Pushover Analysis Using Cyclic Loading for RC Building in Different Seismic Zones Using ETABS Software

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Abstract - Pushover analysis, which is also stated as the non-linear static analysis is widely used procedure for the seismic assessment or evaluation of the structures. The advantage of using the pushover analysis is its simplicity, efficiency in modelling and low computational time. Since the linear static analysis is inadequate in assessing the seismic demand of the structure under severe earthquake. The pushover analysis is widely used to evaluate the seismic demand of the proposed structure or for an existing structure. In this paper the pushover analysis is carried out to understand the behaviour of a residential building with G+10 storeys, using cyclic loading in different seismic zones i.e. zone II and zone IV respectively using ETABS-2017 software. The analysis is carried to check the model for safety against the seismic loads, the seismic loads are given in accordance to the IS 1893:2016. From the analysis results we will compare the maximum lateral loads, storey displacement, storey drift, storey shear, and static push over curve and hinge result for beams and columns.

Keywords – Pushover analysis, cyclic loading, static pushover curve, non-linear static analysis, seismic loads, ETABS.

I. INRODUCTION

Nonlinear static analysis which is also stated as pushover analysis has been developed over the past twenty years and has now become a preferred analysis procedure for design and seismic performance evaluation purposes as it is a relatively simple in procedure and considers post elastic behaviour of the structure. However, the procedure also involves certain approximations and simplifications that some amount of variations are always expected to exist in seismic demand prediction of pushover analysis. The buildings that are designed with earlier i.e. older codes are exposed to earthquake, due to which it causes a wide spread loss of life and property. It is important to study the weakness of the structures in contrast to the seismic activity. In the major cities the buildings that are designed using the older codes are at a major risk in the event of a moderate or a major earthquake or shaking of earth. In order to overcome these problems pushover analysis has been generally used on earthquake response prediction of building structures under severe earthquakes. Pushover analysis or nonlinear static procedure has been widely used for evaluating the performance of existing buildings and verifying the design of seismic retrofits.

Recently there has been a considerable increase in tall buildings for both residential and commercial. The modern trend is towards more taller and slender structures. Therefore the effect of lateral loads like wind loads, earthquake load and blast forces are attaining increasing importance and almost every designer is faced with the problem of providing adequate strength and stability against lateral loads. There is a new development as the earlier buildings and designers used to design the building for vertical loads only, but now it is important also to consider that the structures are been designed for lateral loads also. Structure developed over the past twenty years. It has become the preferred analysis procedure for design and seismic performance evaluation of post elastic behavior of structure. The analysis involves certain approximations and simplifications that some amount of variation is always expected to exist in seismic demand prediction of pushover analysis. Push over analysis is an Improvement over the linear static and dynamic analysis in the sense that allows the inelastic behavior of the structure.

This method is relatively simple to be implemented and provides information about the strength deformation and ductility of the structure and distribution demand. Push over analysis can be done by force controlled method. It will carried out & all parameter like base shear, story drift, point drift, story shear, story displacement. The main Output of push over analysis is in the form of force displacement Curve. It is plot base shear Vs lateral displacement. Push

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over analysis does not account of dynamic characteristics. It gives better result for regular building without torsional irregularity.

1.1 Advantages of the Pushover analysis

It can be seen that pushover analysis procedure leads to evaluation of those response quantity which are otherwise is not possible by static analysis. Response characteristics that can be obtained with the pushover analysis include with

1. Realistic force demands on potentially brittle elements, such as axial demands on columns, moment demands on beam-to-column connections or shear forces demands on short, shear dominated elements.
2. Estimates of the deformation demands on elements that have to deform in elastically, in order to dissipate energy.
3. Consequences of the strength deterioration of particular elements on the overall structural stability.
4. Identification of the critical regions, where the inelastic deformations are expected to be high.
5. Identification of strength irregularities in plan or elevation that cause changes in the dynamic characteristics in the inelastic range.
6. Estimates of the inter-storey drifts, accounting for strength and stiffness discontinuities. In this way, damage on non-structural elements can be controlled.
7. Sequence of the member's yielding and failure and the progress of the overall capacity curve of the structure.
8. Verification of the adequacy of the load path, considering all the elements of the system.
9. The non-linear static analysis gives better understanding and more accurate seismic performance of the building damage or failure element of the structure.

II. Literature Review

V.Paneer Selvam and K.Nagamani [1]

In this paper the author has studied the seismic response of existing RC building under revised seismic zone classification using pushover analysis. In this paper, the author studied a seven storey RC building to investigate the structural seismic response using SAP 2000.The displacement controlled pushover analysis was carried out and the pushover curve was obtained for the building in both X and Y directions. The existing building was studied using the seismic load calculated as per IS 1893:1984 and seismic load calculations as per IS 1893:2002 in zone II and zone III.The building was build 12 years ago using the old code for seismic loads, the objective of the paper was to analyze the old building using the new seismic codes and testing it under different combinations dead, live, wind and seismic code provisions. An analytic model was created representing the existing building and was analyzed using pushover and target displacement of the building was 80mm but the building was analyzed for the displacement upto 200mm under the seismic zones II and III.

