Pushover Analysis of Vertical Irregular RC Building Having the Same Floor Area

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Abstract - *The seismic performance of building frame changes with the variation or the discontinuity in stiffness, strength, diaphragm and mass of the building. These are the reasons for building irregularity. The common type of irregularity is the vertical geometry irregularity. So that pushover analysis is one of the methods to study the seismic behavior of vertical irregular building when the building is subjected to earthquake forces. The present study gives an effect of vertical geometry irregularity RC building having the same floor are on seismic responses by performing pushover analysis. Reinforced concrete buildings have been modeled square shape and analyzed using CSi SAP2000 software. In this study, all building models are considered as having the same floor area, same plan area, same cost, same slab thickness, same beam and column size. Comparison of seismic responses of the irregular RC building in terms of base shear, roof displacement, spectral acceleration, spectral displacement and effective time period has been done by performing nonlinear static pushover analysis. From analysis results, it has been observed that base shear capacity and spectral acceleration is gradually decreased vertical irregular RC building, whereas roof displacement, effective time period and spectral displacement is gradually increased vertical irregular RC building. The analysis also shows the location of plastic hinges at the performance point of the vertical geometry irregular RC building.*

Key Words: Pushover analysis, RC building, square shape, same floor area, irregularity, SAP2000.

1. INTRODUCTION

According to the philosophy of earthquake-resistant design, the control has become a clear design consideration which can be achieved only by introducing some kind structures are designed for the forces, which are much less than the expected design seismic forces. Therefore, when a structure is subjected to ground motion by a strong earthquake, it undergoes inelastic deformation. Although though the structure may not collapse but the damages can be beyond repairs. Thus, damage control has become a more explicit design consideration that can only be achieved with some sort of identification as a non-linear analysis method in seismic design.

Pushover analysis has evolved over the past decade and much more, becoming the preferred method of analysis for performance-based seismic design, PBSD and assessment purposes. It is the method by which the ultimate strength and limitation state can be effectively investigated after yield, which has been applied experimentally to seismic engineering and seismic design. On non-linear static analysis is a possible method for calculating structural response under the event of a strong earthquake. The analysis involves applying horizontal loads or lateral loads to a defined pattern, to the building incrementally, that is pushing the building and plotting the total applied shear force and lateral displacement associated with each increment, up to the condition of collapse. The equivalent static lateral loads almost represent earthquake-induced forces. Pushover analysis is a static nonlinear method in which the amount of structural loading is increasingly increasing. Weak links and structure failure modes are found as the loading levels increase. As the load and displacement increase, the element (beam, column, etc.) begins to inelastically yield and deform. The resulting graphic curve is easy to imagine representing the capacity of the building. Structures with predictable earthquake performance can be created using this method. The basic elements of this method are below: -

Capacity: It represents the efficiency of structures to withstand earthquake demand. Capacity usually refers to the strength at the point of the yield of the capacity curve of a material or structure.
Demand: It is a representation of the ground motion of an earthquake or vibration subject to a building.
Performance: It is an intersection of the capacity spectrum and the demand spectrum. The performance of a building depends on the performance of structural and non-structural elements. After obtaining performance points, the performance of the structures is checked against this performance level.
Immediate occupancy: It is the damage state due to an earthquake in which limited structural damages have

occurred. There is a negligible chance of fatal injury due to structural failure.

Life safety: It is a state where structures can be damaged by earthquakes but it has some margins against total or partial collapse. Traumatic events can occur during an earthquake, but the risk of fatal injury from structural damage is very low.

Collapse prevention: In this state, the building has suffered extreme damage with large permanent drift. The structure may have some residual strength and stiffness with extensive damages occurred to nonstructural.

2. PARAMETERS OF REFERENCE MODELS

In this present study, a 3D building structures of G+5, G+6 and G+7 storeys have been modeled and analyzed using CSi SAP2000 software. The number of three-square shapes regular and irregular buildings is modeled as a bare frame without infill walls.

