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Seismic Performance and Cost Analysis of a Low Rise Reinforced Concrete Building Designed for Different Force/Response Reduction Factors

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ABSTRACT: Reinforced concrete structures are susceptible to lateral forces among them seismic loads which are quite unpredictable. For this reason, several structures have been brought down or have been damaged to almost beyond recognition standard due to the effects of an earthquake. This issue is solved by using nonlinear properties instead of the linear properties. Linear properties are somewhat constrained, compared with nonlinear properties that provide more accurate values. This research concerns the economical point of view of low rise reinforced concrete building in various seismic regions. It establish the degree of difference between pushover analysis and nonlinear time history analysis for a given building in different seismic zones.

KEYWORDS: Reinforced concrete buildings, non-linear pushover and time history analysis, cost analysis, earthquake zones, and SAP2000.

I. INTRODUCTION

A majority of the previous earthquakes' casualties have involved structures made with indigenous building materials including stones, bricks and wood which do not possess engineering properties that facilitate earthquake resistance. The country of India is located on moderate to high seismicity zones and rather frequently it is exposed with strong and catastrophic earthquakes that caused numerous losses of lives and great amount of damage. Many of the major regions lying across the earthquake prone zone are Delhi, Mumbai, Rajasthan, Gujarat, and so on. There is also the need to apply use of earthquake resistance elements for construction works. There is also the need to use earthquake resistant elements in construction works. In future, the kind of buildings that would be constructed should be safe enough and should be able to withstand earthquakes. In the capacity of civil engineers we can notice that there is no awareness about the potential of making buildings earthquake resistant with only a few extra costs. Appropriate requirements must be put in place in construction of buildings to help in the case of an earthquake. It is impossible for earthquakes not to occur because 60% of the geographic area of India is exposed to seismic hazards. Preventing or reducing property and loss of lives encompasses qualities of construction, quality management, and safety measures in construction. Due to the effects of earthquakes and damages to structures, earthquake analysis and design theories exist to help structures withstand the shaking motion of the ground. It is logical that a building may not function again in the future; however, it must perform its function during an earthquake. Critic structures including hospitals, buildings, dams, bridge, malls and others have to be constructed with consideration to withstand an earthquake. Being a structural engineer I have to guarantee safe construction of buildings by modeling reinforced concrete structures and cost analysis in different zones of seism activity.

The aim of this research is to design and assess a G+5 multi-storey building model in different Seismic Zones namely II, III, IV, V and also check the cost.

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II. LITERATURE REVIEW

V. Varalaxmi et al. [1] present an article on the building construction where the main aspect highlighted entails the analysis and design of the beams, columns, and slabs. They described in detail about how the parameters, assign loads, and the distribution of loads utilizing SAP2000. P. Jayachandran et al. [2] explain how to decide on the dimensions of beams, columns, and slabs, dictates load factors, and how to allocate loads with reference to structural members. They also provide information on what material options are available and how to perform analyses in SAP2000. Some of the researchers that address the non-linear pushover analysis procedure and the various codes on the analysis include: Mohammed Ismaiel, Mohammed Saif et al. [3] pushover curves and results interpretation. Ladjinovic et al. describe the results of non-linear time history analysis concerning base shear and story drift [4]. Wason JC and Gayatri Lakshmi et al [5] also examines the areas of cost modeling of buildings with reinforcement of concrete materials developed for various zone seismic. There are other papers, for example, by Mittal A. K and Pradan K. K. , [6] which also consider additional costs for earthquake resistance for buildings of different height (G+12, G+20, G+30, etc.) and with the detailed explanation of reinforcement and concrete volumes depending on the seismicity of the area. V. Thiruvengadam et al. [7] consider the cost aspects of multi-storey buildings of varying heights for various seismic categories.

III. METHODOLOGY

The focus of this study is more specific in determining the non-linear structural response of 5-Storey RC Building subjected to earthquake loads in different zones and the cost incurred in analysis and evaluation of the structure.