V.Mani Deep and P.Polo Raju [2]

In this paper the author has studied a G+9 multistoried residential building located in different seismic zones (II, III, IV, V) using SAP 2000. The investigation is in terms of force-displacement relationships, inelastic behaviour of structure and sequential hinge formations. A G+9 residential building was modelled, analyse and studied. The plan size of the building taken was (20x20), building height 31m. Various graphs such as comparison of maximum base shear of different zones, comparison of maximum displacement of different zones, comparison of maximum time period of different zones and comparison of maximum base shear and maximum displacement were plotted after carrying out the push over analysis over the building using the values obtained. The following conclusion were derived as we go from zone II to zone V seismic demand increases, the performance point changes from linearity to IO, to LS level as the zone is considered from zone II to zone V.

Akshay V.Raut and RVRK Prasad [3]

In this paper the author has studied the behaviour of G+3 reinforced concrete frame structure subjected earthquake forces in zone II.The reinforced concrete structure was analyzed by nonlinear static analysis (pushover analysis) by using SAP2000 software. The structure was checked for the performance levels, behaviour of the components and failure mechanism in the building. The research also showed the types of hinge formation, strength and capacity of the weakest components. The frame was subjected to design earthquake forces as specified in IS code in zone II along longer direction. The pushover curves for the building in X-direction which shows the behaviour of the frame in terms of its stiffness and ductility were obtained. The following results were obtained for the bars frame maximum base shear from pushover analysis was 951.78KN and maximum displacement of 240.65mm in X-direction.

Mukul Rathore, Anik Gupta and Dr.Surajit Das [5]

In this paper the author has carried push over analysis of a multistorey building using sap 2000. Firstly they analysed a G+4 building in STADD.PRO to calculate design seismic force by static analysis method and lateral load distribution with height and then the same building was modelled in SAP platform to carry out pushover analysis. The capacity spectrum, demand spectrum and the performance point of the building was founded in both X and Y direction using the SAP 2000. From the performance point it was concluded by the author that the base shear carried by the

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building is well above the design base shear. Maximum displacement was found to be less than 1% which indicates that the chances of building crossing the elastic state are very less. The building was first deigned in STADD PRO and was analysed for seismic loads using SAP, the seismic loads were given in accordance to the IS 1893:2002.

III. METHODOLOGY AND MODELLING

In this paper a G+10 building is selected for the study. Two zones zone II and zone IV are considered located on medium soil, as per IS 1893: 2016. The structural plan is drawn in AUTOCAD-2016 as shown in fig.1. The building is modeled using ETABS-2017 software. The pushover analysis is carried out in ETABS. Here the developed RC structure model is subjected to response spectrum analysis and pushover analysis using cyclic loading is performed as per IS 1893:2016. The table no.1 shown below shows the different parameters considered for the development of the structural model. The dead load and live loads are taken as per the codal provision IS 875-1987 (part-1) and IS 875-1987 (part-2) respectively. For earthquake IS 1893:2016 is considered for the analysis. The seismic parameters for zone II and zone IV are shown in table no. 2 and table no. 3 respectively. This shows the zone selected, soil type, importance factor, response reduction factor, dampness ratio, wind speed and terrain category. The cross sectional dimension of the slabs, beam, columns are chosen by trial and error method in such a way that the RC members are safe. The model so generated in ETABS is shown in Figure no.2 it shows the plan view and 3-D view