Table -1: Common parameters and material properties of models

Model 1	Regular building
Model 2	Irregular building
Model 3	Irregular building
Storey height	3.048 m
Live load	1.916 KN/m2
Partition wall load	0.958 KN/m2
Floor finish load	0.958 KN/m^2
Importance factor	1
Number of storey	G+5, G+6 and G+7
Seismic zone	II (Dhaka)
Cost of Building	26800000 Tk
Floor area	1576.07m2
Plan area	262.68 m^2
Beam size	254×406.4 mm
Slab thickness	152.4 mm
Column size	406.4 ×406.4 mm
Crushing strength of concrete (f'_c)	27.579 MPa
Modulus of elasticity of concrete (E)	24855.576 MPa
Seismic zone factor	0.15 (For Dhaka)
Response reduction factor	8
Yield strength of steel (f y)	413.685 MPa
Type of building	Residential

The general parameters and material properties for modeling and analysis of the structure are shown in Table 1 above.

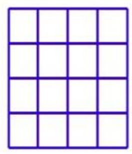
Fig1.Model 1 plan view

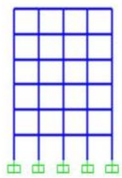
Fig2.Model 1 elevation view

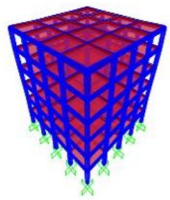
Fig3.Model 1, 3D view

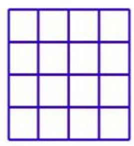
Fig4.Model 2 plan view

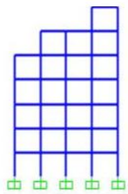
Fig5.Model 2 elevation view

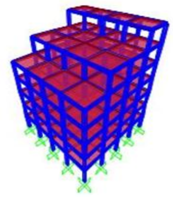
Fig6.Model 2, 3D view

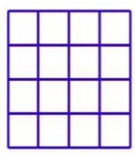
Fig7.Model 3 plan view

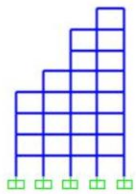
Fig8.Model 3 elevation view

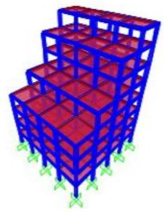
Fig9.Model 3, 3D view

Plan, elevation and 3D view all of the models shown in above figure 1-12.

3. PUSHOVER ANALYSIS PROCEDURE

1. 3D models are made for all the structures considered.
2. All material properties, sections properties, load cases are defined and assigned.
3. Select the properties of all beams and columns and assign the hinge properties according to ATC-40 on the frame elements. The hinges of flexure (M3) and shear (V2) are assigned for the beams and the axial force and bending moment are assigned to the hinges of the column (P M2 M3).
4. Define nonlinear static analysis. Then run the analysis.
5. Following the design of the structure, nonlinear static analysis is performed to determine the pushover curve and performance points.

4. RESULT

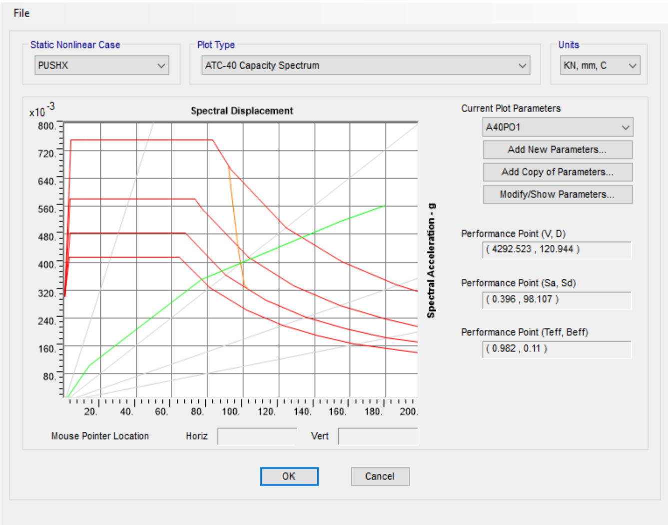

Fig- 10: ATC-40 Capacity Spectrum (Model 1)

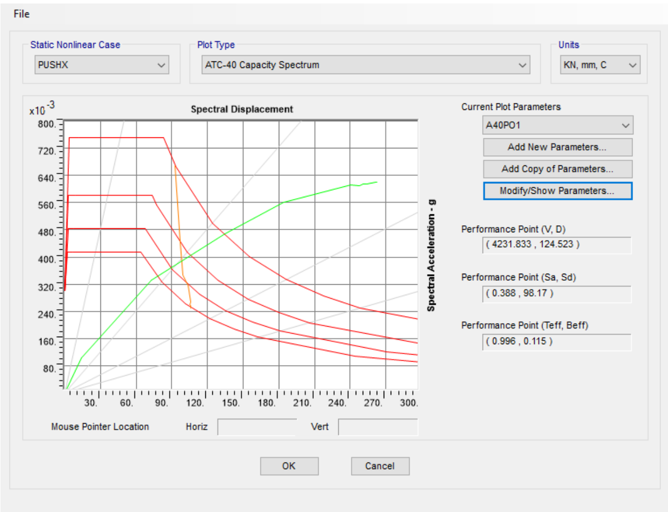

Fig- 11: ATC-40 Capacity Spectrum (Model 2)