3.1 Details of the Structure

Sever earthquake loads according to IS 1893-2016 has been considered for the structure.
a. Grade of Concrete and Steel: Concrete grade is M20 and Reinforcement steel is Fe 415.
b. Floor to Floor Height: Vertical height between two floors is 3 meters.
c. Slab Thickness: The thickness of slabs is 150mm.
d. Wall Thickness: External walls are 230mm thick whereas internal walls are 150mm thick.
e. Column and Beam Sizes: The column dimension is 300mm x 450mm and the dimension of beams are also 300mm x 450mm.
f. Live loads: This load is 3 KN/m^2 for the floor and 1.5 KN/m^2 for the roof.
g. Floor Finish and Roof Treatment: The load allowable on the floor surfaces is 1 KN/m^2, while on the roof treatment is allowable at 1.5 KN/m^2.
h. Seismic Zones: The site falls under seismic zones II, III, IV, and V.
i. Soil Type: The ground is of medium type the texture of the soil type also has features of being medium the soil depth is relatively medium.
j. Importance Factor: In this case, the important factor is considered as 1.
k. Building Frame Type: The building frame type is a special moment resisting frame (SMRF).
l. Density of Materials: The density of concrete is 23 KN/m^3 and therefore the density of masonry walls is estimated to be 20 KN/m^3.

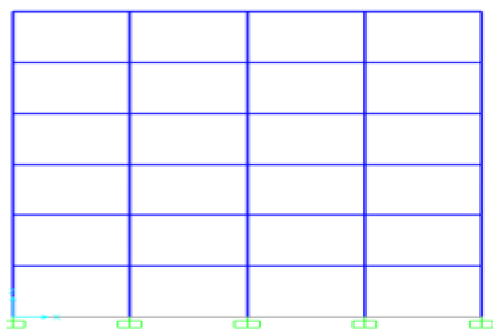

Fig-1 Elevation of the building

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3.2 Procedure in SAP 2000: This model is generated from SAP 2000 and the structure's G+5 Three dimensional is shown in the following figure 1.

Procedure for establishing the structural model using SAP2000:

Define a New Project: To perform this analysis, begin by opening the software called SAP 2000, and then under the main menu select the option known as 'new project' which will create a new project. Select the correct units and measurement settings that you shall use while making an adjustment to the instruments. Set up the Model: These lines should now be established and there must be determination of the story heights of the building.

Create the Geometry: Design the points of the structure and then shape the structural points into the geometry of the construction of the building.

Assign Material: Identify mechanical material properties along with cross-sectional properties of the structure of interest.

Define Load Cases: Distinguish such loads as Dead load, Live load, EQ-X (earthquake in the X direction) and EQ-Y (earthquake in the y direction).

Define Supports: Let the support conditions be Support be assigned by using fixed supports.

Select and Run Analysis**:** Choose the type of analysis that needs to be done (nonlinear) and perform the analysis.

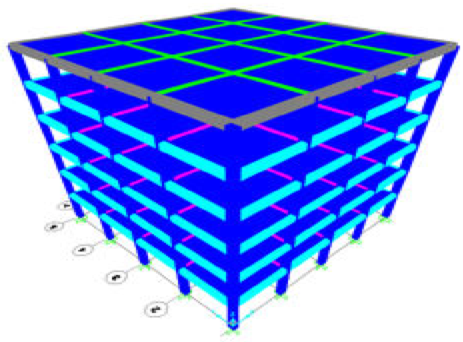

Fig-2 G+5 Building 3D model

3.3 Building load Assignments: As shown in the table it explains about the type of loads for different cases and parameters mainly for earthquake purposes as per the requirements.

Calculations: External beam: Slab height – beam depth = wall height x thickness wall x masonry wall x 1m 3 – 0. 45 = 2. 55 x 0. 23 x 20 x 1 = 11. 73 KN/m

Internal beam: slab height – beam depth = wall height x thickness wall x masonry wall x 1m 3 – 0. 45 = (2. 55 x 0. 15 x 20 x 1 = 7. 65 KN/m).

External Parapet wall: So the calculated value of design load =1.5 x 0.23 x 20 x 1 = 4.9 KN/m

Internal parapet wall: 1.5 x 15 x 20 x 1 = 4.5KN/m.

Load Type	Self-weight	Type
Dead	1	Dead load
Live load floor	0	Live load
Live roof	0	Live roof
Brick External	0	Super dead load
Brick Internal	0	Super dead load
Brick Parapet	0	Super dead load
Floor Finish	0	Super dead load
Roof Treatment	0	Super dead load

Table-1 Load case details

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3.4 Response spectrum analysis: A method used by structural engineer to know the extent to which the given building or structure will be affected by the earthquakes As per IS-1893-2016. The clause mentions that: 'If building located in seismic zones 2 3 4 5 and number of stories is greater than or equal to 3 then it would need to go through response spectrum analysis. The design base shear shall be as follows: The design base shear ~~= VB~~ The base shear (VB) shall be obtained from the formula Ta = 0. 09h/√d, if (~~VB) is~~ less than (VB) one has to multiply the necessary multiplier to the response spectrum. The response spectrum should be in X and Y direction. Need to follows the following code as per to IS-1893-2016 (Part-1).