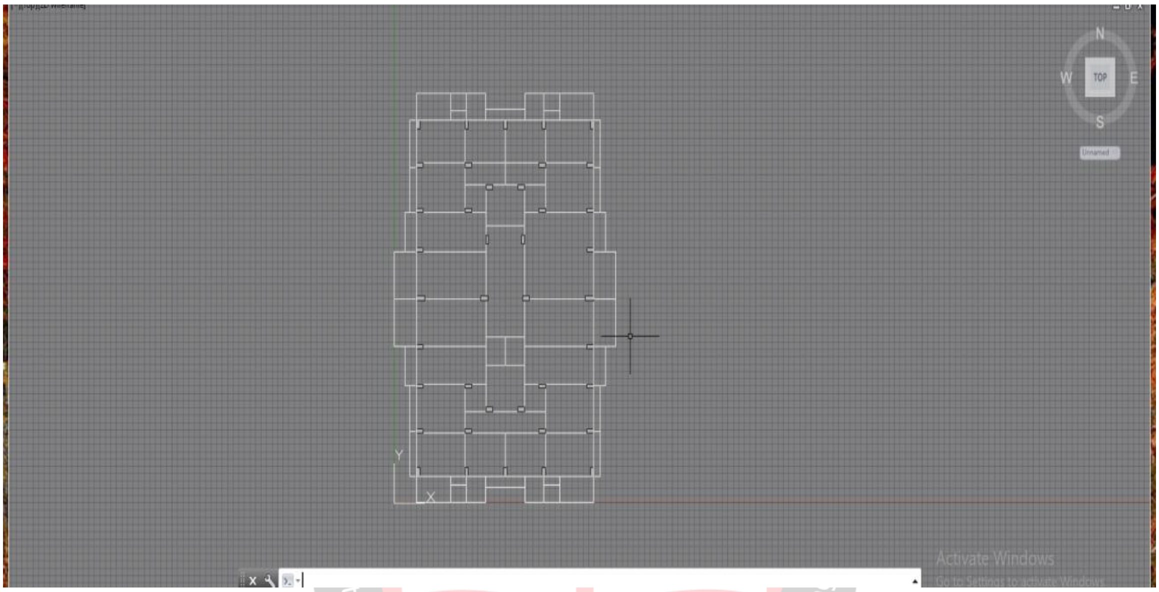

Fig.no.01: Structural plan in AutoCAD.

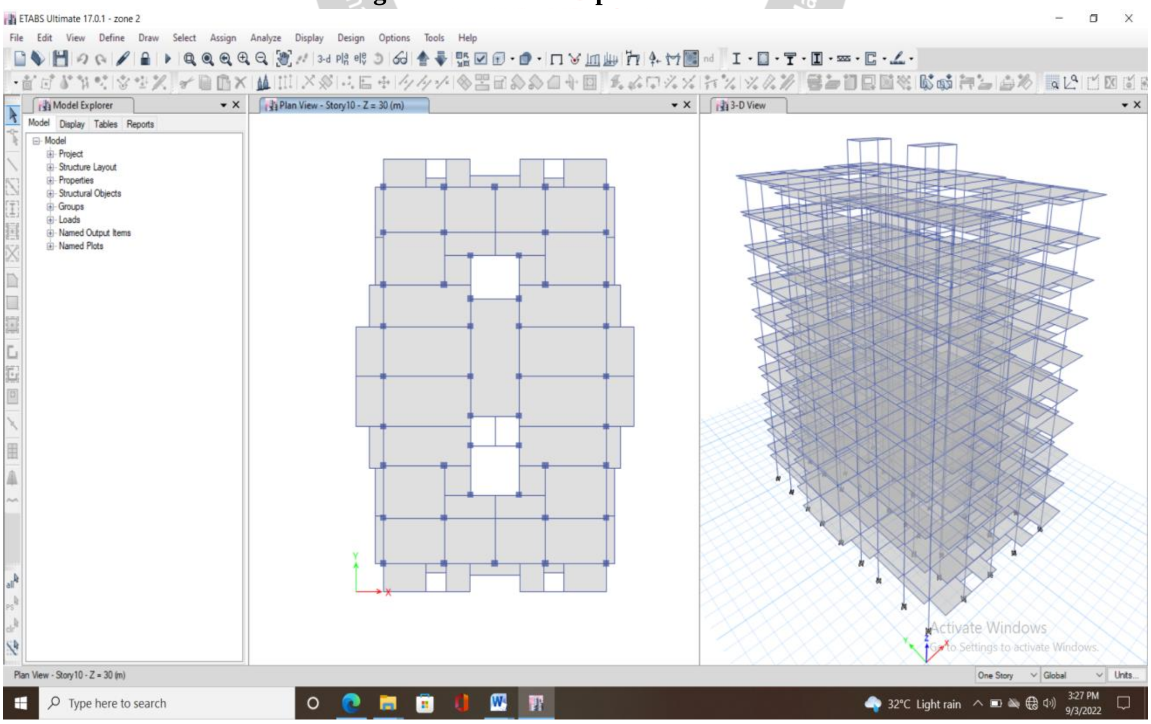

Fig.no.02: Plan view of building model in ETABS-2017.