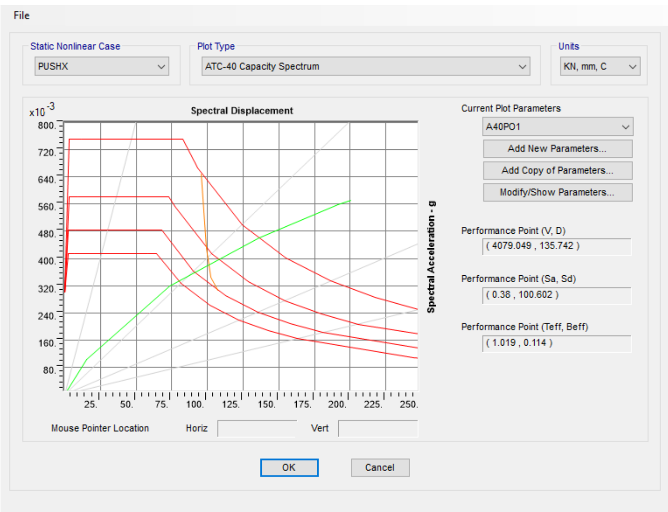

Fig- 12: ATC-40 Capacity Spectrum (Model 3)

A comparison of performance points for the regular and irregular buildings is shown in figure 10-12 above. The performance point is obtained by intersecting the capacity and demand spectrum, where the demand curve is shown in red and the capacity curve is displayed in green. Performance points represent the global behavior of building.

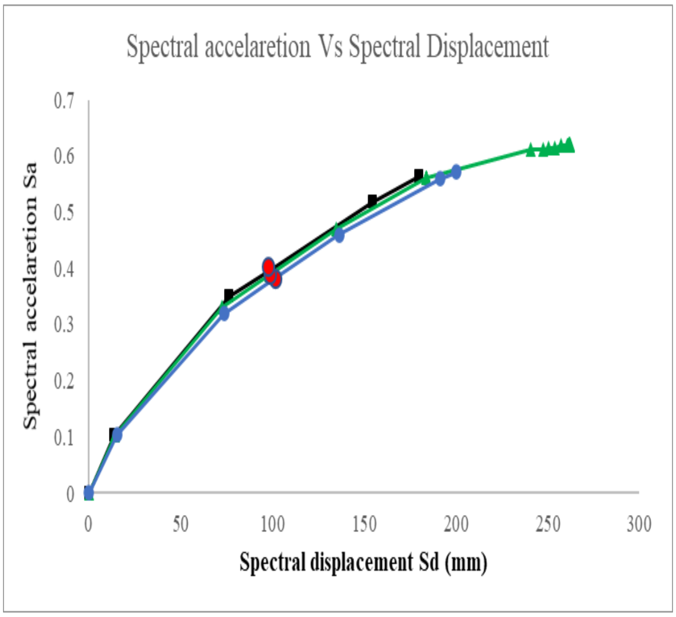

Fig- 13: Comparison of spectral acceleration Vs spectral displacement

Comparison of spectral acceleration vs spectral displacement for, the regular and irregular buildings is shown in figure 13 above. The rate points of figure 13 indicate the performance point of MODEL1, MODEL-2 and MODEL-3 respectively where capacity meets the demand.

