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# Effect of Irregular Configurations on Seismic Vulnerability of RC Buildings

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**Abstract** Many buildings in the present scenario have irregular configurations both in plan and elevation. This in future may subject to devastating earthquakes. In case, it is necessary to identify the performance of the structures to withstand against disaster for both new and existing one. The present paper made an attempt to study two kinds of irregularities in the building models namely plan irregularity with geometric and diaphragm discontinuity and vertical irregularity with setback and sloping ground. These irregularities are created as per clause 7.1 of IS 1893 (part1)2002 code. In Oder to identify the most vulnerable building among the models considered, the various analytical approaches are performed to identify the seismic demands in both linear and nonlinear way. It is also examined the effect of three different lateral load patterns on the performance of various irregular buildings in pushover analysis. This study creates awareness about seismic vulnerability concept on practicing engineers.

**Keywords** Seismic, Irregularities, Pushover, Non-linear

## 1. Introduction

Earthquakes are the most unpredictable and devastating of all natural disasters, which are very difficult to save over engineering properties and life, against it. Hence in order to overcome these issues we need to identify the seismic performance of the built environment through the development of various analytical procedures, which ensure the structures to withstand during frequent minor earthquakes and produce enough caution whenever subjected to major earthquake events. So that can save as many lives as possible. There are several guidelines all over the world which has been repeatedly updating on this topic. The analysis procedure quantifying the earthquake forces and its demand depending on the importance and cost, the method of analysing the structure varies from linear to non linear. The behaviour of a building during an earthquake depends on several factors, stiffness, adequate lateral strength, ductility, simple and regular configurations. The buildings with regular geometry and uniformly distributed mass and stiffness in plan as well as in elevation suffer much less damage compared to irregular configurations. But nowadays need and demand of the latest generation and growing population has made the architects or engineers inevitable towards planning of irregular configurations. Hence earthquake engineering has developed the key issues in understanding the role of building configurations.

### 1.1. Objective of the Study

To obtain the Seismic performances of different irregular buildings located in severe earthquake zone (V) of India, and also identify the most vulnerable building among them.

### 1.2. Scope of the Study

The Present work is focused on the study of Seismic demands of different irregular R.C buildings using various analytical techniques for the seismic zone V (hard rock) of India. The configuration involves plan irregularities such as diaphragm discontinuity, re-entrant corners and vertical irregularities such as geometrical irregularity, buildings resting on sloping ground. The performance was studied in terms of time period, base shear, lateral displacements, storey drifts and eccentricity in linear analysis using a code – IS1893 (Part 1):2002 .Whereas the performance point and hinge status in Non linear analysis using ATC40. Also an attempt was made in pushover analysis to identify the correct lateral load pattern when different irregular buildings were considered. The entire modelling, analysis and design was carried out by using ETABS 6.0 nonlinear version software.

## 2. Illustrative Examples

The Layout of plan having 5X4 bays of equal length of 5m Figure 1. The buildings considered are Reinforced concrete

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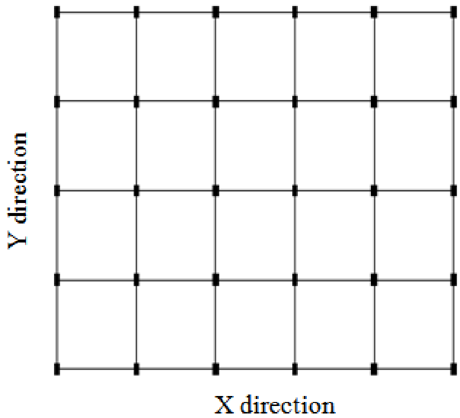
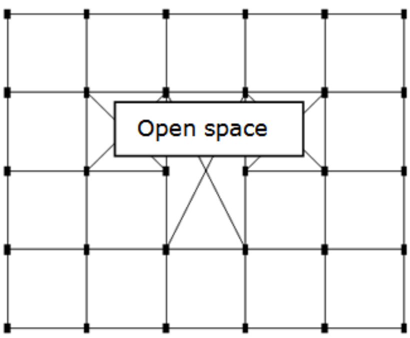
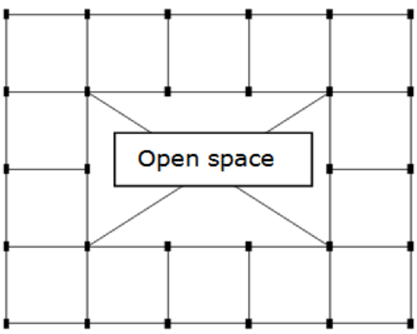
ordinary moment resisting frame building of three storeys with different irregular configurations. Here stiffness of the infill is neglected in order to account the nonlinear behaviour of seismic demands. The storey height is kept uniform of 3m for all kind of building models which are as below,