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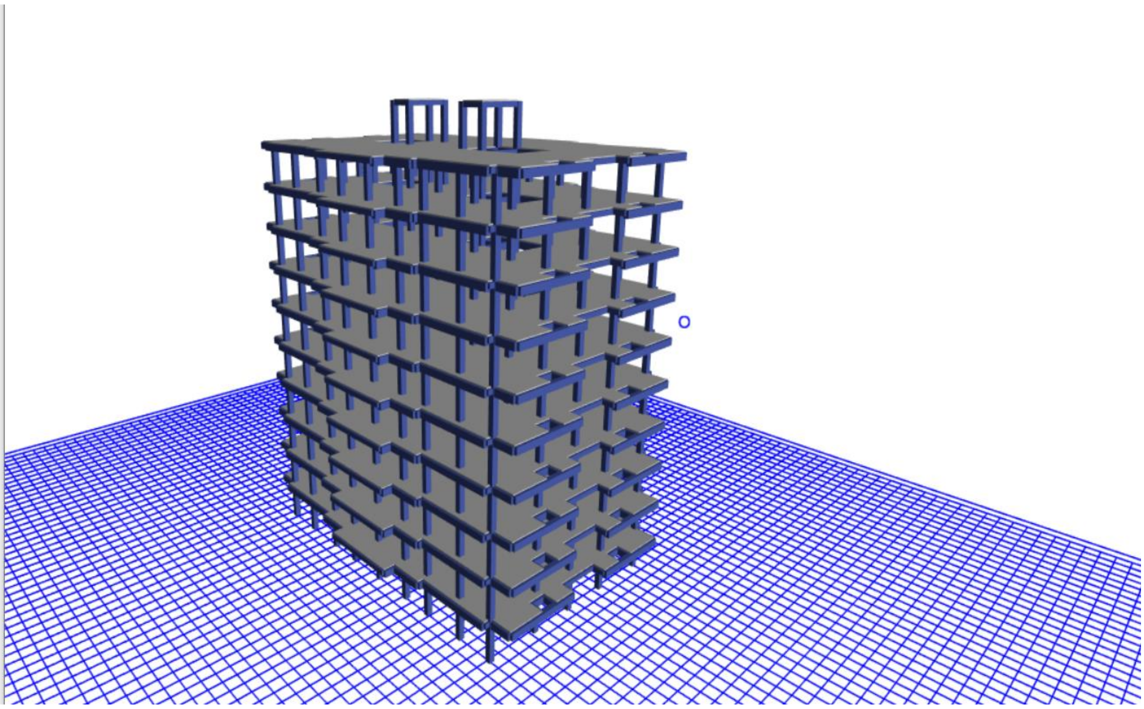

Fig.no.03: 3-D view of building in ETABS.

3.1 Parameters considered for modelling and analysis.

Table no.1: Parameters considered for modelling of building.

SR.NO	PARAMETERS	REMARKS
1.	Type of Structure	Residential
2.	Total Stories	G+10
3.	Total Height	30 m
4.	Bay Width in X-direction	19.950 m
5.	Bay Width in Y-direction	28.500 m
6.	Size of Beam	300mm x 300 mm
7.	Size of Column	400mm x 450mm
8.	Slab Thickness	150mm
9.	Story Height	3m
10.	Grade of Concrete for Beam	M20
11.	Grade of Concrete for Column	M25
12.	Grade of Concrete for Slab	M20
13.	Grade of Steel (main bars)	FE 415
14.	Grade of Steel (Lateral ties)	FE 250
15.	Density of Concrete	25 Kn/m^3
16.	Density of Bricks	20 Kn/m^3
17.	Live load on floor	4 Kn/m^3
18.	External wall load	13.5 Kn/m^2
19.	Internal wall load	6.75 Kn/m^2
20.	Floor finish	2 Kn/m^3

Table no.2: Seismic Parameters for Zone II

SR.NO	Seismic Parameters	Remarks
1.	Zone Type	II
2.	Damping Ratio	3%

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3.	Soil Type	Medium (II)
4.	Zone factor	0.10
5.	Importance factor	1.2
6.	Response reduction factor	3.0
7.	Wind speed	39 m/s (Aurangabad)
8.	Terrain category	3.0

Table no.3: Seismic Parameter for Zone IV

SR.NO	Seismic Parameters	Remarks
1.	Zone Type	IV
2.	Damping Ratio	5%
3.	Soil Type	Medium (II)
4.	Zone factor	0.24
5.	Importance factor	1.2
6.	Response reduction factor	3.0
7.	Wind speed	39 m/s (Aurangabad)
8.	Terrain category	3.0

3.2 Procedure for Pushover analysis

The building is pushed in one horizontal direction and the behaviour of the building is studied in the form of top deflection. The lateral load intensity is gradually increased in a controlled manner such that the plastic hinges formation and failures in structural elements are recorded. The following steps were followed

1. The building is model is prepared and all the parameters are defined such as beam, column, slab and concrete grade is defined and analysed and loads are defined and assigned as per the loading patterns and the model is prepared.
2. For pushover analysis the force Pa-X and Pa-Y is defined in load pattern under nonlinear static case to push the building in X and Y direction respectively.
3. Hinges are assigned to beams and columns in the building using define hinge properties before the analysis the hinge overwrite is performed.
4. The model is checked for error before the analysis, the model showed no warring.
5. The analysis is carried out using run analysis and results are obtained.