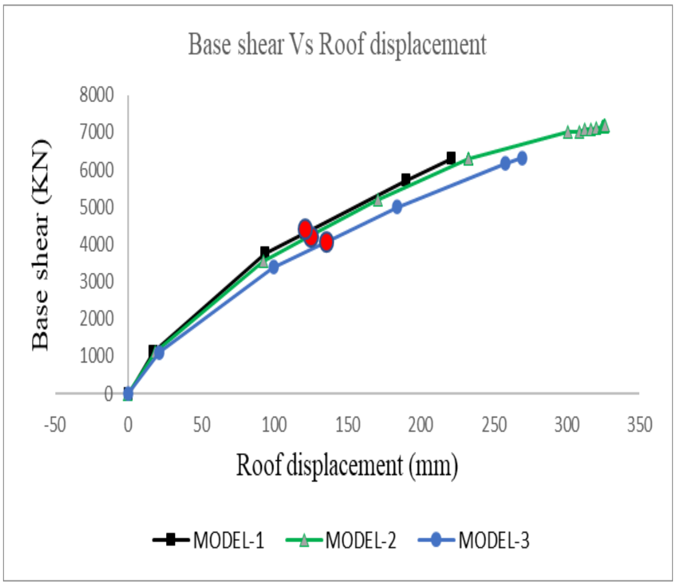

Fig- 14: Comparison of base shear Vs roof displacement

A comparison of pushover curves for the regular and irregular buildings is shown in figure 14 above. The rate points of figure 14 indicate the performance point of MODEL1, MODEL-2 and MODEL-3 respectively where capacity meets the demand. This curve is obtained from performing a non-linear static pushover analysis. The pushover curve displays the base shear vs. displacement derived from the pushover analysis.

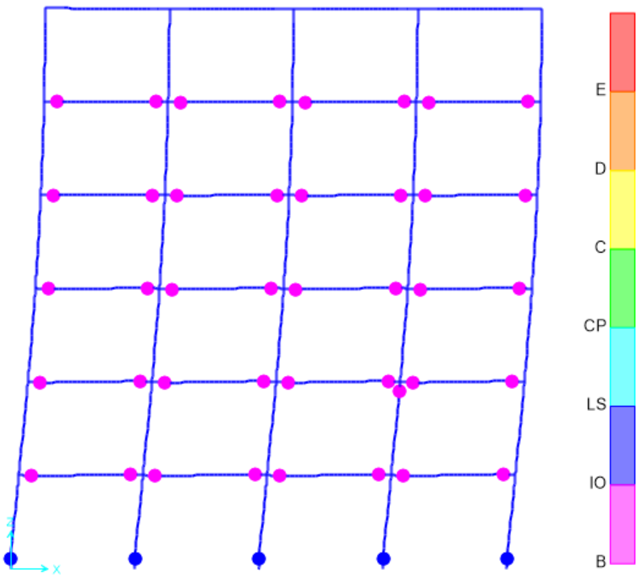

Fig- 15: Comparative location of plastic hinges at performance point (model 1)

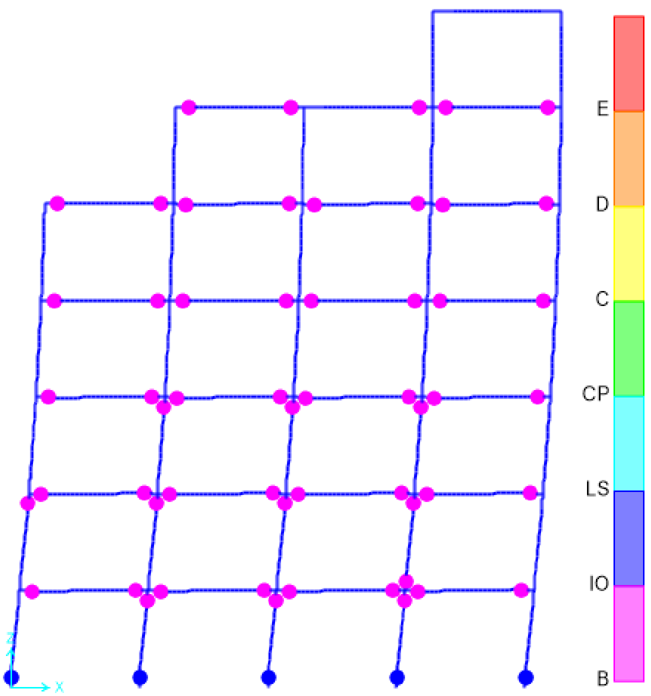

Fig- 16: Comparative location of plastic hinges at performance point (model 2)