3.5 Non-Linear Static Pushover Analysis: The assessment of the seismic performance of the structure can be done by using a method known as NSPA which stands for Nonlinear Static Pushover Analysis. It points out the other nonlinear characteristics of the structure and predicts the locations of the possible failures more effectively. This analysis can also point out the critical members that are likely to reach critical stages during an earthquake, thus aspects that need to be focused on during design and detailing. Also imply the elaboration of the fragility curve of the building which differentiates the building in the categories of slight, moderate, extensive, and collapsed states. Another analysis procedure used in this study is the pushover analysis procedure which is a nonlinear analysis that is used to evaluate the strength capacity of the structure.

3.6 Non-Linear Time History Analysis: It is a method called as Nonlinear Time History Analysis-NTHA which is used to assess the dynamic response of the structure that receives the time dependent loads such as the earthquake loads. It entails attempting to describe the structure and, at the same time, incorporating the fact that material response is nonlinear. This analysis also calculates the numerical values of the forces, displacements and the base shear capacity and also shows at which points the structure fails with time. Design seismic forces obtained by performing dynamic analysis to disturb the structure to different levels along the height of the building and various lateral loads, NTHA determines how it would act over time and let to understand how a structure would behave under seismic loads for which it is designed for.

3.7 Quality and Cost of the Structure: The general cost of the structure in the initial stages of planning as well as design is determined by several factors. The primaries of the quality and structural costs are again relying on the experience and data form constructed building. These approaches assess parameters related to cost which includes; structural design, seismic impacts, construction techniques and classification of the building. Cost models are vital in the understanding and control of costs. The intended purpose of the study is to provide the structural cost modeling of the reinforced concrete framed building with special moment resisting frame (SMRF). This also involves a low rise reinforced concrete building with reinforcement details based on seismic code and also considers model for very high seismic regions including II, III, IV, and V.

IV. RESULTS AND DISCUSSION

4. 1 NSPA Results

In this pushover analysis, the capacity curve was developed and used to plot the base of shear and the lateral displacement of the building for seismic performance along the X and Y directions. The below are some of the results of the pushover analysis for Seismic zone V. Fig 3 and 4 Capacity curves from push over analysis.

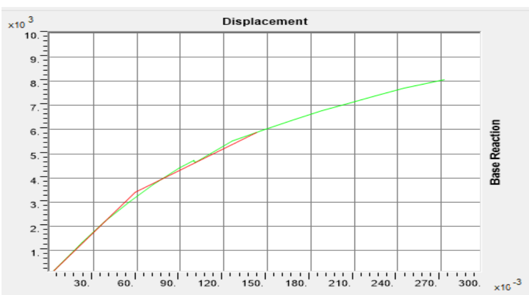

Fig-3 Pushover curve in X-direction

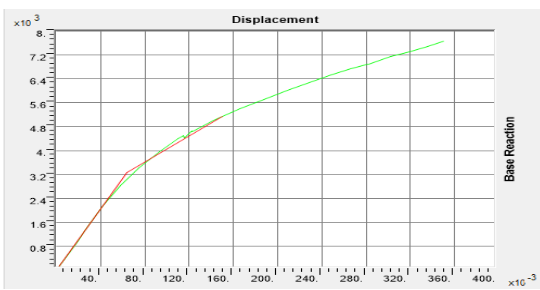

Fig-4 Pushover curve in Y-direction

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Fragility curves:

Fragility curves are graphical tools used in the engineering field in an effort to establish the likelihood of a structure suffering a specific level of damage given the severity of a given risk factor like earthquake. FEMA P -58, ACT-58, ASCE 41, and EUROCODE-8: with the help of these code we can formulate the fragility curves. Figure gives details about the fragility curve of the structure in zone-2 to 5. With the help of pushover analysis curves we can draw the fragility curves.