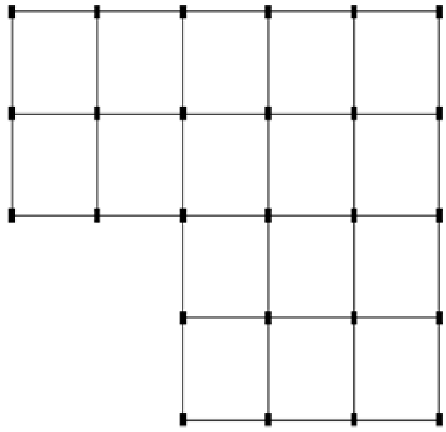

Model - 1



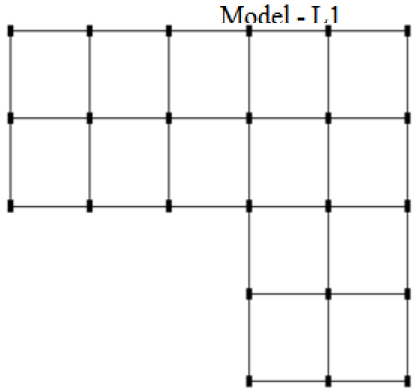

Model – D1



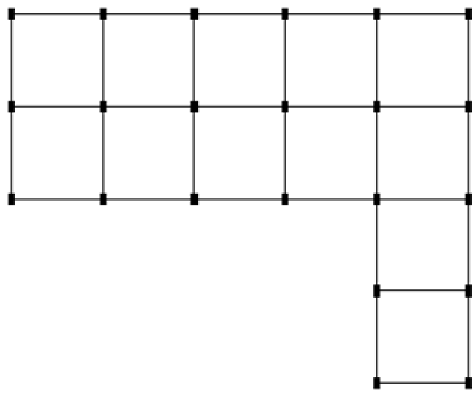

Model – D2



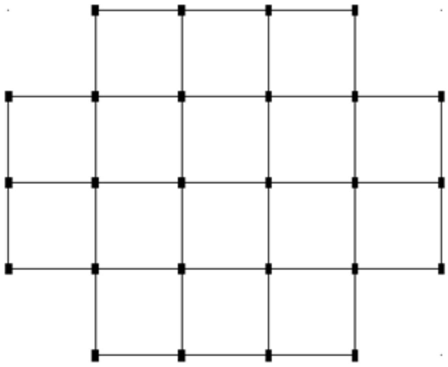
Model - L1



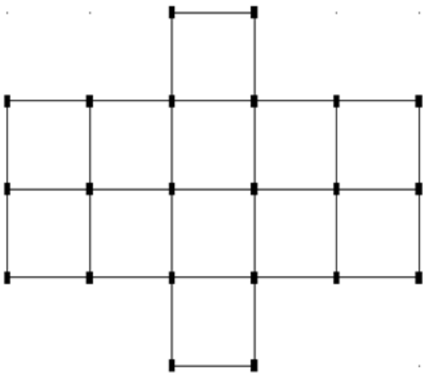
Model – L2



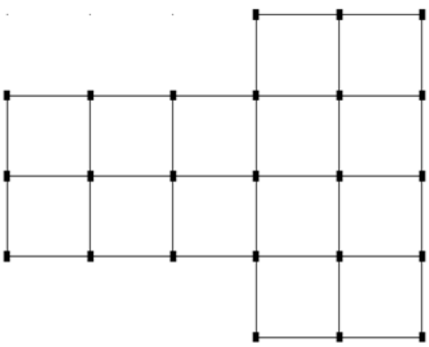
Model – L3



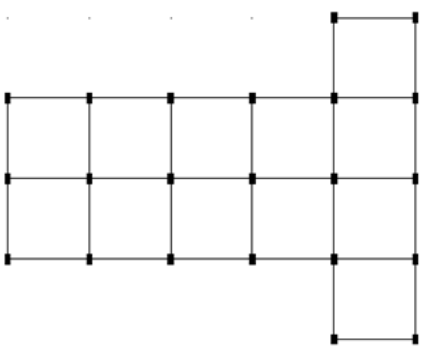
Model - P1



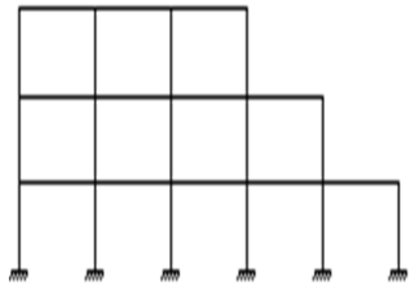
Model – P2



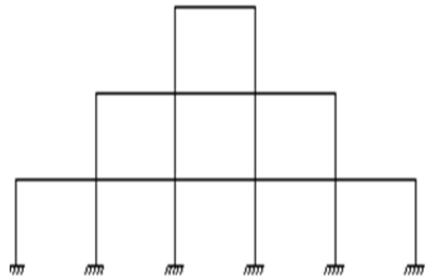
Model – T1



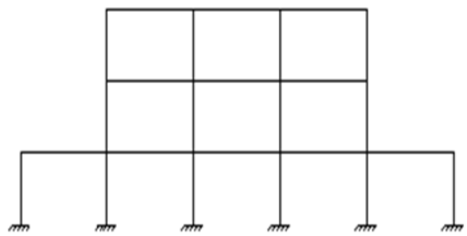
Model – T2



