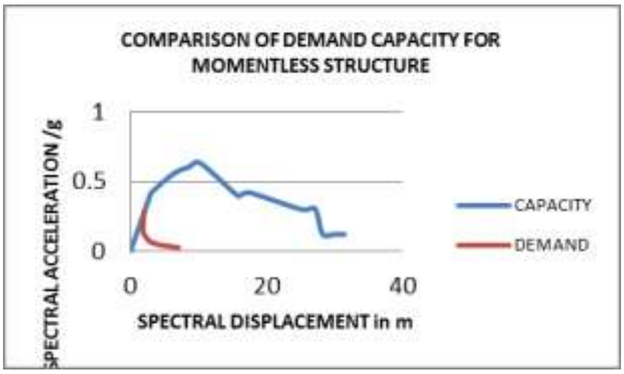

Fig 24: Demand vs. Capacity for G+ 3 moment less structure

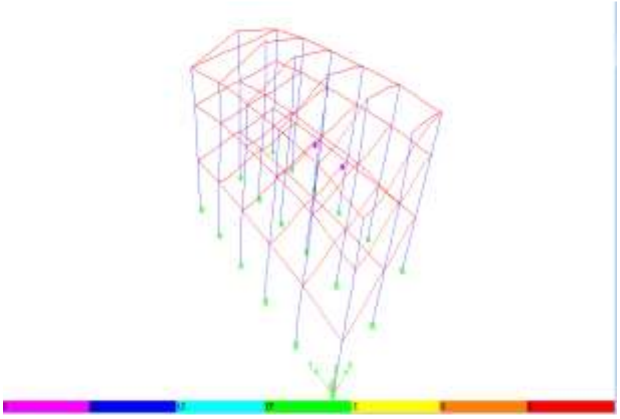

Fig 25: Hinge form at rigid connection

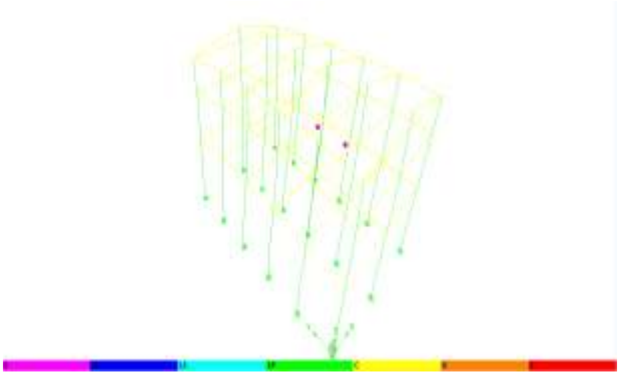

Fig 26: Hinge form at semi rigid connection

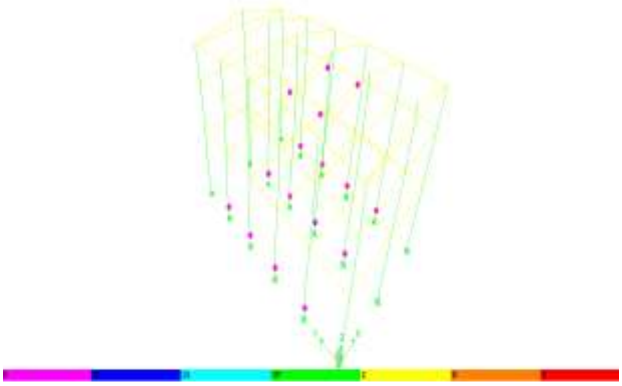

Fig 27: Hinge form at moment less connection

VI. CONCLUSION

In the present study, influence of seismic activities with various parameters is studied using nonlinear pushover analysis. Structures with soft storey at different floors are chosen in the study. An attempt is also made to study the effectiveness of incorporation of bracings and connections at ground story of buildings and comparing their base shear capacity and displacement with structures having no bracing and structures with different connections. All frames are modeled and analyzed using ETABS software.

- Structures with soft story tend to behave poorly when compared to regular structure. It was seen that structures with soft storey showed about 8% and 3%drop in base shear carrying capacity compared to regular structure for three and six storey structures respectively. Also the performance point was located at much vulnerable damage stages and status of hinges formed was more vulnerable for soft storey structures.
- The comparisons of soft storey at different floors from pushover analysis indicated that buildings with soft story at ground floor are more vulnerable and have less base shear capacity compare to regular and soft storey structures at other floors.
- From pushover analysis it is seen that strengthening the bottom storey by providing linear bracings resulted in higher base shear capacity and lesser displacement of buildings compared to buildings without bracings.
- It was found that provision of bracing improved the base shear capacity by 12% and more than 30 % respectively for three and six storey structures respectively.
- Applying rigid connections, semi rigid connections and moment less connections to structures and carrying out the pushover analysis indicated that rigid connections have higher base shear carrying capacity and lower displacement than other two connections.
- The study of performance point for structures with different parameters indicated that the structures with regular, braced and rigid connections have performance points at less vulnerable damage states than irregular structure, structure without bracing and semi rigid and moment less connections. The performance point shows the performance of buildings during seismic activities. Here the moment less connection tend to have less performance point and may lead to premature failure of building during earthquake.

- Review of hinges formed during pushover analysis for regular structure, irregular or soft storey structure, structure with and without bracing and structure with rigid, semi rigid and moment less connections revealed that higher percentage of hinges reached more vulnerable damage states in case of irregular buildings, structure without bracing and structure with moment less connection compared to building with regular configuration, bracing and other connections.

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