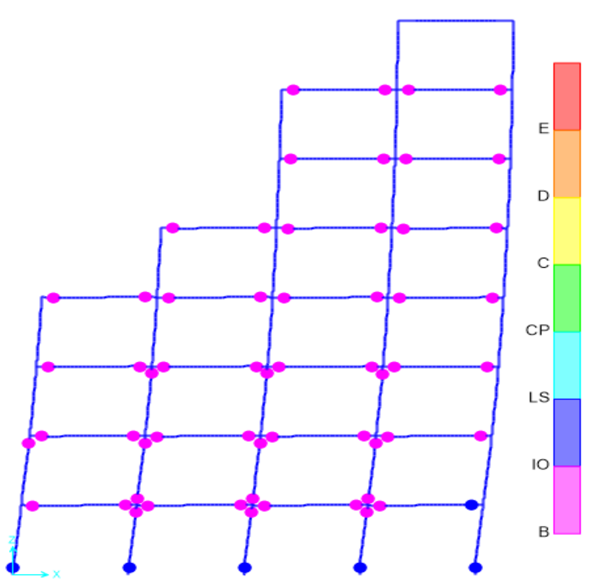

Fig- 17: Comparative location of plastic hinges at performance point (model 3)

The above figure 15-17 shows the location of plastic hinges at the performance point of the regular and irregular building.