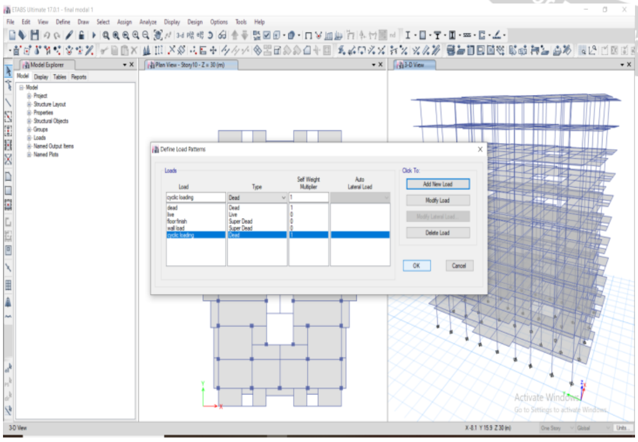

Fig. 04 – Window showing load cases defined.

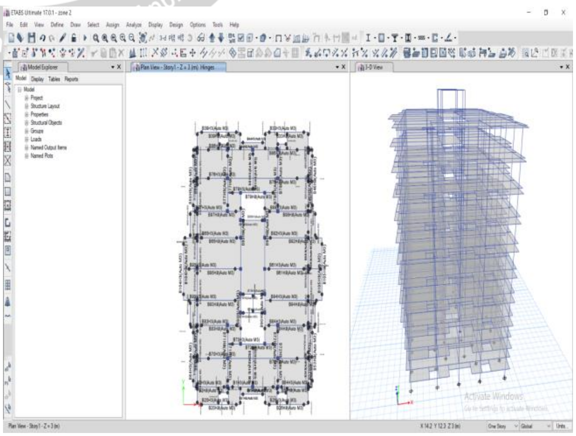

Fig. 05-Window showing Hinges formed in Beams

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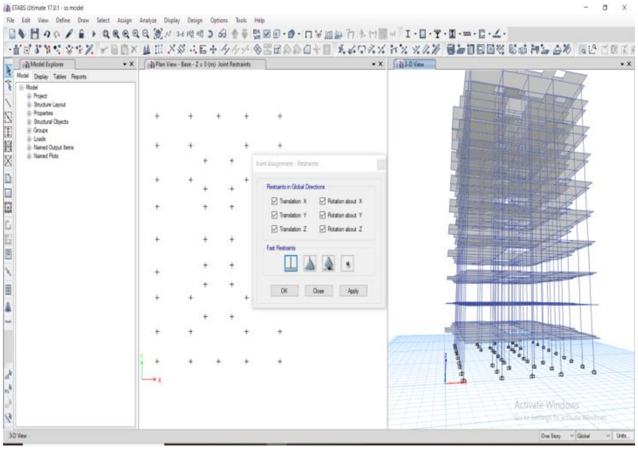

Fig. 06 – Window Showing the support conditions defined

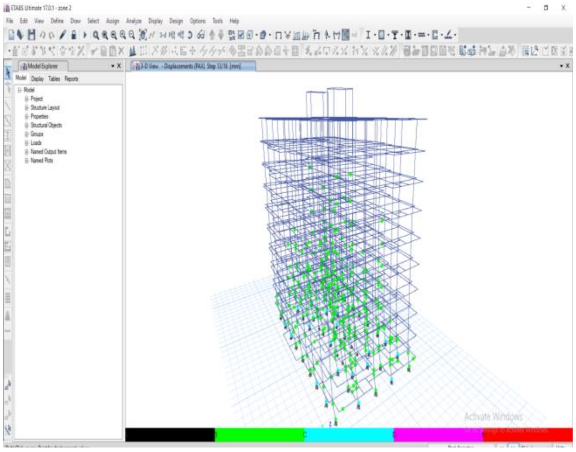

Fig. 07 – Window Showing Hinges formed in building.

