

Research Paper

# COMPARATIVE STUDY OF REINFORCED CONCRETE SHEAR WALL ANALYSIS IN MULTI-STOREYED BUILDING WITH OPENINGS BY NONLINEAR METHODS

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The reinforced concrete shear wall is one of the most commonly used lateral load resisting in high rise building. The reinforced concrete shear wall building is high in plane stiffness and strength which can be used to simultaneously resist large horizontal load and support gravity load. The scope of the present work was to study seismic responses of the ten storey RC shear wall building with and without opening. Developed mathematical modeling and analyzed the reinforced concrete shear wall building by using different nonlinear methods (time history and pushover method). These methods differ in respect to accuracy, simplicity, transparency and clarity of theoretical background. Non-linear static procedures were developed with the aim of overcoming the insufficiency and limitations of linear methods, whilst at the same time maintaining a relatively simple application. All procedures incorporate performance-based concepts paying more attention to damage control. Analysis is carried out by using standard package SAP2000. The comparison of these models for different parameters like displacement, storey drift and base shear has been presented by RC shear wall building with and without opening.

**Keywords:** Seismic evaluation, Pushover analysis, Time history analysis, RC shear wall Building, Openings

## INTRODUCTION

The reinforced concrete shear wall is important structural elements placed in multi-storey buildings which is situated in seismic zones because they have a high resistance to lateral earthquake loads. RC shear walls must have sufficient ductility to avoid brittle failure under the action of strong lateral seismic loads. The

adverse effect for tall building is the higher lateral loads due to wind and expected earthquake. Thus shear walls are introduced into modern tall buildings to make the structural system more efficient in resisting the horizontal and gravity loads, ground motions as well thereby causing less damage to the structure during earthquake. Shear walls in apartment

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buildings will be perforated with rows of openings that are required for windows in external walls or doors ways or corridors in internal walls. However the opening sizes in the shear wall building may have an adverse effect on seismic responses of frame-shear wall structures. Relative stiffness of shear walls is important since lateral forces are distributed to the individual shear wall according to their relative stiffness. Simplified methods for stiffness of shear walls with openings are recommended in several design guidelines. It is necessary to know the effects of openings sizes and configurations in shear wall on stiffness as well as on seismic responses and behavior of structural system so that a suitable configuration of openings in shear walls can be made.

Reinforced concrete shear wall buildings are designed primarily to serve the needs of an intended occupancy. One of the dominant design requirements is therefore the provision of an appropriate internal layout of buildings. Once the functional layout is established then to develop a structural system that will satisfy the established design criteria as efficiently and economically as possible while fitting into the architectural layout. The vital structural criteria are an adequate reserve of strength against failure, lateral stiffness and an efficient performance during the service life of the buildings.

## **SEISMIC ANALYSIS METHODS**

### **Nonlinear Static Analysis - Pushover Analysis**

Pushover analysis is an approximate analysis method in which the structure is subjected to monotonically increasing lateral forces with an

invariant height-wise distribution until a target displacement is reached. Pushover analysis consists of a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure. A two or three dimensional model which includes bilinear or trilinear load-deformation diagrams of all lateral force resisting elements are first created and gravity loads are applied initially. A predefined lateral load pattern which is distributed along the building height is then applied. The lateral forces are increased by some members yield. The structural model is modified to account for the reduced stiffness of yields members and lateral forces are again increased until additional members yield. The process is continued until a control displacement at the top of the building reaches a certain level of deformation or structure becomes unstable. The roof displacement is plotted with base shear to get the global capacity curve.

Pushover analysis can be performed as force-controlled or displacement-controlled. In force-controlled pushover procedure, the full load combination is applied as specified, i.e., force-controlled procedure should be used when the load is known (such as gravity loading). Also, in force-controlled pushover procedure some numerical problems that affect the accuracy of results occur since target displacement may be associated with a very small positive or even a negative lateral stiffness because of the development of mechanisms and P-delta effects.

