IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 5 Ser. II (Sep. - Oct. 2019), PP 19-28
www.iosrjournals.org

Seismic Response of Setback RCC Buildings under Revised BNBC Code by Pushover Analysis

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Abstract: *Buildings with irregularity in plan or elevation suffer much more damage in earthquake than buildings with regular configuration. In this study, four vertical geometric irregular setback building models have been analyzed by pushover analysis method to observe their seismic behavior in seismic zone II of Bangladesh. Four vertical geometric irregular setback building models have four different A/L ratios such as 2, 6, 8 and 12. Pushover analysis is performed to determine the performance levels, drift ratios and plastic rotations of structural members. The performance levels, drift ratios and plastic rotations are compared for 4 building models in both X and Y directions by using ETABS 2016 version. In this study pushover analysis based on FEMA-356 capacity spectrum method employed to analyze the building models. All the plastic hinges developed in the buildings are in life safety performance levels. Also the building showed a weak beam and strong column behavior.*

Keywords: *Pushover analysis, setback buildings, BNBC code, performance levels, performance points, plastic hinges, demand curve, capacity curve, pushover curve.*

Date of Submission: 09-09-2019 Date of acceptance: 25-09-2019

I. Introduction

The pushover analysis is a static non-linear analysis under permanent gravity loads and gradually increasing lateral loads. Static pushover analysis is an attempt by the structural engineering profession to evaluate the real strength of the structure and it promises to be a useful and effective tool for performance based design. A plot of the total base shear versus top displacement in a structure is obtained by this analysis that would indicate any premature failure or weakness. The analysis is carried out up to failure, thus it enables determination of collapse load and ductility capacity [1].

II. Objectives of the Study

1) To find out the suitable setback building model by pushover analysis.
2) To observe the seismic effects on different types of setback buildings.
3) To observe and compare the performance point of setback buildings.
4) To observe the performance level of the building models.
5) To observe the hinges location and hinges status during performance point.
6) To compare the lateral displacement, drift ratios and plastic rotations with allowable plastic rotations and allowable drift ratios given by FEMA-273 & 356.

III. Literature Review

Buildings with irregularity in plan or elevation suffer much more damage in earthquake than buildings with regular configuration [6]. According to BNBC 2017 those building will be considered as vertical irregular or setback buildings which will fall into following conditions.

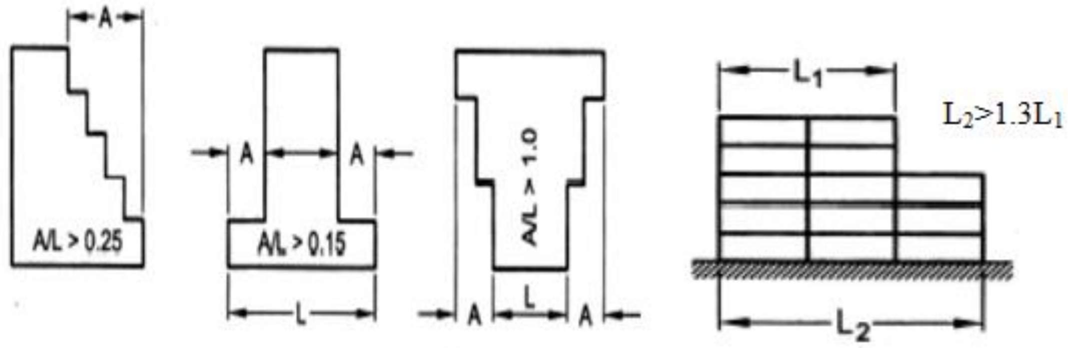

Figure 1: Vertical Geometric Irregularity (Setback Structures)

Performance is the combined performance of both structural and non-structural components of the building. Different performance levels are used to describe the building performance using the pushover analysis which is described below.

Operational Level (OL): As per this performance level building are expected to sustain no permanent damages. Structure retains original strength and stiffness. Major cracking is seen in partition walls and ceilings as well as in the structural elements [2] [3].

Immediate Occupancy Level (IO):Buildings meeting this performance level are expected to sustain no drift and structure retains original strength and stiffness. Minor cracking in partition walls and structural elements is observed. Elevators can be restarted. Fire protection is operable [2] [3].

