# Seismic Behavior of Flat Slab Building with Steel Bracing System using Pushover Analysis on ETABSv17

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***Abstract—*** ***In present era, conventional RC Frame buildings are commonly used for the construction. The use of flat slab building provides many advantages over conventional RC Frame buildings in terms of architectural flexibility, use of space, easier formwork and shorter construction time. In the present work three flat slab building models (1) flat slab with drop (2) flat slab with 'X' bracing system (3) flat slab with '/\' inverted bracing systems are considered. The performance of all three flat slab building modals were studied and for the analysis, non linear static pushover analysis method was adopted ,in order to determine the nonlinear behavior of buildings under lateral loads, base shear, displacement relationships, i.e. capacity curve are obtained by Pushover analysis. It is a type Non-linear Static Analysis, in which the strength of the structure is tested beyond the elastic limit of the structure. The analysis is done with using ETABSv17 software. All three building models having G+10 in heights and 15*25m in area . The obtained results are compared in terms of Base shear, Displacement, Storey drift. The primary objective of this work was to study the non linear behavior of flat slab building under seismic load and to study the effect of different lateral force resisting system such as steel bracings in flat slab building under seismic excitation. To study the comparative results of base shear, displacement and storey drift etc parameters as per IS-1893:2016 for different models.***

**Index Terms—** ***pushover analysis, base shear, story displacement, flat slab building, G+10 building.***

## 1. INTRODUCTION

Seismic analysis is a subset of structural analysis and is the calculation of the response of a building (or nonbuilding) structure to earthquakes. It is part of the process of structural design or earthquake engineering in regions where earthquakes are prevalent. The earliest provisions for seismic resistance were the requirement to design for a lateral force equal to a proportion of the building weight (applied at each floor level). It later became clear that the dynamic properties of the structure affected the loads generated during an earthquake. Since from the last century, structural designing problem has taken various forms, and improvements in design philosophy and methods have been done. There are two types of methods for the seismic design of structures,

1) Conventional method: This is the traditional method to resist lateral force is by increasing the design capacity and stiffness. Ex- shear wall, Braced frames or Moment resisting frames.

2) Non conventional method: Based on reduction of seismic demands instead of increasing capacity. ex-base isolation, dampers.

### 1.1 FLAT SLAB

The word "flat slab" is better understood as the slab without beams resting directly on supports. In case of flat slab, large bending moment and shear forces develop near the columns. Due to this, stresses are developed leading to cracks in concrete which may be further responsible for the failure of slab. Therefore in order to avoid this, flat slab are usually provided with drop and column head or capitals.

Flat-slab building structures possesses major advantages over traditional slab-beam-column structures because of the free design of space, shorter construction time, architectural –functional and economical aspects. Because of the absence of deep beams and shear walls, flat-slab structural system is significantly more flexible for lateral loads than traditional RC frame system and that make the system more vulnerable under seismic events. Reinforced concrete flat slabs are commonly used in construction as they provide a number of benefits to the designer including:

- Thin sections allowing for greater roof heights and lighter floors.
- Exposed ceilings
- Flexible column arrangements, this is more difficult to achieve for a beam-column design
- Fast and cheap construction using simple formwork.

### 1.2 STEEL BRACING SYSTEM

A braced frame is a structural system designed to resist wind and earthquake forces. Members in a braced frame are not allowed to sway laterally (which can be done using shear wall or diagonal steel sections also). Most braced frames are concentric. This means that, where members intersect at a node, the centroid of each member passes through the same point .Concentrically braced frames can further be classified as either ordinary or special. Ordinary concentric braced frames (OCBFs) do not have extensive requirements regarding members or connections, and are frequently used in areas of low seismic risk.

In construction, cross bracing is a system utilized to reinforce building structures in which diagonal supports intersect. Cross bracing can increase a building's capability to withstand seismic activity. Bracing is important in earthquake resistant buildings because it helps keep a structure standing. Cross bracing is usually seen with two diagonal supports placed in an X shaped manner; these support compression and tension forces. With Different forces, one brace will be under tension while the other is being compressed. It helps make structures stand sturdier and resist lateral forces.