IV. RESULTS AND DISCUSSIONS

The results that are obtained from response spectrum analysis and pushover analysis for the developed structure model as per IS 1893-2016 using ETABS (Version 2017) software are as follows

1. Base shear vs displacement (PUSH OVER CURVE)

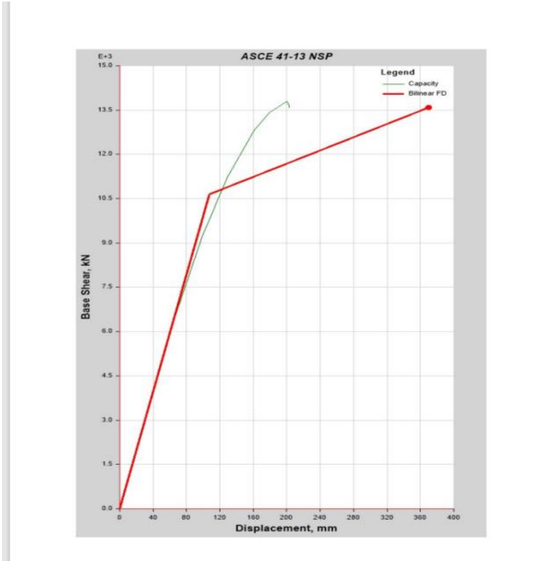

Fig. 08 - Base shear v/s monitored displacement (II)

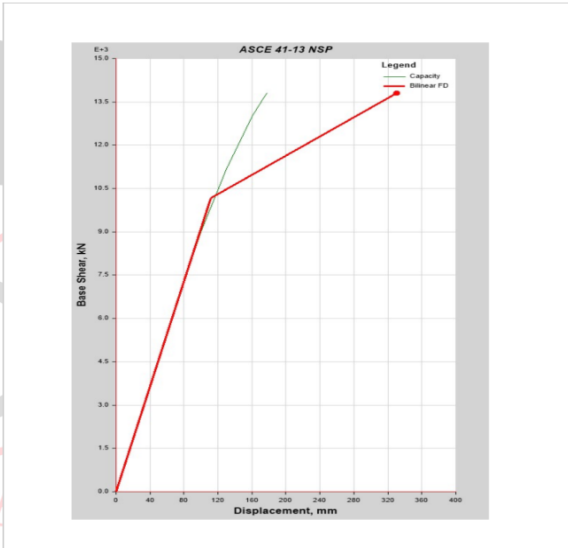

Fig. 09 - Base shear v/s monitored displacement (IV)

The base shear v/s displacement plot as per ASCE 41-13 NSP for zone II and zone IV is shown in the figure 04 and 05 respectively.

2. Hinge results

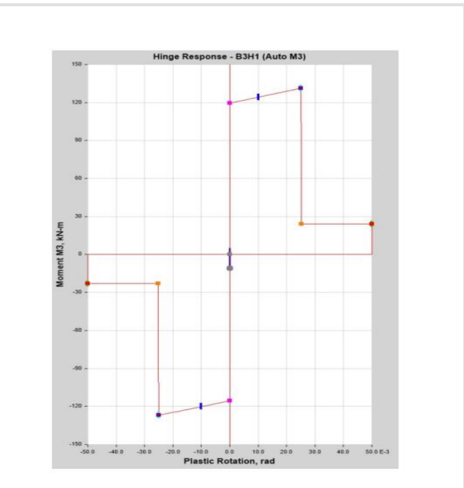

Fig. 10 – Hinge response in beam for PX (II)

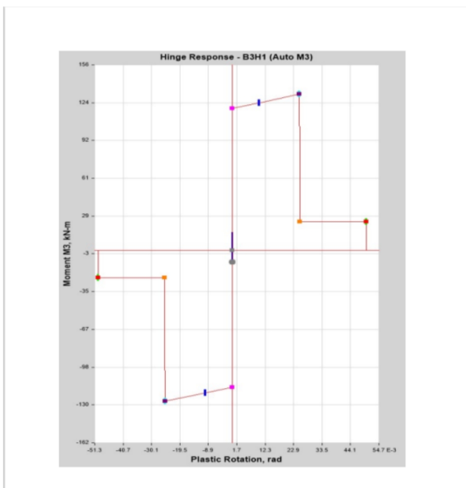

Fig. 11- Hinge response in beam for PX (IV)

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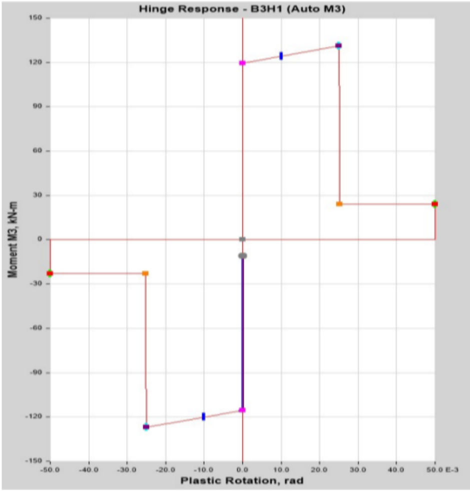


Fig. 12 – Hinge response in beam for PY (II)