Pushover analysis has been the preferred method for seismic performance evaluation of structures by the major rehabilitation guidelines

and codes because it is conceptually and computationally simple. Pushover analysis allows tracing the sequence of yielding and failure on member and structural level as well as the progression of the overall capacity curve of the structure.

### **Nonlinear Dynamic Analysis – Time History Analysis**

Nonlinear dynamic analysis is most accurate method to determine the seismic responses of structures. In this method the structure is subjected to actual ground motion which is the representation of the ground acceleration versus time. The ground acceleration is determined at small time step to give the ground motion record. Then the structural response is calculated at every time instant to know its time history and the peak value of this time history is chosen to be design demand. Hence, “A mathematical model directly incorporating the nonlinear characteristic of individual component and element of the building shall be subjected to earthquake shaking represented by ground motion time history to obtain forces and the displacement”. Since numerical model directly accounts for the effect of material nonlinearity, inelastic responses and calculated internal forces will be reasonably approximate to those expected during the design earthquake. There are two methods by which the time history analysis is carried out (a) Nonlinear Modal Time History Analysis; and (b) Nonlinear Direct Integration Time History Analysis.

### **Nonlinear Modal Time History Analysis**

As mentioned earlier, from the fundamental of structural dynamics it is clear that the response

of the MDOF system can be estimated from its modal responses. In this analysis, also called as Response history Analyses, the modal load vectors are determined for the predefined no of modes. For the selected mode, the static analysis of the structure is carried out to estimate its modal static responses, the structure being subjected to corresponding modal load vector. Then the dynamic analysis of the corresponding ESDOF system is carried out to get its spectral ordinates at every time step. This spectral ordinate at each time step is multiplied with the corresponding modal static response to get the actual Time history of that response for that modal quantity. The same procedure is carried out to other modes and corresponding modal response history is determined. These modal responses are then added at each time step to get the time history of the selected response for the design ground motion record.

### **Nonlinear Direct Integration Time History Analysis-**

The fundamental equation governing the response of MDOF system subjected to ground acceleration is given by  $\ddot{u}(t)$

$$m\ddot{u} + c\dot{u} + f_s(u, \dot{u}) = -m\ddot{u}_g(t)$$

The only unknown quantity in the above expression is the displacement vector  $u$ . In this method the above equation is formulated for the entire structure at every time step at which the ground acceleration is determined. This equation is then solved by any of the well known methods to get directly the displacement at each time step. The other response quantity time history is then calculated from known displacement time history. The peak from the

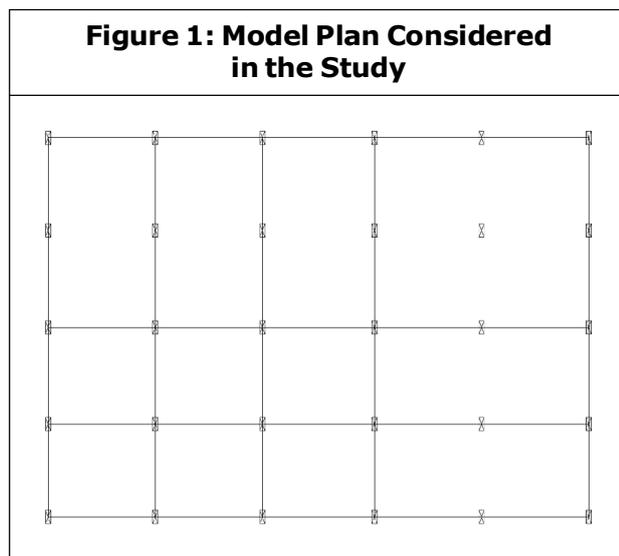
particular response time history is then selected as the design demand.

## STRUCTURAL MODELING AND ANALYSIS

The finite element analysis software SAP2000, Nonlinear is utilized to create 3D models and run all analyses. The software is able to predict the geometric nonlinear behavior of space frames under static or dynamic loadings, taking into account both geometric nonlinearity and material inelasticity. The software accepts static loads (either forces or displacements) as well as dynamic (accelerations) actions and has the ability to perform eigenvalues, nonlinear static pushover and nonlinear dynamic analyses.