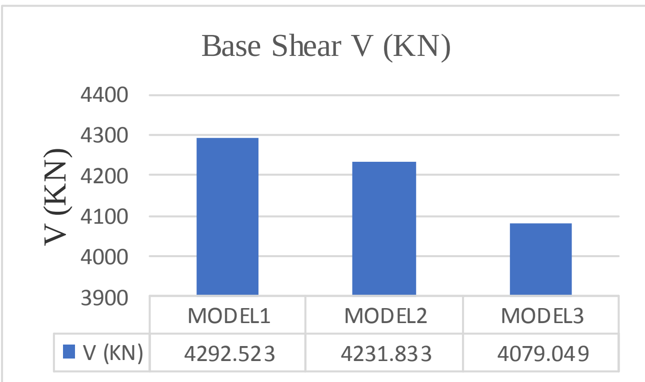

Fig-18: Comparison of base shear at performance point

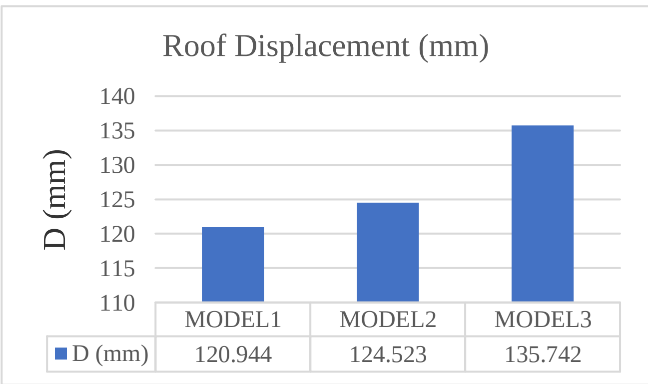

Fig-19: Comparison of roof displacement at performance point

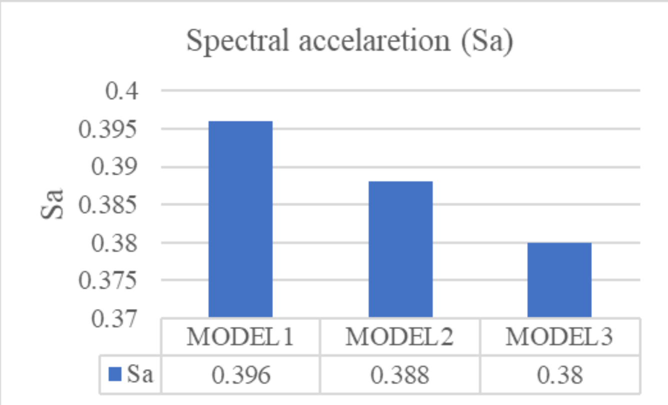

Fig-20: Comparison of spectral acceleration at performance point

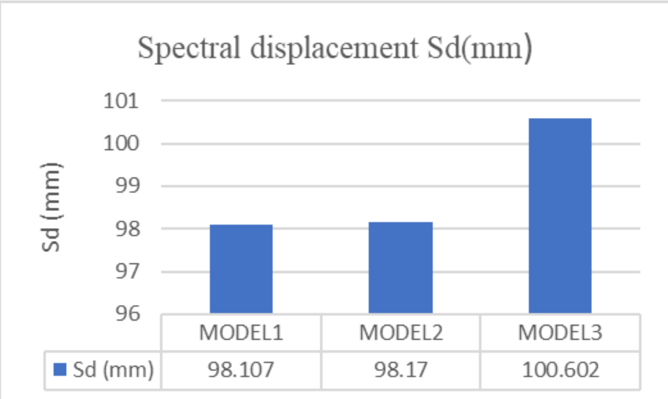

Fig-21: Comparison of spectral displacement at performance point

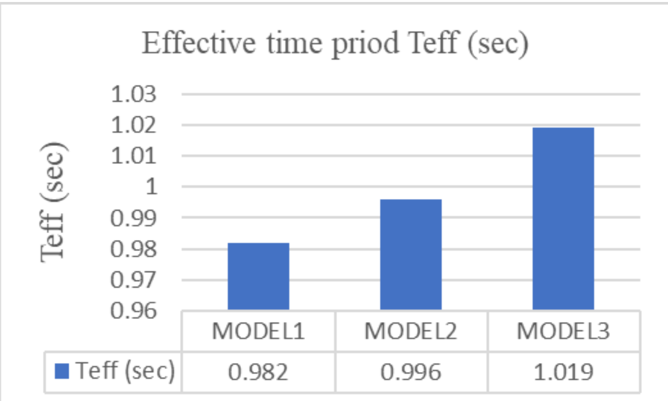

Fig-22: Comparison of effective time period at performance point

Comparison of base shear, roof displacement, spectral acceleration, spectral displacement and effective time period from the pushover analysis for regular and irregular buildings is shown in figure 18-22 above.

Table -2: **Performance points were compared with all models**

Type of building	Regular (M1)	Irregular (M2)	Irregular (M3)
Base shear (KN)	4292.523	4231.8	4079
Roof displacement (mm)	120.944	124.52	135.74
Spectral acceleration	0.396	0.388	0.38
Spectral displacement (mm)	98.107	98.17	100.6
Effective time period (sec)	0.982	0.996	1.019
Effective damping coefficient (β_{eff})	0.11	0.115	0.114

Table-3: Performance points were compared with base shear and roof displacement

MODEL No.	MODEL-1	MODEL -2	MODEL-3
% of Total Irregularity	0	433.31	483.31
Base Shear, (KN)	4292.523	4231.8	4079
Change of Base Shear with Respect to MODEL-1	--	-1.41%	-5%
Roof Displacement, D (mm)	120.944	124.52	135.74
Change of Roof Displacement with Respect to MODEL-1	--	+2.95%	+12.24%

Table-4: Performance points were compared with spectral acceleration and spectral displacement

MODEL No.	MODEL-1	MODEL-2	MODEL-3
% of Total Regularity	0	433.31	483.31
Spectral Acceleration	0.396	0.388	0.38
Change of Spectral Acceleration with Respect to MODEL-1	--	-2.02%	-4.04%
Spectral Displacement, D (mm)	98.107	98.17	100.6
Change of Spectral Displacement with Respect to MODEL-1	--	+0.07%	+2.55%

Table-5: Performance points were compared with effective time period

MODEL No.	MODEL-1	MODEL-2	MODEL-3
% of Total Irregularity	0	433.31	483.312
Effective Time Period, T_{eff} (sec)	0.982	0.996	1.019
Change of T_{eff} MODEL-1	-	+1.43%	+3.77%

Comparison of performance points in terms of base shear, roof displacement, spectral acceleration, spectral displacement and effective time period for all the building models considered for the analysis is shown in table 2-5 above.

5. CONCLUSION

The major objective of the present study was to understand the effect of irregularity as having the same floor area, same plan area, same cost, same slab thickness, same beam and column size of the reinforced concrete building structure. From the analysis results, it has been observed that the base shear capacity and spectral acceleration are gradually decreasing regular to irregular RC building, whereas roof displacement, time period and spectral displacement are gradually incising regular to irregular RC building. Compared to this 483.312% irregular building, the base shear capacity and spectral acceleration capacity of that regular building are found to be 5% and 4.04% higher and at the same time roof displacement, spectral displacement and effective time period is 12.24%, 2.55% and 3.77% less. Therefore, despite having the same cost and same floor area, the capacity of the irregular building is less than that of the regular building. So regular building will give more performance for earthquakes. The location of plastic hinges at performance point of the structures is also determined and it has been observed that most of the hinges lie within immediate occupancy to life safety performance level. In this level, the damage is within the light-to-moderate category, but still, there is residual strength and stiffness in all buildings which means there will be probably no collapse locally at this level of earthquake. Pushover analysis showed actual nonlinear static behavior of the structure which helps in the performance-based seismic design of the structure.

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BIOGRAPHIES

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