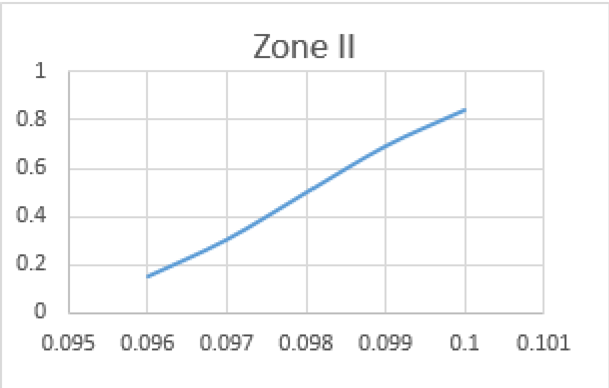

Fig-5 Zone II Seismic zone of the building

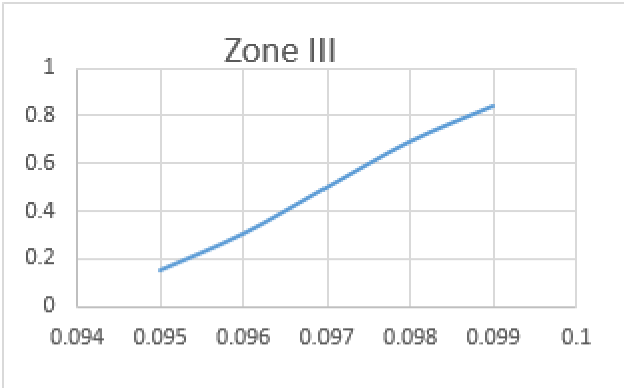

Fig-6 Zone III Seismic zone of the building

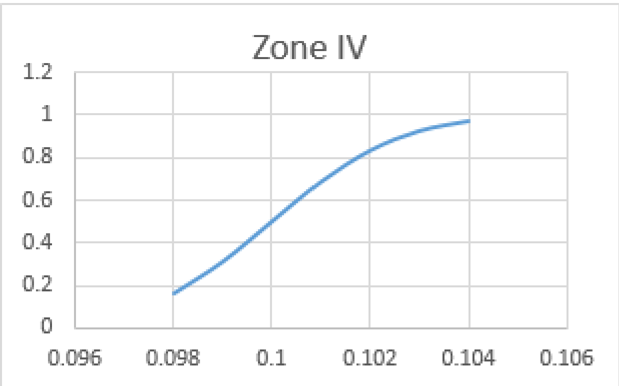

Fig-7 Zone IV Seismic zone of the building

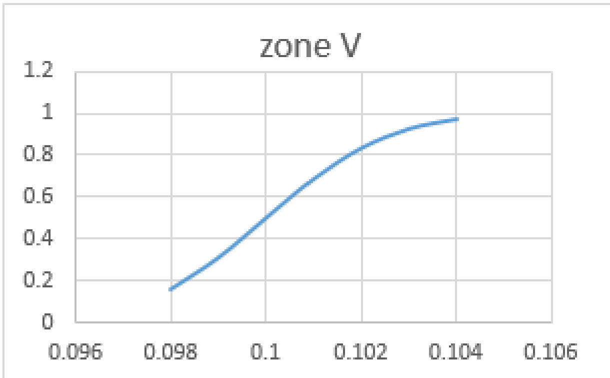

Fig-8 Zone V Seismic zone of the building

Hinges and different Zones: The results of the analysis are then employed to categorize the structure as poorly performing or well performing in a bid to try and search for proofs of formation of plastic hinges. Figure 5 and 6 shows the development of the plastic hinges starting from the initialization step till the final stage of the analysis. The hinges are labeled from A to F, whereas the hinges are labeled from A to F, where:

- AB reflects linear elasticity where 'A' is the stress to which the body has been subjected to before beginning the experiment, 'B' is the strain that was observed at the beginning of the experiment.
- BC stands for response reduction,
- As for CD, it reveals a significant increase or a sharp decrease in value.
- EF indicates reduce resistance, and
- EF is a symbol of a decrease in the resistance.
- F is an unable example; it is even incomplete.

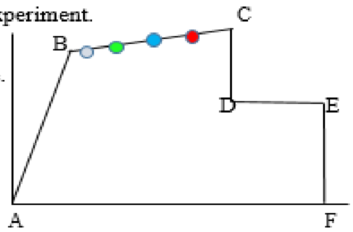

Fig-9 Typical hinge properties, showing from IO to CP

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Hinges are related with various nonlinear states including Immediate Occupancy (IO), Life Safety (LS), and Collapse Prevention (CP) that refer to specific hinges. This segment BC is used to distinguish between these criteria in the composition of organizational strategy. Red color indicates the outer hinge property while Blue color shows the inner hinge property Green color shows geometrical hinge property and Grey color is used to represent pattern hinge property as described below in the following figure. Table-2

Table-2 The above table explains about the damages at each zones from Zone 2 to Zone 5.