### Details of the Model

The model which has been adopted for the study are ten storeys (G+9) RC shear wall building. The buildings consist of wall thickness 230 mm. The floor slabs are taken as 125 mm thick. The height of all the ten stories is 3 m.. The live load is taken as 3.5 KN/m<sup>2</sup> and 2 KN/m<sup>2</sup> for floor and terrace, respectively from IS 1893-2002 (Part-I) (Figure 1).



Rectangular shear walls building with and without opening were modeled using shell elements available in structural analysis program SAP2000. For the parametric study, the percentage of centered opening in the external face of the building was increased from 0%, 14%, 25%, 33%, and 42% model. The following models have been considered.

Model	Opening %
1	0
2	14
3	25
4	33
5	42

### Dimensions of Proposed Model

Plan dimension of structure = 20 m × 12 m

No of bays in X-direction = 5

No of bays in Y-direction = 4

Spacing of bays in X-direction = 4.0 m

Spacing of bays in Y-direction = 3.0 m

Height of all typical floors (including ground floor) = 3.0 m

Height of parapet wall = 1 m (all around the periphery of roof floor)

## RESULTS AND DISCUSSION

Analyze the reinforced concrete shear wall buildings with and without opening by using the nonlinear dynamic method-Time History analysis

The time history procedure is used if it is important to represent inelastic response characteristics or to incorporate time

dependent effects when computing the structures dynamic response. The real earthquake ground motions are taken time history analysis of koyana earthquake (x direction), damping of 5% is taken for earthquake ground motions

**Lateral Displacements**

Figure 2 shows the comparison of storey height and displacement curves for different storey height wise distributions for all the models.

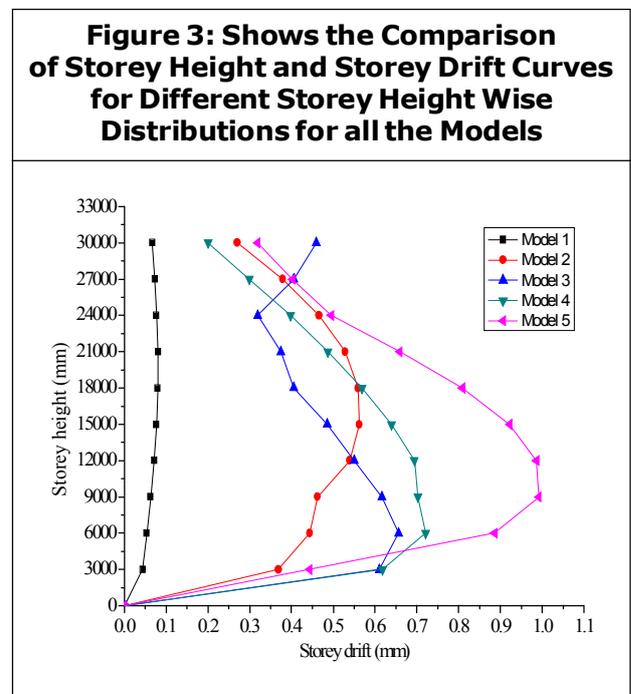
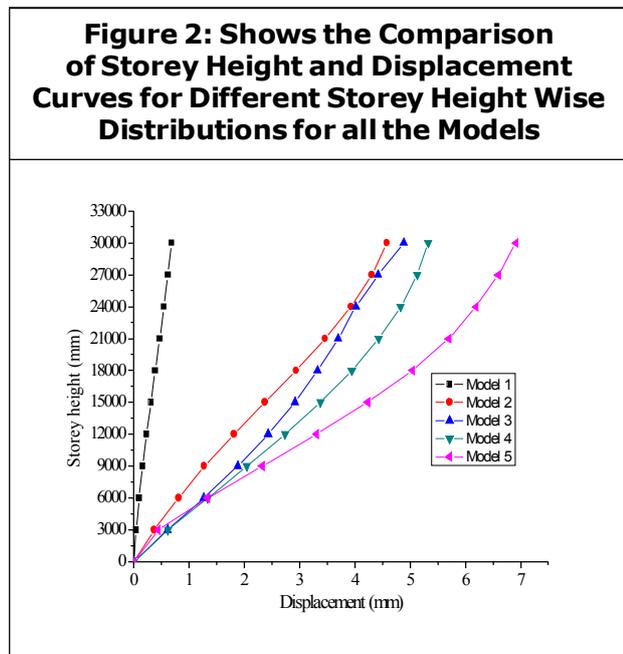
From Figure 2 observed that the displacement of model 2, 3, 4, 5 is increased to 84.97%,