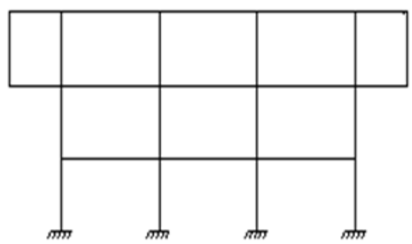
Model – V1



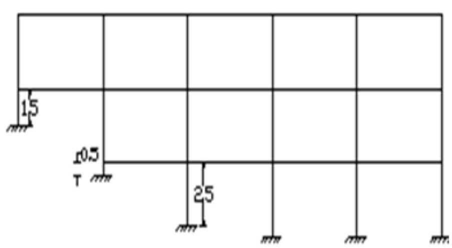
Model – V2



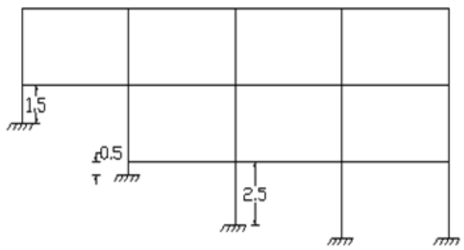
Model – V3



Model – V4



Model – V5




Model – V6

**Figure 1.** Building Models

(i)The Plan configuration consists of

Model 1 – Building in rectangular shape

Model D1 – Diaphragm discontinuity, which is in T shape.

Model D2 – Diaphragm discontinuity, which is in rectangular shape.

Model L1, L2, L3 – Re-entrant corners in L Shape. Both projections provided are 40% 60%, 80% in X direction and 50% in Y-direction.