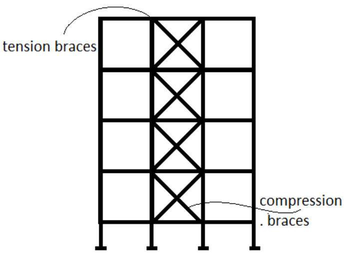

Fig.1 X bracing in building

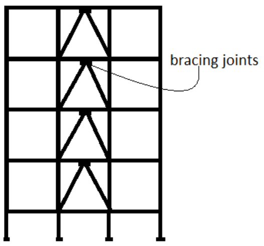

Fig.2 (/\) inverted bracing in building

## 2. LITERATURE REVIEW

A brief review of previous studies on the performance of bracing systems in flat slab buildings is presented in this section. This literature review focuses on recent contributions related to non linear static analysis of flat slab multi-storey structures and past efforts most closely related to the needs of the present work.

Ashwini Ghorpade (july 2018), In this paper, a three-dimensional RC flat Slab structure (L shape) building is modelled using SAP 2000. Flat slab model with and without shear wall and perimeter beams are analysed for earthquake loads using equivalent static method for Z-III and Z-IV and non-linear static method (Pushover Analysis). The results are extracted like displacements, story drifts, torsional moments, member forces, shear wall forces from equivalent static analysis and the pattern of hinge formations, performance points using pushover analysis. The results are compared with all the structural systems of flat slab with and without shear walls and perimeter beams. In this research work, modeling and study of seismic response along with earthquake forces on ten storey (G+9) flat slab multi-storey building in absence and presence of shear wall had been done. It can be concluded that, Flat slab with shear wall structures are preferable than RC structure since storey displacements and drifts are found to be less for both equivalent static and pushover analysis.

Md. Mahmud Hasan Mamun (2018) , In this paper , three building models are designed according to BNBC (2006) for this study, which are a beam-column frame structure, a Flat-Plate structure, and other Flat-Slab with peripheral beam structure. Non-linear static pushover analysis by using ETABS (9.7.4) was performed to assess seismic performance of these three type structures according to two main guidelines FEMA-273 and ATC 40. A nonlinear static pushover analysis is carried out for evaluating the structural seismic response. The performances of these structures are analyzed with the help of capacity curve, capacity spectrum, deflection, drift, and seismic performance level. It has found that some points of these structures can be moved up to 600 mm for 2500 KN force. To achieve this objective, three framed buildings with 5, 8, and 12 stories respectively were analyzed. Based on the research following conclusions are extrapolated -The base shear force is maximum for Flat-Plate Structure (6350 kN) and this value reduces in accordance with the increment of story numbers. Due to seismic effect, the story drift ratio and displacement are maximum for Flat Plat System. Storey-5 exhibits highest drift ratio (0.002) whereas the displacement is largest at the apex of the structure .The Flat-Plate Structure is most susceptible due to the earthquake as it has maximal point displacement. It has found that some points of these structures can be moved up to 600 mm for 2500 kn force .The pushover analysis is a relatively simple way to explore the nonlinear behavior of Buildings. A nonlinear static pushover analysis is carried out for evaluating the structural seismic response.

Rathod Chiranjeevi (oct 2016) ,in their paper presented work, the main objective is to study seismic demand for different regular R.C flat slab with drop and conventional slab structure by using push over analysis procedure as per ATC 40. In order to determine the nonlinear behavior of buildings under lateral loads, base shear , displacement relationships, i.e. capacity curve are obtained by Pushover analysis. In this work six numbers of conventional RC frame and Flat Slab with drop buildings of six, eight, and ten storey building models are considered. The performance of flat slab and conventional slab were studied and for the analysis, seismic zone III is considered. The analysis is done with using E-Tabs software. The obtained results are compared in terms of Time period, Base shear, Displacement, Storey drift. On comparison the base shear for flat slab is found to be greater than conventional slab structure, the variation is 67%, 59% and 49% for six, eight and ten storey building. On comparison the displacement for flat slab is found to be less than conventional slab structure, the variation is 64 %, 56% and 41% for six, eight and ten storey building. The natural time period increases as height of building increases, irrespective of type of building. Base shear for flat slab is found to be greater than conventional slab, the variation is 67%,59% and 49% for 6,8,10 storey building . Displacement for flat slab is found to be less than conventional slab, the variation is 64%,56% and 41% for 6,8,10 storey building . Lateral displacement will be minimum at plinth level and maximum at terrace level.