85.91%, 87.09%, 90.05%, respectively which is considerable when compared to the values of model 1. The percentage variation of top displacements for all the models shown in Table 2.

**Storey Drift**

Storey drift is the displacement of one level relative to the other level above or below. Figure 3 shows the comparison of curves for different storey height and storey drift.

From Figure 3 observed that storey drift increases as the height of storey increased



**Table 2: Percentage Variation in Displacement for all the Models**

Model No.	Variations of Top Displacement (%)
1	0
2	84.97
3	85.91
4	87.09
5	90.05

**Table 3: Percentage Variation in Storey Drift for all the Models**

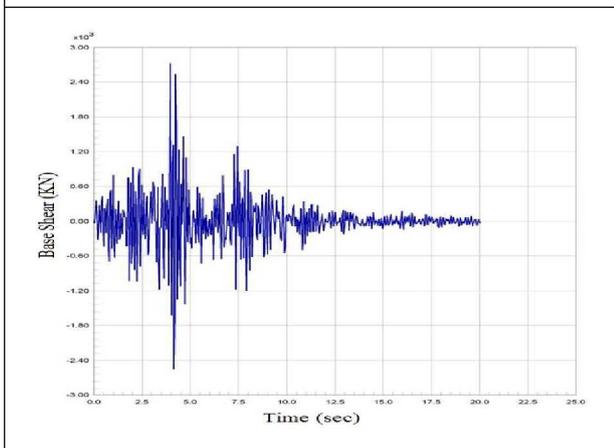
Model No.	Variations of Storey Drift (%)
1	0
2	75.27
3	85.43
4	66.50
5	79.00

and reduced at the top floor. The percentage variation of model 2, 3, 4, 5 is variable to 75.27, 85.43, 66.50, 79, respectively which is considerable when compared to the values of model 1 shown in Table 3.

**Time History Curves of Base Shear and Time**

The base shear and time of all the building as obtained from time history analysis in SAP2000. From Figures 4 to 8 shows the maximum and minimum base shear and time.

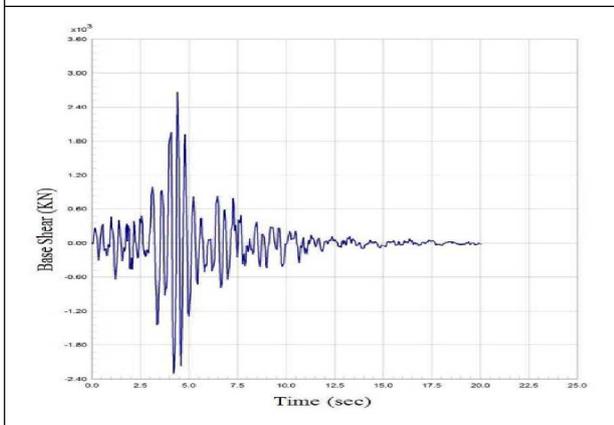
**Figure 4: Shows the Base Shear Vs. Time for Model 1**