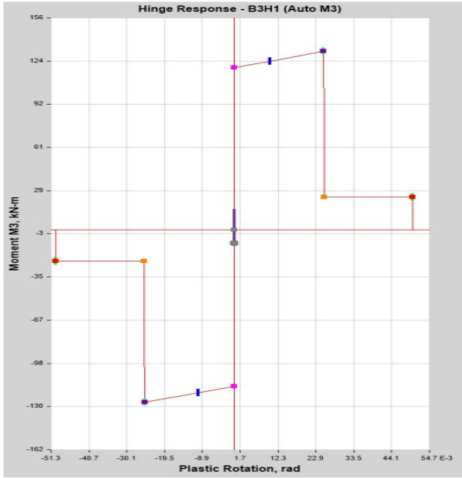
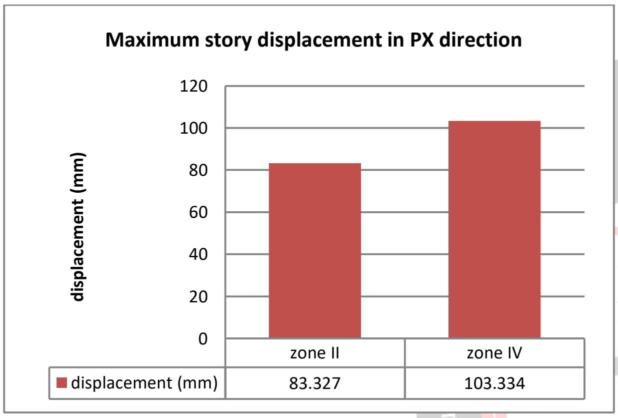


Fig. 13 – Hinge response in beam for PY (IV)

Hinge results obtained from nonlinear static analysis for beams and columns for zone II and IV are shown in figure 6, 7, 8 and 9 respectively.

3. Maximum story displacement



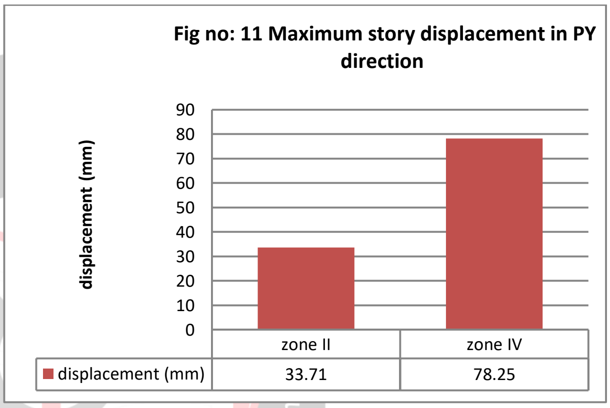
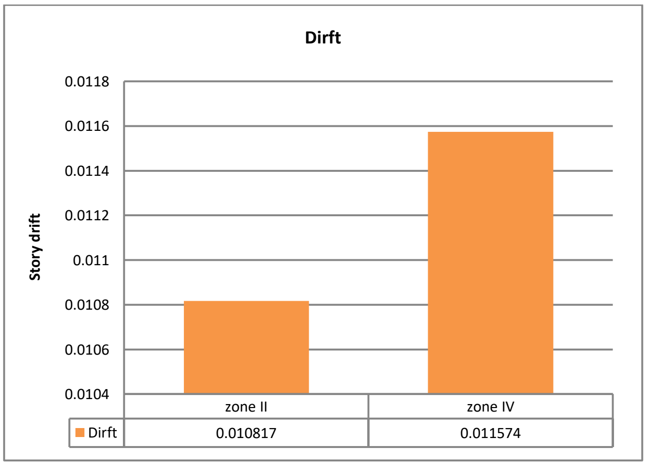


Fig no: 14 Maximum story displacement in PX direction **Fig no: 15 Maximum story displacement in PY direction**

The maximum displacement values obtained using pushover analysis in X and Y directions for different zones are shown in figure 10 and 11.