Anuj Bansal , Dakshayani S (jan 2016) , The object of this paper work was to compare the behavior of multi-storey buildings having flat slab with that of having grid slab and to study the effect of base shear, storey drift and maximum displacement on it under seismic forces. For this purpose three cases of multi-storey buildings are considered with area 20 m x 20 m having 4 storey, 8 storey and 12 storey with 3.6 m storey height considered. All the three cases are considered having flat slab and grid slab, and also analyzed software SAP2000.Observation shows that pushover analysis is a simple way to explore the nonlinear behavior of building. Also pushover analysis is an approximation method based on static loading. Performance points for flat slab are larger than in grid slab models. Resultant displacements for flat slab are quite larger than in grid and also base shear in both types of slabs.

Bhavesh Rajesh Sahni (march 2015) , the main objective of this paper to prove that flat slab with the application of shear wall show same results as that of conventional slab. The analysis is done by using Etabs software and results being compared in all seismic zones. As I.S.1893-2016 does not allow flat slab in higher seismic zone we have studied various parameters in this paper such as deflection, story drift, overturning moment resistance and base reactions and compared three models first being conventional slab, second being pure flat slab and third being flat slab with shear wall. Flat slab gives the advantage over conventional slab with reduced floor to floor height which gives flexibility in construction and reduction in construction time. As I.S.1893-2016 does not allow flat slab in higher seismic zone there are various parameters studied in this paper such as deflection, story drift, overturning moment resistance and base reactions and compared three models first being conventional slab, second being pure flat slab and third being flat slab with shear wall. From this study it was conclude that flat slab structure is more flexible than conventional frame structure and because of that it does not perform well in higher seismic zones but with the application of shear wall flat slab structures showcase properties same or even better than conventional structure.

## 3. METHODOLOGY

To examine the seismic behaviour of flat slab building with and without steel bracing system, comparative analytical study has been carried out between the models using static non-linear pushover analysis method. The analyses have been performed using ETAB version 17.0. In pushover analysis method, for the calculation of different parameters like displacement and member forces, only the maximum values are considered. The work started with modeling and analysis of flat slab building for three cases. (1) flat slab building without bracings (2) flat slab building with X bracing system and (3) flat slab building with inverted (/\) bracing system . In the present study steel bracings are used as a lateral force resisting system. After analysis of flat slab building model using E-TABS 17.0 version software, maximum lateral forces are obtained. By using these values steel bracings are designed and the same is used for the rest model analysis.

### 3.1 METHOD USED FOR ANALYSIS

**3.1.1 Pushover Analysis:** Pushover is a static-nonlinear analysis method where a structure is subjected to gravity loading and a monotonic displacement-controlled lateral load pattern which continuously increases through elastic and inelastic behavior until an ultimate condition is reached. Lateral load may represent the range of base shear induced by earthquake loading, and its configuration may be proportional to the distribution of mass along building height, mode shapes, or another practical means.

**3.1.2 Why Pushover Analysis method:** The need for a simple method to predict the non-linear behaviour of a structure under seismic loads saw light in what is now popularly known as the Pushover Analysis (PA). PA is a non-linear analysis procedure to estimate the strength capacity of a structure beyond its elastic limit (meaning Limit State) up to its ultimate strength in the post-elastic range.