Max. Base shear = 2724 kN at time 3.96 s

Min. Base shear = -2553 kN at time 4.16 s

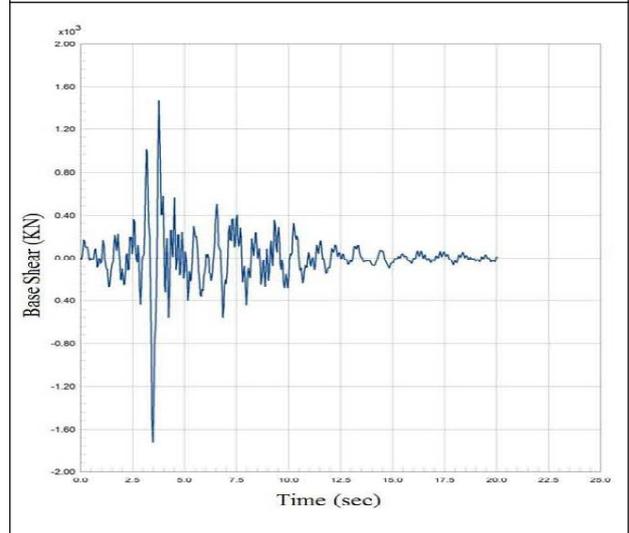
**Figure 5: Shows the Base Shear Vs. Time for Model 2**



Max. Base shear = 2659 kN at time 4.40 s

Min. Base shear = -2304 kN at time 4.20 s

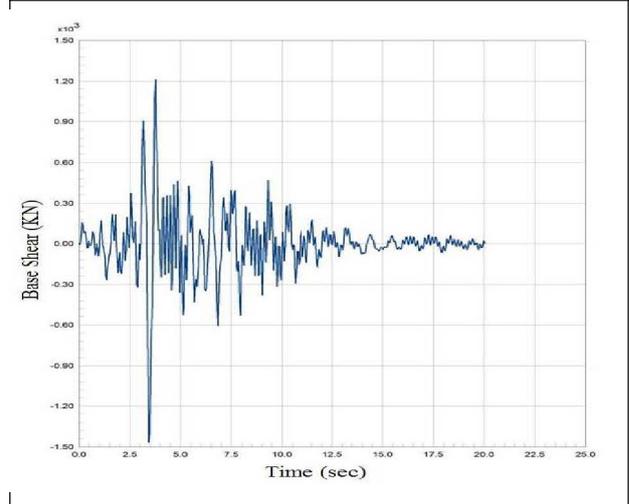
**Figure 6: Shows the Base Shear Vs. Time for Model 3**



Max. Base shear = 1595 kN at time 4.12 s

Min. Base shear = -1668 kN at time 3.44 s

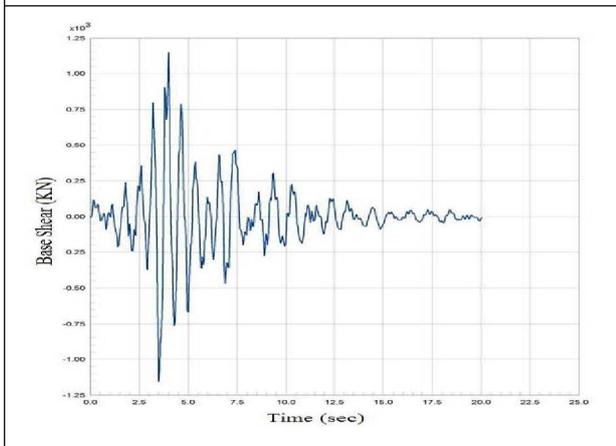
**Figure 7: Shows the Base Shear Vs. Time for Model 4**