Push -X	A-IO	IO-LS	LS-CP	BEYOND CP
Zone II	547	149	7	77
Zone III	521	174	8	77
Zone IV	554	196	4	50
Zone V	536	157	7	80

The pushover analysis in the Y direction with nonlinear conditions is also done in similar manner as explained where pushover analysis in the X direction is carried out.

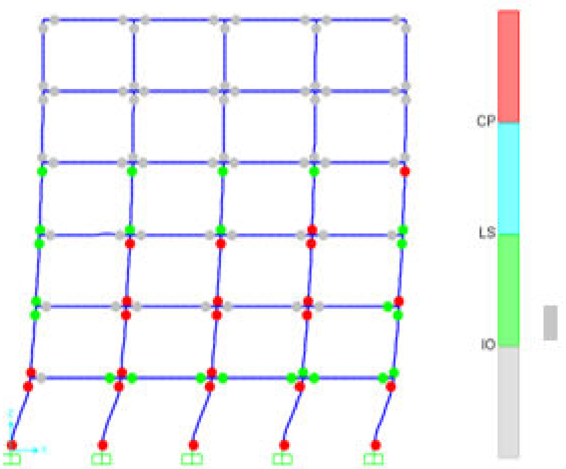

Fig-10 Plastic hinges occurred in X- Direction

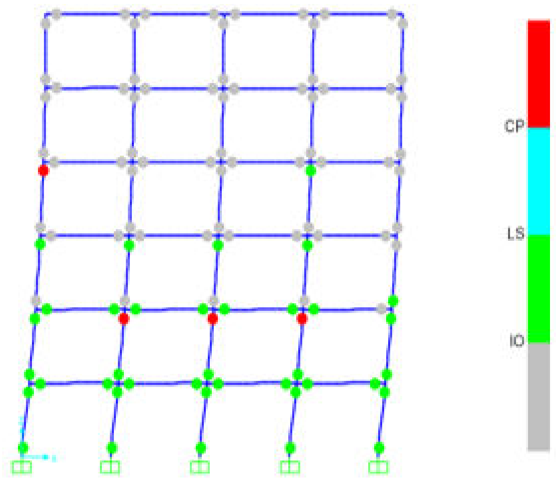

Fig-11 Plastic hinges occurred in Y-Direction

4.2 NTHA Results

This analysis signifies the nonlinear characteristics of materials and structural members in a structure as well as offering information regarding how the structure responds to dynamic loads. For each of the ground motions, nonlinear time history analysis is applied and the time history of the base shear force and displacement are obtained.

To calculate the get the story drift divide the difference in meters between floor levels divided by the height of a floor, so story drift equals height of the top floor minus the height of the bottom floor divided by the height of the floor.
Base shear of THA in x direction has the form of an eight based on the configuration shown in the figure below.

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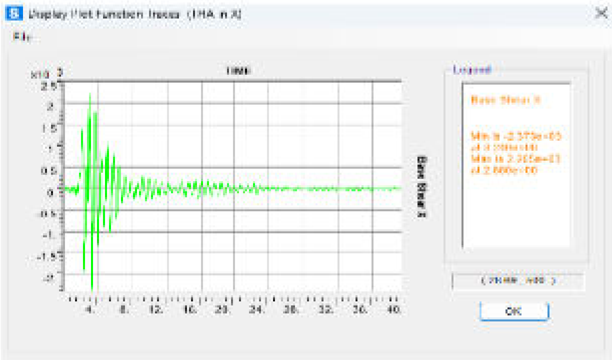