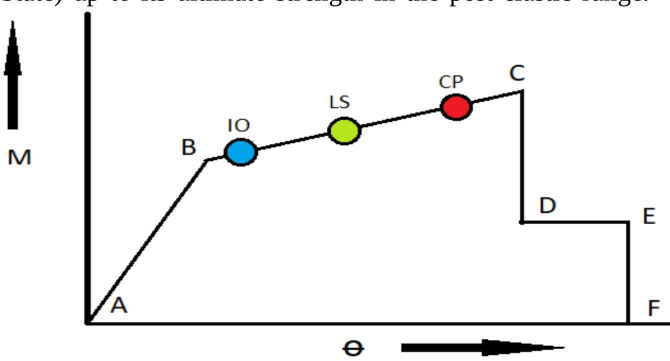


Fig.3 static pushover curve

in Fig.3. AB represents the linear elastic range from unloaded state A to its effective yield B, followed by an inelastic but linear response of reduced (ductile) stiffness from B to C. CD shows a sudden reduction in load resistance, followed by a reduced resistance from D to E, and finally a total loss of resistance from E to F. Hinges are inserted in the structural members of a framed structure typically as shown in Fig.2. These hinges have non-linear states defined as 'Immediate Occupancy' (IO), 'Life Safety' (LS) and 'Collapse, Prevention' (CP) within its ductile range. This is usually done by dividing B-C into four parts and denoting IO, LS and CP, which are states of each individual hinges (in spite of the fact that the structure as a whole too have these states defined by drift limits)

**3.1.3 The Plastic Hinges-** Hinges are points on a structure where one expects cracking and yielding to occur in relatively higher intensity so that they show high flexural (or shear) displacement, as it approaches its ultimate strength under cyclic loading. These are locations where one expects to see cross diagonal cracks in an actual building structure after a seismic mayhem, and they are found to be at the either ends of beams and columns, the 'cross' of the cracks being at a small distance from the joint. Hinges are of various types – namely, flexural hinges, shear hinges and axial hinges.

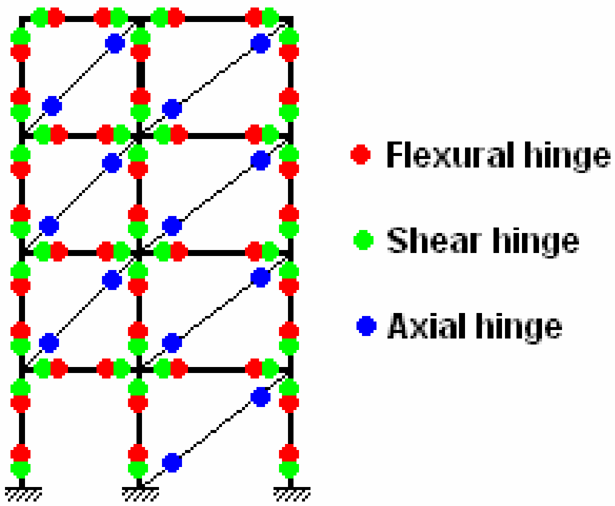


Fig. 4 plastic hinge formation

## 4. DESCRIPTION OF THE BUILDING

### 4.1 Geometrical Properties

Table 1

| SNo. | PARAMETERS | DIMESIONS |
|---|---|---|
| 1 | Building type | Commercial Building |
| 2 | Type of frame | Flat Slab System |
| 3 | Plan dimension | 25x15 (X*Y) |
| 4 | No. of stories | G+10 |
| 5 | Floor to floor height | 3m |
| 6 | Total height ff building | 30m |
| 7 | Flat slab thickness | 150mm |
| 8 | Thickness of the drop | 200mm |
| 9 | Width of drop | 1.5m |
| 10 | Column size | 400x400mm |

**4.2 material properties (IS 456:2000)**

Table 2

| S.No | Material | Grade(N/mm$^2$) |
|---|---|---|
| 1 | Grade of concrete (drop & slab) | M20 |
| 2 | Grade of concrete(column) | M25 |
| 3 | Rebar | Fe415 |

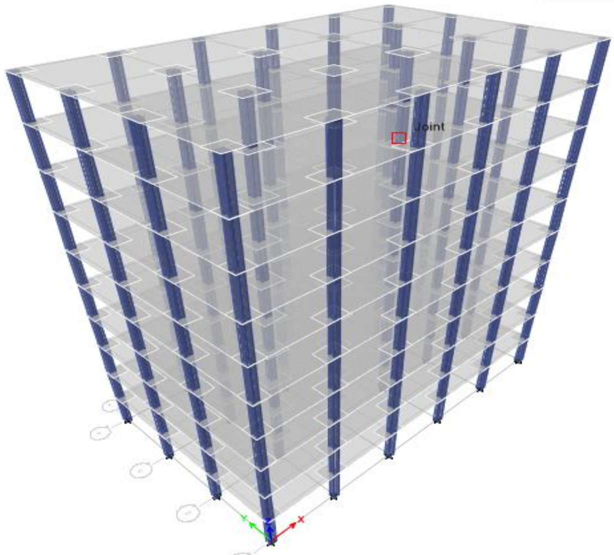

Fig. 7 Model 1 flat slab building (3D view)