Max. Base shear = 1212 kN at time 3.76 s

Min. Base shear = -1468 kN at time 3.44 s

**Figure 8: Shows the Base Shear Vs. Time for Model 5**



Max. Base shear = 1150 KN at time 4.00 s

Min. Base shear = -1154 KN at time 3.48 s

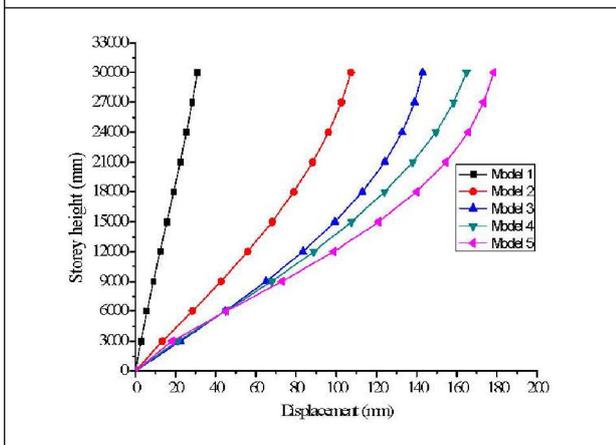
**Analyze The Reinforced Concrete Shear Wall Buildings With And Without Opening By Using The Nonlinear Static Method- Pushover Analysis**

**Lateral Displacement**

Lateral Displacement of models at each storey height for all the models is shown in Figure 9.

From Figure 9 observed that the displacement of model 2, 3, 4, 5 is increased

**Figure 9: Shows the Comparison of Pushover Curves for Different Displacements and Storey Height**



to 71.14%, 78.32%, 81.21%, 82.63% respectively which is considerable when compared to the values of model 1. The percentage variation of top displacement for all the models shown in Table 4.

**Table 4: Percentage Variation in Top Displacement for all the Models**

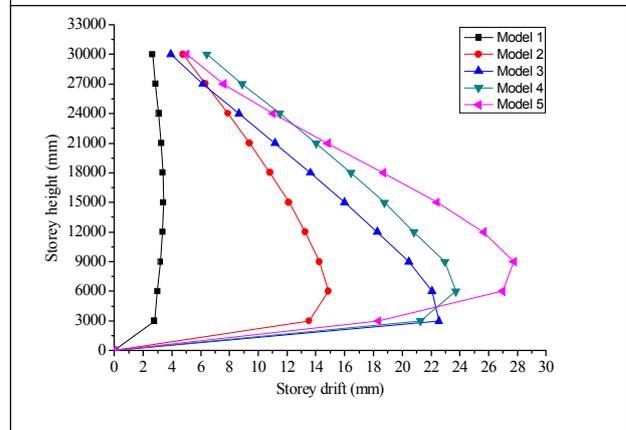
Model No.	Variations of Top Displacement (%)
1	0
2	71.14
3	78.32
4	81.21
5	82.63

**Storey Drift**

Storey drift is the displacement of one level relative to the other level above or below. Figure 10 shows the comparison of curves for different storey height and storey drift.

From Figure 10 observed that storey drift is increased as the height of storey increased and reduced at the top floor. The percentage variation of model 2, 3, 4, 5 is variable to 44.53, 32.74, 58.83, 47.32, respectively which is considerable when compared to the values of model 1 shown in Table 5.

**Figure 10: Shows the Comparison of Curves For Different Storey Height and Storey Drift**



**Table 5: Percentage Variation in Storey Drift for all the Models**

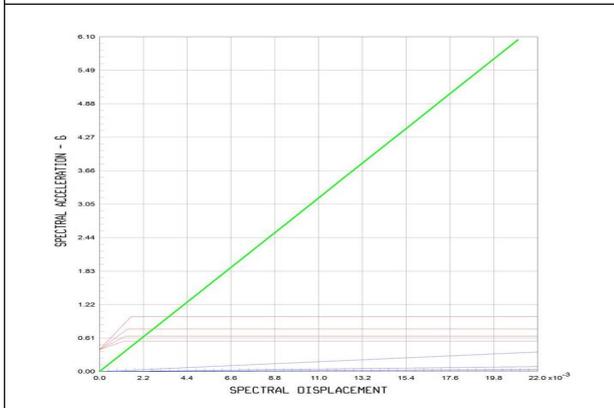
Model No.	Variations of storey drift (%)
1	0
2	44.53
3	32.74
4	58.83
5	47.32

**Capacity Spectrum**

Capacity spectrum is the capacity curve transformed from base shear vs. roof displacement coordinates into spectral acceleration vs. spectral displacement ( $S_a$  vs.  $S_d$ ) coordinates. The performance point is obtained by superimposing demand spectrum on capacity curve transformed into spectral coordinates. To have desired performance, every structure has to be designed for the spectral acceleration corresponding to the performance point.