Model P1 and P2 – Re-entrant corners, in plus (+) Shape. Both projections provided are 20% of the plan dimension in their respective directions and 40% of the plan dimension in X direction, 25% in Y-direction.

Model T1 and T2 – Re-entrant corners in T-Shape. Both projections provided are 60% and 80% of the plan dimension in X direction and 25% in Y-direction.

(ii) a). The Vertical configuration of a structure and lateral force resisting system in

Model V1 – top story consists of an offset of 40% in X direction only on one side.

Model V2 – top story consists of an offset of 20% in X direction on both sides.

Model V3 – top story consists an offset of 40% in X direction on both sides.

Model V4 – adjacent story consists of an offset of 10.4% in X direction on both sides.

(ii) b). The Vertical configuration of a structure and lateral force resisting system is

Model V5 – Resting on a sloped ground in X direction.

Model V6 – Resting on a sloped ground in Y direction.

# 3. Analysis Methods

Analysis methods are broadly classified as linear static, linear dynamic, nonlinear static and nonlinear dynamic methods. In these the first two methods are suitable when the structural loads are small and no point, the load will reach to collapse load and are differs in obtaining the level of forces and their distribution along the height of the structure. Whereas the non- linear static and non-linear dynamic analysis are the improved methods over linear approach. During earthquake loads the structural loading will reach to collapse load and the material stresses will be above yield stresses. So in that case material nonlinearity and geometrical nonlinearity should be incorporated into the analysis to get better results. These methods also provide information on the strength, deformation and ductility of the structures as well as distribution of demands.

### 3.1. Equivalent Static Method

Equivalent static method of analysis is a linear static procedure, in which the response of building is assumed as linearly elastic manner. The analysis is carried out as per IS1893-2002 (Part 1) [6]

### 3.2. Response Spectrum Method

Linear dynamic analysis of the building models is performed using ETABS. The lateral loads generated by ETABS correspond to the seismic zone V and 5% damped response spectrum given in IS 1893-2002 (Part 1) [6]. The fundamental natural period values are calculated by ETABS, by solving the eigenvalue problem of the model. Thus, the total earthquake load generated and its distribution along the height corresponds to the mass and stiffness distribution as modelled by ETABS.

### 3.3 Pushover Analysis

Pushover analysis is one of the methods available to understand the behaviour of structures subjected to earthquake forces. As the name implies, it is the process of pushing horizontally with a prescribed loading pattern incrementally until the structure reaches a limit state [ATC-40 1996][3].The static approximation consists of applying a vertical distribution of lateral loads to a model which captures the material non - linearity of an existing or previously designed structure, and monotonically increasing those loads until the peak response of the structure is obtained on a base shear versus roof displacement plot.

Here three static pushover cases are considered. In the first case gravity load is applied to the structure, in the second case lateral load is applied to the structure along X-direction and in the third case lateral load is applied to the structure along Y-direction for the three types of loading patterns

a).Code type - The force distribution is taken as per IS1893-2002(Part1) ELF (Equivalent Lateral Force) method of vertical distribution.

$$F_j = m_j \, h_j k \tag{1}$$

Where "m" is the mass, "h" is the height and "F" is the lateral force at $j^{th}$ floor, k is 2.

b).Uniform - The force distribution is uniform only if all the floor masses are equal

$$F_j = m_j \tag{2}$$

"m" is the mass and "F" is the lateral force at $j^{th}$ floor.

c).1st mode – The force distribution is permitted when morethan 75% of the total mass participates in the $j^{th}$ floor.

$$F_j = m_j \, \varnothing_{j1} \tag{3}$$

Where "m" is the mass, "$\varnothing_{j1}$" is the fundamental mode shape component at the $j^{th}$ floor.

The buildings are pushed to a displacement of 4% of height of the building to reach collapse point as per ATC 40 (Applied Technology Council). Tabulate the nonlinear results in order to obtain the inelastic behaviour.