4. Drift and Base reaction



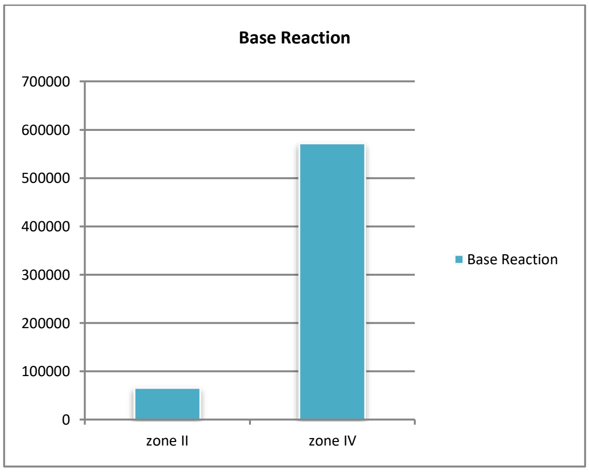


Fig no: 16 storey drift **Fig no: 17 Base Reaction**

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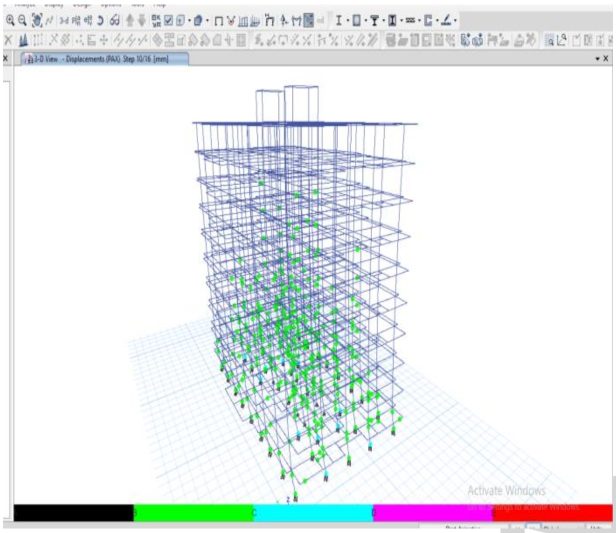
The storey drift is shown in the figure 12 for the both the zones i.e. II and IV respectively it can be seen that the storey drift is more in zone IV.

The figure number 13 shows the values of the base reaction obtained.

5. Hinge formation during the pushover analysis.

Hinge Formation in zone (II) **Hinge Formation in zone (IV)**



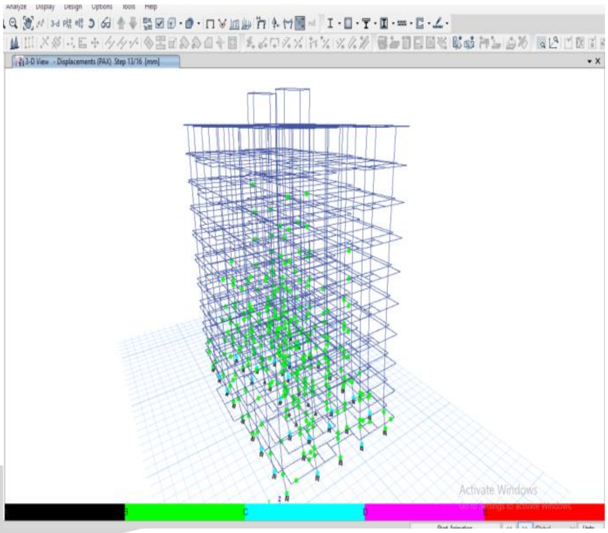


Fig. 18 – Hinge Formation in zone (II) **Fig. 19– Hinge Formation in zone (IV)**

The hinges formed in zone II after the push is applied shows the hinges formed in green colour as shown in the figure number 14, shows that the hinges formed are in safe zone as shown in the figure above. Hence the building is safe.

V. CONCLUSION AND FUTURE SCOPE

In the present study, seismic parameters such as story displacement, story drifts, lateral load to stories and static pushover curves for base force v/s monitored displacement plots are obtained and shown, comparison is been carried out for zone II and zone IV.

- The target displacement limit has shown no failure when the structure is subjected to Pushover analysis as shown in the figure number 10 and 11 respectively.
- Hinge formations are seen in the beams and columns, when pushover analysis is performed. In this study more hinges are formed in X direction when compared to Y direction.
- Also it has been seen that the hinges are formed between IO (intermediate occupancy) to LS (life safety) which indicates the building is safe. Hence the structure model analyzed in this state is safe. This can be clearly seen from the figure 14 and 15 shown above.
- The lateral load to stories is more in zone IV compared to zone II.
- The maximum story displacement as per IS 456:2000 is 0.004H (0.132mm) for the height of the building i.e. 33.5m. The maximum story displacement form the analysis obtained is 103.334m in X direction which is well within the limit, hence the building is considered safe.
- The maximum allowable story drift as per IS code is 0.7 to 0.25% of Height, therefore the value so obtained for 33.5m is (0.23m to 0.825m) and the result obtained 0.011574m which is well within the range of the building.
- The maximum monitored displacement is within the value of target displacement that is assumed. The behavior of the structure is significant to resist the lateral loads.
- Form the above results it can be concluded that the building so analysed with the given parameters is safe for design in zone II and zone IV under earthquake, for zone IV some design changes is recommended for safety and stability.

FUTURE SCOPE

In this study pushover analysis is performed without infill walls, but this work can be extended with considering infill walls and shear walls. In the present study the frame has been analyzed under the cyclic loading, this can be also analyzed under the monotonic loading so that the load-deflection curves can be monitored. The nonlinear static procedure is extended for seismic damage assessment of asymmetrical buildings and symmetrical too.

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