The reduced demand spectra intersected the capacity spectra. The performance point calculated is within 5% of the assumed value. The calculated spectral displacement is the inelastic displacement that the equivalent single degree of freedom structure will experience for the given level of earthquake.

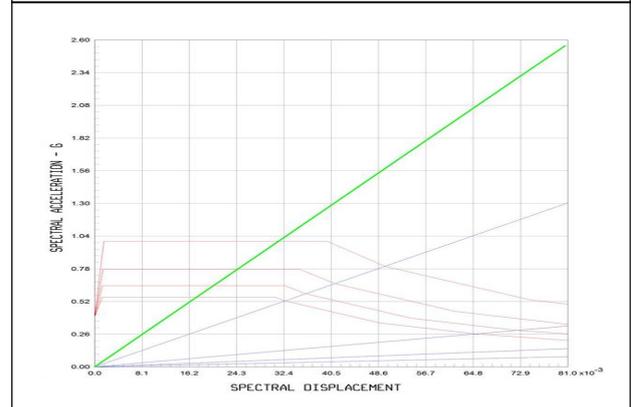
**Figure 11: Shows The Capacity Spectrum For Model 1**



A roof displacement that the structure will undergo = 5.142 mm

Drift ratio =  $5.142 * 100 / 30000 = 0.44 \% < 1\%$   
(Immediate occupancy state)

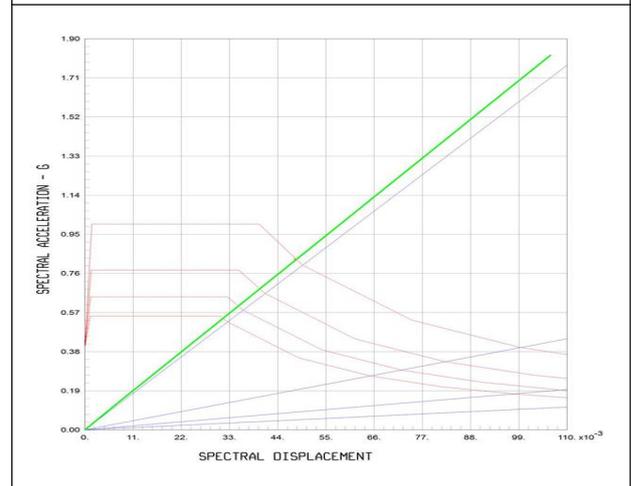
**Figure 12: Shows The Capacity Spectrum For Model 2**



A roof displacement that the structure will undergo = 42 mm

Drift ratio =  $42 * 100 / 30000 = 0.14 \% < 1\%$   
(Immediate occupancy state)

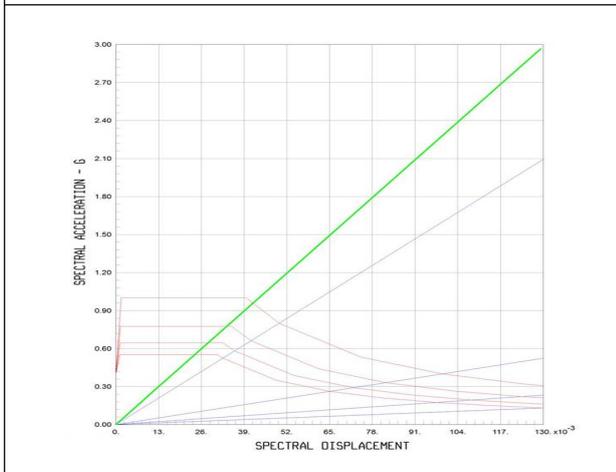
**Figure 13: Shows The Capacity Spectrum For Model 3**