Fig-12 THA base-shear force of X directional

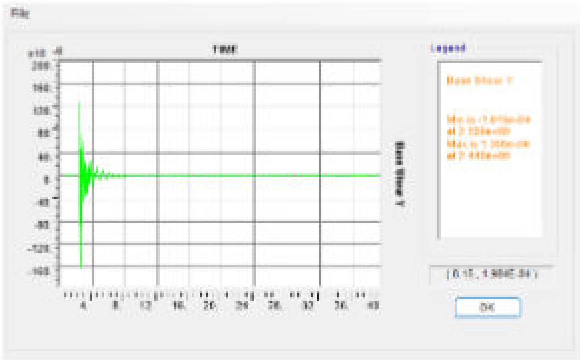

Fig-13 THA base-shear force of Y directional

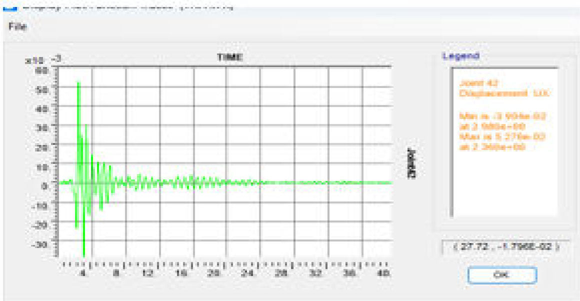

Fig-14 Roof displacement in X- direction with respect to time (sec)

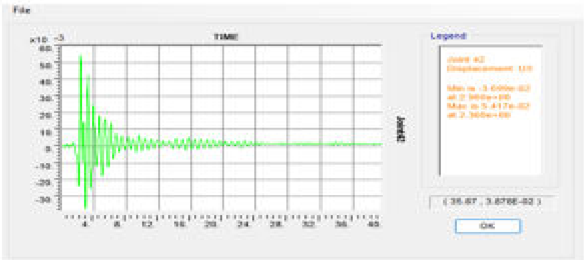

Fig-15 Roof displacement in Y- direction with respect to time (sec)

The paper also illustrates the result of the base shear of THA in X-direction and Y-direction through the bar chart of figure 8, 9 and the roof displacement of THA in X-direction and Y-direction is shown through figure 10, 11.

Table-3 Base shear in X-direction with different zones

THA X	Fx(kN)	Fy(kN)	Fz(kN)	Mx (kNm)	My (kNm)	Mz (kNm)
Zone 2	2204.6	0.147	21537.8	172302.7	146427.1	18984.2
Zone 3	2206.1	0.172	21538.4	172308.3	146374.5	18987.1
Zone 4	2227.6	0.206	21541.0	172223.9	149284.9	19200.8
Zone 5	2232.9	0.212	21557.9	172303.9	146019.2	19661.5

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Displacement or movement of multi-storey in x & y directions

To view the values of multi-storey drift and displacement, follow these steps: The following procedures should be followed in order to calculate storey drift or displacement.

Go to – Display option which is in the main menu bar > select table from the drop down list which appears > select 'analysis results' and then 'joint displacement' > then, you select the required load cases such as EQ-X, EQ-Y,THA-X,THA-Y. It is your need to write down the values in whichever format you prefer. It is also important to look at the storey drift values for seismic zone 2 to 5.

Table-4 shows the drift values in X and Y directions in Zone II

Floor	Storey drift in X-Direction (m)	Storey drift in Y-Direction (m)
6	0.054	0.055
5	0.048	0.049
4	0.038	0.038
3	0.026	0.026
2	0.012	0.016
1	0.008	0.007

Table-5 shows the drift values in X and Y directions in Zone III

Floor	Storey drift in X-Direction (m)	Storey drift in X Direction (m)
6	0.056	0.056
5	0.050	0.048
4	0.039	0.037
3	0.027	0.025
2	0.015	0.015
1	0.006	0.006

Floor	Storey drift in X-Direction (m)	Storey drift in X-Direction (m)
6	0.054	0.055
5	0.049	0.049
4	0.038	0.038
3	0.026	0.026
2	0.014	0.015
1	0.008	0.007

Table-6 shows the drift values in X and Y directions in Zone IV

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Floor	Storey drift in X-Direction (m)	Storey drift in X-Direction (m)
6	0.057	0.058
5	0.052	0.052
4	0.041	0.040
3	0.028	0.027
2	0.017	0.017
1	0.007	0.007

Table-7 shows the drift values in X and Y directions in Zone V

According to IS 1893:2002,
Clause 7. 11. 1, Stoery drift limitation:
The story drift in any storey due to the minimum specified lateral force, with partial load factor of 1.0, shall not exceed 0.004 times the storey height. Maximum permissible storey drift = 0.004 x 18m = 0. 072m.