## 5. MODELLING AND ANALYSIS

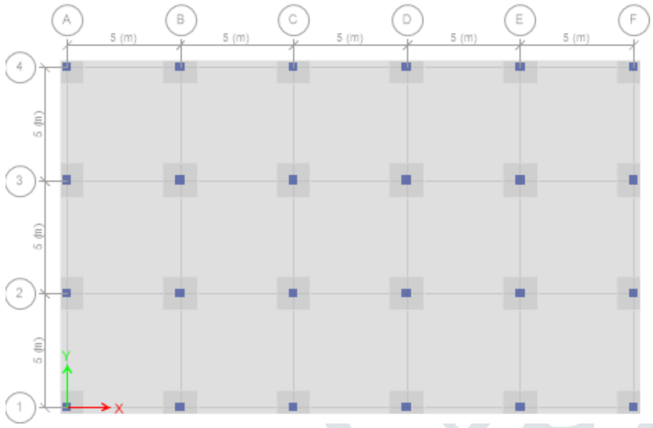


Fig. 5 Model 1 flat slab building (plan view)

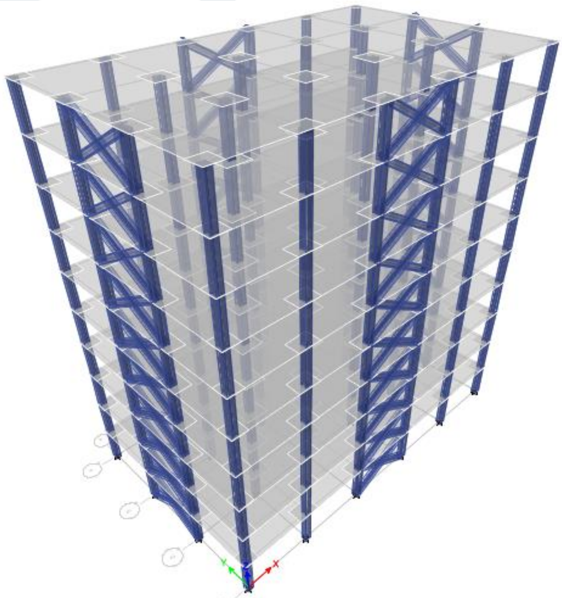

Fig. 8 Model 2 flat slab with X bracing (3D view)