## 4. Results and Discussion

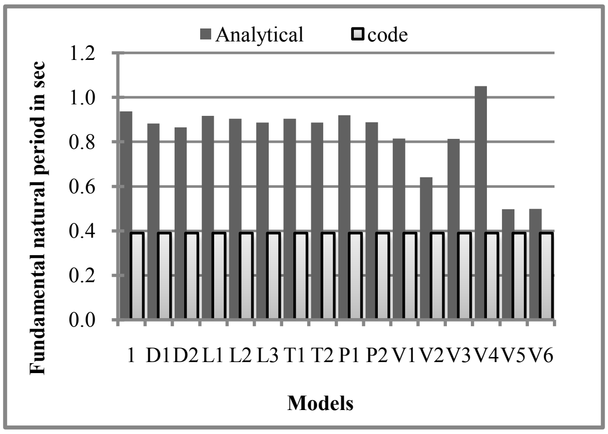



**Figure 2.** The Fundamental natural period for 3 storey building models

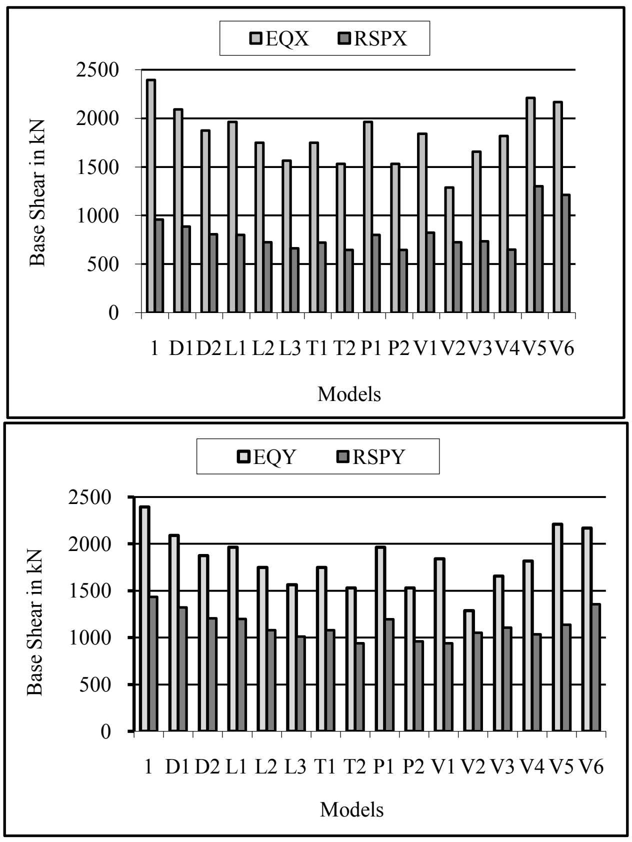



**Figure 3.** The Comparison of Base shear for 3 storey building models in X and Y direction

The comparison of natural period and base shear presented in the Figure 2 and Figure 3 shows that, the code IS 1893 (part-I) 2002 uses empirical formula to calculate natural period which is directly depends on the height of the building. Whereas the analytical procedure calculates the natural period on the basis of mass and stiffness of the building (Eigen value and Eigen vectors).Since, the code doesn't consider the irregular effects. The models D1, L2, L3, T1, T2, V1, V4, V5 and V6 subjected to displacements in both directions when the load was applied in particular direction. Which may results in twisting of building.

Here in all the three storied models the total number of hinges were varies from model to model that is mainly because of the shape of the building the structural members i.e. beams and columns are getting reduced. The plan irregular models shows the displacement obtained are similar to model 1 for lower base shears in comparison to vertical irregular models. This shows that plan irregular models can deform largely for less amount of forces. Among all vertical irregular models the model V4 was more vulnerable. Whereas vulnerability of sloping ground models was found remarkable. Hence, they attract large force to deform moderately.