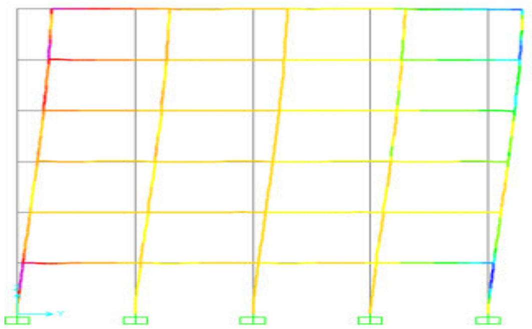

Fig-16 Storey drift in X-Direction

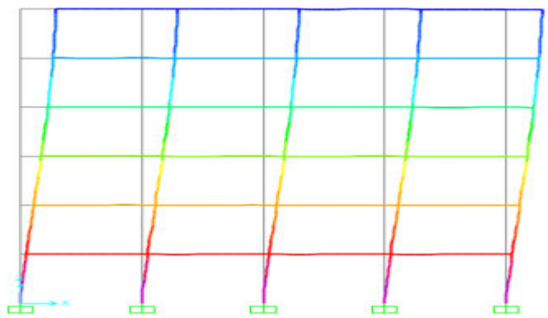

Fig-17 Storey drift in Y-Direction

4.3 quality & cost analysis of a building

The quality and cost modeling of the building is done through the elemental cost of the building. In this we detailed explained about the Quantities and Cost altogether in each group element is carried out.

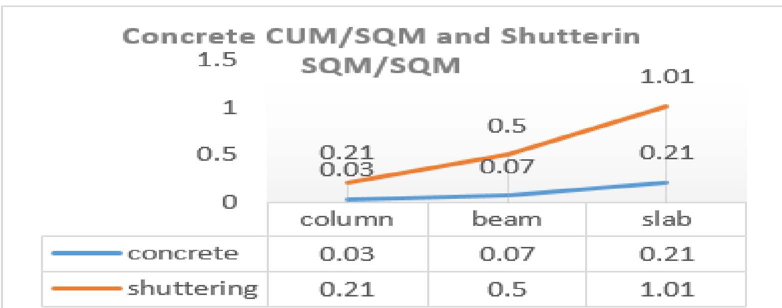

Fig-18 values of concrete and shuttering also have been provided.

The superstructure is further sub-divided at beam, column and shear walls elements and the quantity and cost of the super structure of the building is expressed in term of quality and cost / sq. m. of construction of structural concrete, steel reinforcement and shuttering materials used in the construction of 6-storied building.

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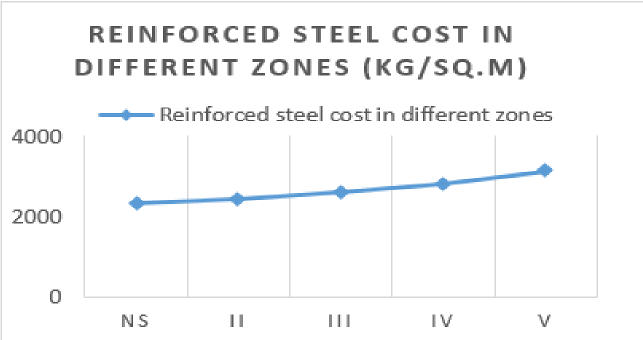

Fig-19 Reinforced steel cost

All these results are describing about the nonlinear pushover analysis, nonlinear time history analysis, quality as well as cost of the building under different seismic conditions like II, III, IV, and V.

V. CONCLUSION

The seismic resistant design by using non-linear pushover analysis and non-linear time history analysis also the cost estimation of the representative building in the range of G+5 storey under various level of seismic forces in different seismic zones of the Indian subcontinent. From pushover analysis we find out the number of hinges takes place in IO, LS, CP. This shows the exact values and where to change the properties in the different seismic zone conditions. And we can also draw the fragility curves of the building in different zones with the help of pushover curves. Non-linear time history analysis help to find out the various base shear in x and y direction with respect to the time history of El Centro earthquake is plotted and similarly the various of storey drift in x and y direction with respect to time history. The study has highlighted the cost aspect to include the cost modeling with qualified values for low rise reinforced concrete building. The cost and quality of concrete, steel reinforcement and shuttering shown the cost increases due to the performance of seismic zones from II to V. however it also ensure with the historical records of seismically designed and constructed buildings in different seismic categories of the Indian subcontinent. Apart from this raising awareness on the cost implications of seismically safety designs, and the study would also be useful in structural options under various levels of seismically and cost control.

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