A roof displacement that the structure will undergo = 64 mm

Drift ratio =  $64 * 100 / 30000 = 0.21 \% < 1\%$   
(Immediate occupancy state)

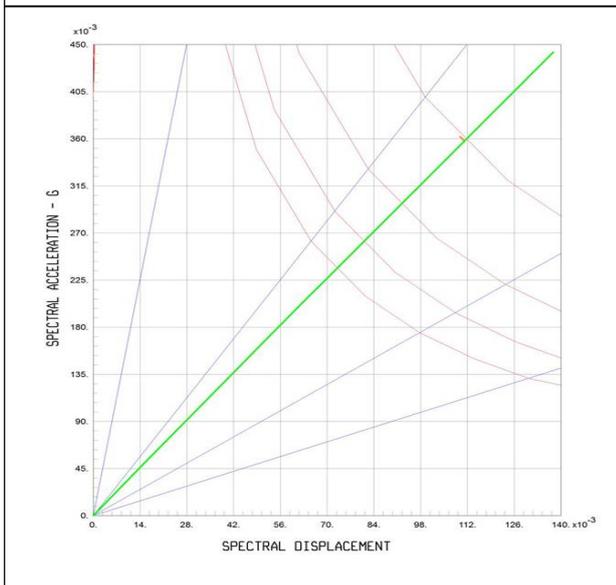
**Figure 14: Shows The Capacity Spectrum For Model 4**



A roof displacement that the structure will undergo = 53 mm

Drift ratio =  $53 \times 100 / 30000 = 0.18\% < 1\%$   
(Immediate occupancy state)

**Figure 15: Shows The Capacity Spectrum For Model 5**



A roof displacement that the structure will undergo = 144 mm

Drift ratio =  $144 \times 100 / 30000 = 0.48\% < 1\%$   
(Immediate occupancy state)

## Evaluation of Seismic Performance of Buildings

The seismic performance of a building is measured by the state of damage under a certain level of seismic hazard. The state of damage is quantified by the drift of the roof and the displacement of the structural elements. Initially, gravity push is carried out using the force control method. It is followed by a lateral push with displacement control using SAP2000. For carrying out displacement based pushover analysis, target displacement needs to be defined. Pushover analysis gives an insight into the maximum base shear that the structure is capable of resisting. A building performance level is a combination of the performance levels of the structure and the nonstructural components. A performance level describes a limiting damage condition which may be considered satisfactory for a given building with specific ground motion. The structural performance levels as per FEMA 356 are; (1) Operational, (2) Immediate Occupancy (IO), (3) Life Safety (LS), (4) Structural Stability and (5) Collapse Prevention (CP). Typical values of roof drifts for the three performance levels (FEMA356) are; (i) Immediate Occupancy: Transient drift is about 1% or negligible permanent drift, (ii) Life Safety: Transient drift is about 2% or 1% permanent drift, (iii) Collapse Prevention: 4% transient drift or permanent drift.

## CONCLUSION

In this work, by performing of RC shear walls building with openings ten storey building was carried out to compare the different sizes of the opening analysis by nonlinear static and nonlinear dynamic method. The analysis of RC shear walls with openings building was carried

out using the SAP2000 nonlinear software tool. The following conclusions are drawn on the basis of the numerical results obtained by software.

1. The values of seismic responses namely base shear, storey displacement and storey drift for the both methods are found to be increasing order for model 1, 2, 3, 4, and 5.
2. The variation in the height-wise distribution of top displacement increase by 84.97%, 85.91%, 87.09%, 90.05% in time history analysis and 71.14%, 78.32%, 81.21%, and 82.63% in pushover analysis for model 2, 3, 4, 5, respectively as compared to value of model 1.
3. As a percentage of opening increases with increases displacements.
4. The distribution of the story drift ratio over the frame height becomes non uniform as frame height increases for both the methods. Storey drift ratios for different damage states of class of buildings designed as per IS1893-2002.
5. The capacity spectrum method gives demand curve intersects the capacity curve at event IO (immediate occupation), so plastic hinges occurred in the structure remains stable.

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