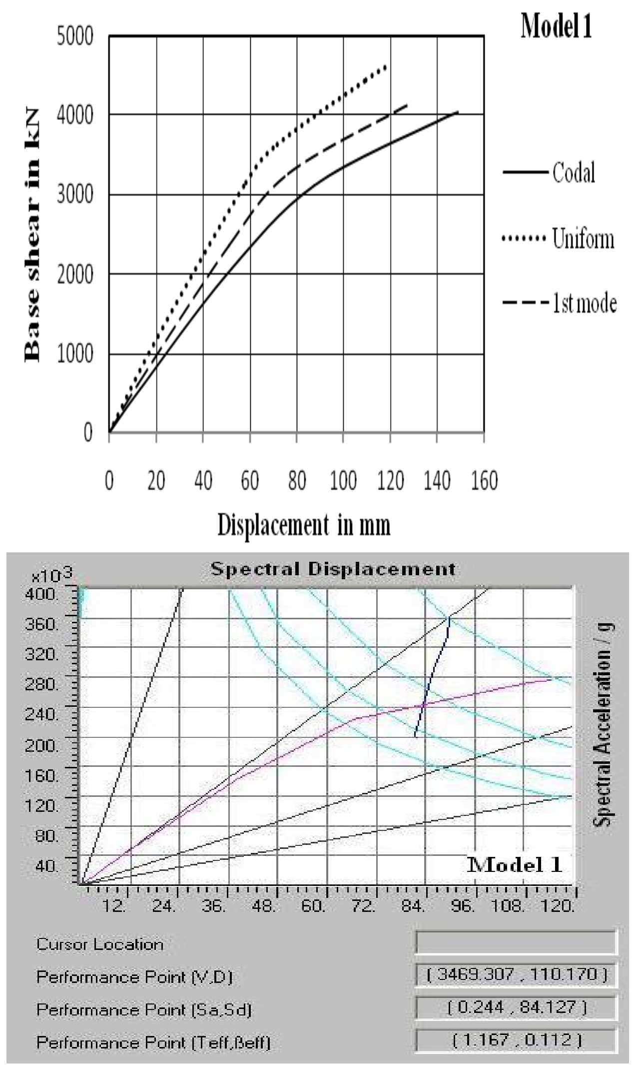



**Figure 4.** Pushover curve and Performance point

The diaphragm discontinued models D1 and D2 shows the performance levels at CP-C and LS-CP. This shows that there is a lack of transferring of forces to each vertical member due to irregular shape of opening. The re-entrant corner buildings (L1 to P2) decreases the performance point as the offsets increases. The vertical irregular models on plain ground (V1 to V3) shows the performance levels between Life Safety (LS) and Collapse prevention (CP), but model V4 shows a large displacement for very less base shear and the performance level obtained in between collapse prevention and point C (collapse). Whereas in sloping ground models the model V5 was found more vulnerable to earth quake. Since the performance goal was not achieved here. The model V6 achieves the performance after collapse point. Figure 4 shows pushover curve and performance point for model 1. Table 1 indicates performance point and its performance level for all 3 storey building models using codal type lateral load pattern.

## 5. Conclusions

1. The equivalent static method doesn't consider the irregular effects in the building and since it depends only on empirical formula the results obtained will be abnormal in comparison to response spectrum method.

2. The eccentricity between centre of mass and centre of rigidity varies even though in the absence of dual systems i.e. shear walls.

3. In pushover analysis the codal type of vertical distribution of lateral force was found more detrimental in low rise models. Since more number of hinges are formed for a given displacement level compared to the other two patterns.

4. The performances of all the models except sloping ground (V5 and V6) are lies in between life safety and collapse prevention. This shows the buildings resting on sloping ground are more vulnerable to earthquake than rest of the models.

5. The result also shows that, capacity of the buildings may be significant but the seismic demand varies with respect to the configurations.