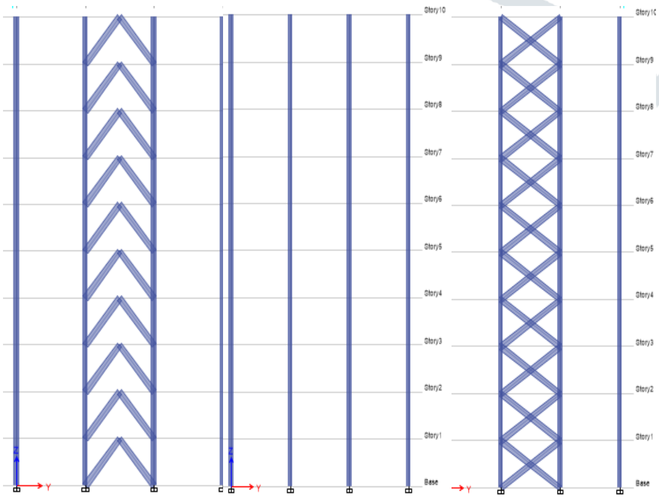

Fig.6 Elevation view of all three models

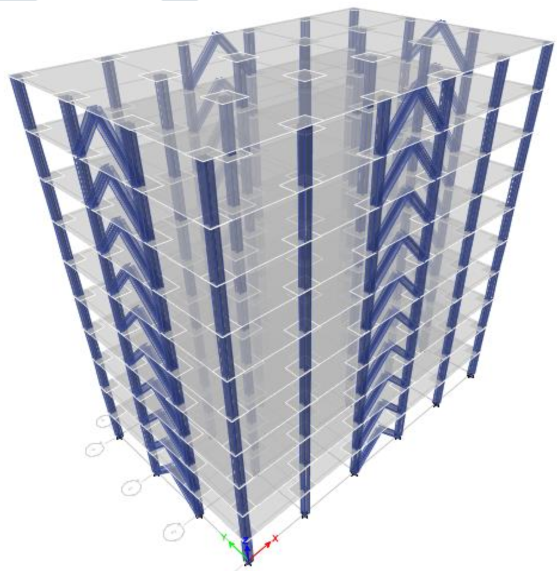

Fig.9 Model 3 flat slab building with /\ bracing system

## 6. RESULTS AND DISCUSSION

### 6.1 Base shear and monitored displacement curve : X

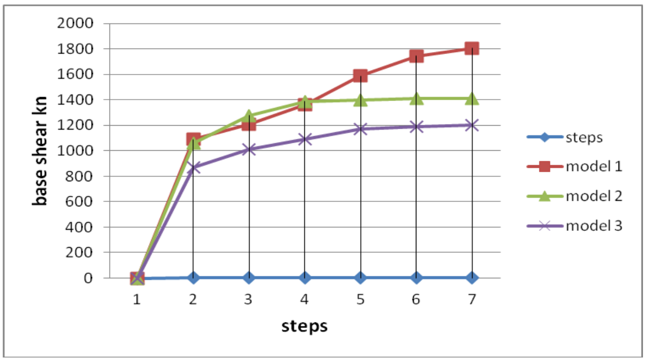


Fig. 10 pushover curve in x direction

### 6.2 Base shear and monitored displacement curve :Y

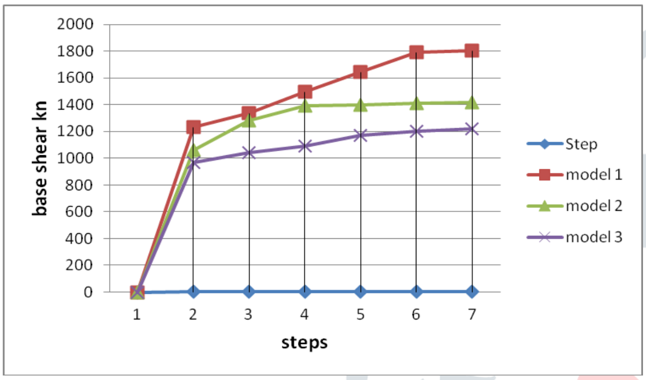


Fig. 11 pushover curve in y direction

### 6.3 Story Displacement :X

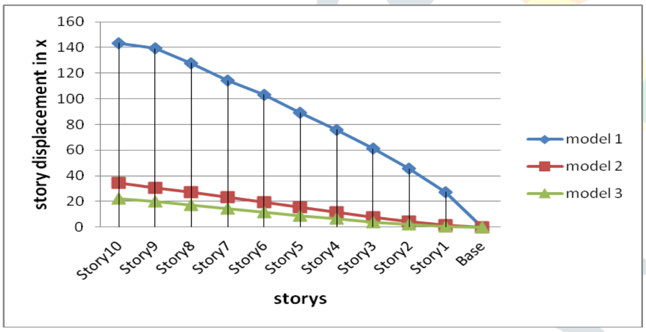


Fig. 12 story displacement curve in X direction

### 6.4 Story Displacement :Y

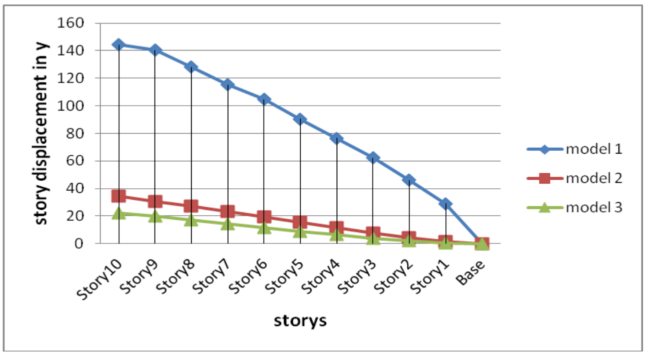


Fig. 13 story displacement curve in Y direction

### 6.5 Story Drift: X

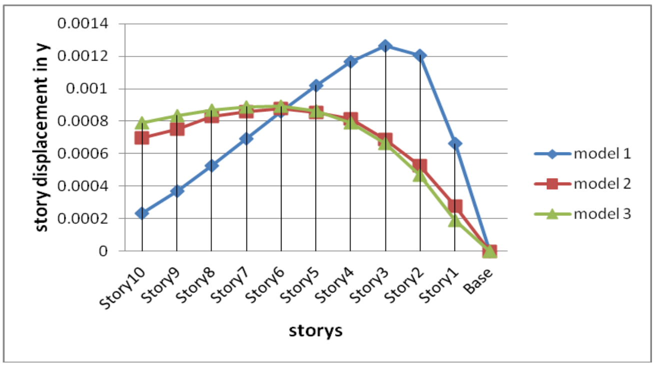


Fig. 14 story drift in x direction

### 6.6 Story Drift: Y


Fig. 15 story drift in y direction

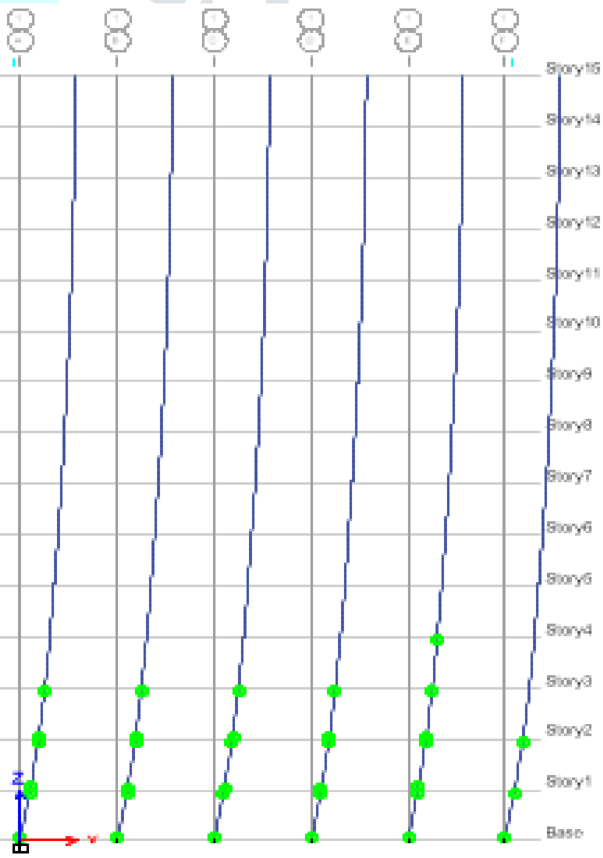

Fig. 15 Formation of Plastic Hinges

## 7. CONCLUSION

This research represents the study flat slab G+10 commercial building along with steel bracing system, on the basis of analysis following conclusions have been drawn for flat slab structural framework:

1. Model 1 i.e. flat slab building shows poor performance during earthquake excitation when compared to flat slab building with X bracing system due less lateral stiffness.

2. To increase the performance of the flat slab building structure under horizontal loads, particularly when speaking about seismically prone areas modifications of such system can be done by adding structural elements such as shear wall or steel bracings.

3. The inter storey drift in model 1 building as per clause 7.11.1 in IS 1893:2016 part 1 did not exceed the allowable limits but shows very poor performance as compared to other models.

4. The overall performance of all three buildings has been studied with various seismic parameters. It was found that the base shear of the model 3 was comparatively greater among all the other model structures.

5. Within the limitations of this study, it is recommended that the flat slab building with /\ bracing system should be preferred because of considerable difference in storey displacement, base shear and storey drift, when compared to the other model.

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