**Table 1.** Performance point and its performance level for 3 storey building models using Codal type lateral load pattern

| Models | Displacement in mm | Base Shear in kN | Performance level | Displacement in mm | Base Shear in kN | Performance level |
|---|---|---|---|---|---|---|
| direction | X-direction | | | Y-direction | | |
| Model - 1 | 110.2 | 3469.3 | LS-CP | 82.4 | 5200.5 | LS-CP |
| Model - D1 | 104.9 | 3279.8 | CP-C | 80.5 | 4732.3 | LS-CP |
| Model - D2 | 103.1 | 3012.7 | LS-CP | 78.9 | 4264.4 | LS-CP |
| Model - L1 | 108.4 | 2921.5 | LS-CP | 82.5 | 4310.6 | LS-CP |
| Model - L2 | 106.0 | 2691.5 | LS-CP | 81.6 | 3870.8 | LS-CP |
| Model - L3 | 105.5 | 2488.4 | LS-CP | 71.2 | 3842.5 | LS-CP |
| Model - T1 | 107.2 | 2655.3 | LS-CP | 81.8 | 3883.3 | LS-CP |
| Model - T2 | 105.6 | 2419.8 | LS-CP | 73.8 | 3274.0 | LS-CP |
| Model - P1 | 107.9 | 2914.3 | LS-CP | 81.6 | 4332.4 | LS-CP |
| Model - P2 | 106.4 | 2377.6 | LS-CP | 79.8 | 3429.5 | LS-CP |
| Model - V1 | 105.4 | 3191.8 | LS-CP | 94.6 | 3953.1 | LS-CP |
| Model - V2 | 100.9 | 2870.7 | LS-CP | 73.7 | 3729.2 | LS-CP |
| Model - V3 | 105.1 | 2815.8 | LS-CP | 75.3 | 3777.2 | LS-CP |
| Model - V4 | 115.3 | 2310.2 | CP-C | 79.2 | 3684.1 | LS-CP |
| Model - V5 | - | - | Doesn't exist | 83.4 | 6019.2 | D-E |
| Model - V6 | 53.5 | 4444.5 | >E | 31.5 | 5124.0 | C-D |

Note: Performance levels are as follows,
IO-Immediate Occupancy,
LS- Life Safety,
CP- Collapse Prevention,
C-Collapse,
A, B- Performance Points before Immediate Occupancy &
D, E- Performance Points beyond Collapse

# REFERENCES


[1] Abhilash.R, "Effect of lateral load patterns in Pushover analysis", 10th National Conference on Technological Trends (NCTT09) 6-7, India, 2009.

[2] Andreas.J.Kappos, "Performance-based seismic design of 3D R/C buildings using inelastic static and dynamic analysis procedures", ISET journal of earthquake technology, paper no. 444, vol. 41, no. 1, pp. 141-158, 2006.

[3] ATC-40, "Seismic Evaluation and Retrofit of Concrete Buildings", Applied Technology Council, Seismic Safety Commission, Redwood City, California, Volume 1&2, 1996.

[4] Birajdar.B.G, "Seismic analysis of buildings resting on sloping ground", 13thWorld Conference on Earthquake Engineering, Vancouver, B.C., Canada, Paper No. 1472, 2004

[5] FEMA-356, "Prestandard and Commentary for the Seismic Rehabilitation of Buildings", Federal Emergency Management Agency, American society of civil engineers, 2000.

[6] IS 1893-2002(Part-1), "Criteria for Earthquake resistant design of structures, General provisions and buildings", Bureau of Indian Standards, New Delhi

[7] IS 456:2000, "Plain and Reinforced concrete – Code of practice", Bureau of Indian Standards, New Delhi.

[8] Kadid.A, "Pushover analysis of reinforced concrete frame structures", Asian journal of civil engineering (building and housing) vol. 9, no.1, pages 75-83, 2008

[9] M. Seifi, "Nonlinear Static Pushover Analysis in Earthquake Engineering State of Development", University Putra Malaysia, ICCBT 2008.

[10] K. Soni Priya, "Non-Linear Pushover Analysis of Flatslab-Building by using SAP2000", International Journal of Recent Technology and Engineering (IJRTE), ISSN: 2277-3878, Volume-1, Issue-1, April 2012.