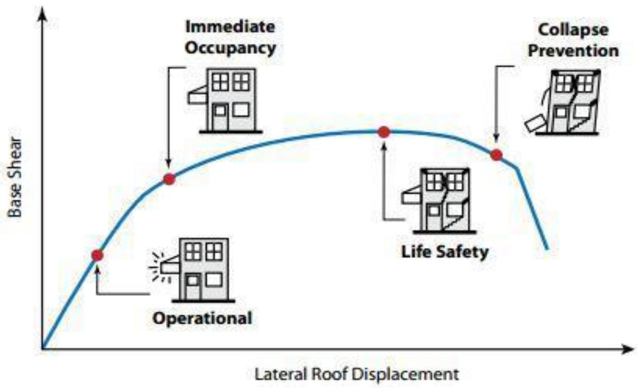

Figure-2: Performance levels of buildings according to FEMA-356

Life Safety Level (LS): This level is indicated when some residual strength and stiffness is left available in the structure. Gravity load bearing elements function no out of plane failure of walls and tripping of parapet is seen. Some drift can be observed with some failure to the partition walls and the building is beyond economical repair. Among the non-structural elements failing hazard mitigates but many architectural and mechanical systems get damaged [2] [3].

Collapse Prevention Level (CP): Buildings meeting this performance level are expected to have little residual strength and stiffness but the load bearing structural elements function such as load bearing walls and columns. Building is expected to sustain large permanent drifts, failure of partitions infill and parapets are extensive damage to non-structural elements. At this level the building remains in collapse level [2] [3].

Capacity:It is defined as the expected ultimate strength (in flexure, shear and axial loading) of the structural components excluding the reduction factors commonly used in the design of concrete members. The capacity generally refers to the strength at the yield point of the element or structure's capacity curve. For deformation controlled component's capacity beyond the elastic limit generally includes the effect of strain hardening [2] [3].

Demand:Demand is represent by estimation of the displacement or deformation that the structure is expected to undergo. This is in contrast to conventional linear elastic analysis procedures in which demand is represented by prescribed lateral forces applied to the structure[2] [3].

Performance Point:It is the point where the capacity spectrum intersects the appropriate demand spectrum. To have the desired performance in structure performance level it should be designed by considering these points of forces [2] [3].

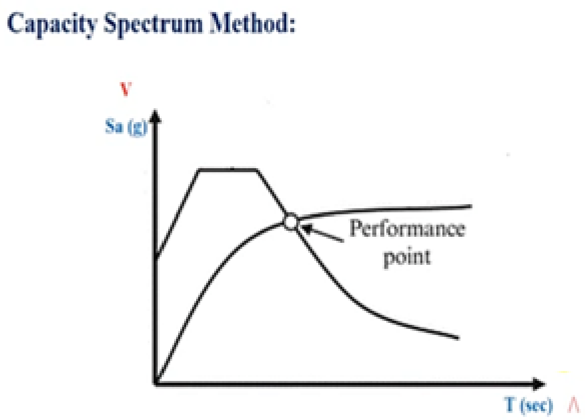

Figure-3: Plot between spectral acceleration and spectral displacement

Capacity Curve: The plot between base shear and roof displacement is referred as capacity curve or pushover curve [2] [3].

Capacity Spectrum: The capacity curve transformed from base shear v/s roof displacement (V v/s d) to spectral acceleration v/s spectral displacement (Sa v/s Sd) is referred as capacity spectrum [2] [3].

Demand Spectrum: It is plot between average spectral acceleration versus time period. It represents the earthquake ground motion in capacity spectrum method [2] [3].

Types of pushover analysis:

Capacity Spectrum Method: Capacity Spectrum Method is a non-linear static analysis procedure which provides a graphical representation of the expected seismic performance of the structure by intersecting the structure's capacity spectrum with the response spectrum (demand spectrum) of the earthquake. The intersection point is called performance point and the displacement coordinates (dp) of the performance point is the displacement demand on the structure for the specified level of seismic hazard [1] [2] [3].

Displacement Coefficient Method: Displacement Coefficient Method is a non-linear static analysis procedure which provides a numerical process for estimating the displacement demand on the structure, by using a bilinear representation of the capacity curve and a series of modification factors or coefficients to calculate a target displacement. The point on the capacity curve at the target displacement is the equivalent of the performance point in the capacity spectrum method [1] [2] [3].

IV. Methodology

Total four types of vertical irregular buildings having different A/L ratios have been considered for pushover analysis. Each and every beam and column dimensions has been assumed constant in a 10storey building. Entire analysis work has done by using Etabs 2016. Review a pushover displaced shape and sequence of hinge formation on step-by-step basis and display the hinge status and rotation of hinges. At the end of the work all the data's have been accumulated and compared for better understanding the behavior of setback buildings under seismic loading by nonlinear static analysis.

Table -1: Structural dimensions of setback buildings

Component	Model-1	Model-2	Model-3	Model-4
A/L Ratio	2.0	6.0	8.0	12.0
Beam size (in2)	12 x 15			
Column size (in2)	15 x 15			
Slab thickness (in)	5			
No. of stories	10			
Height of storey	10 ft			
Span size	5 by 5			

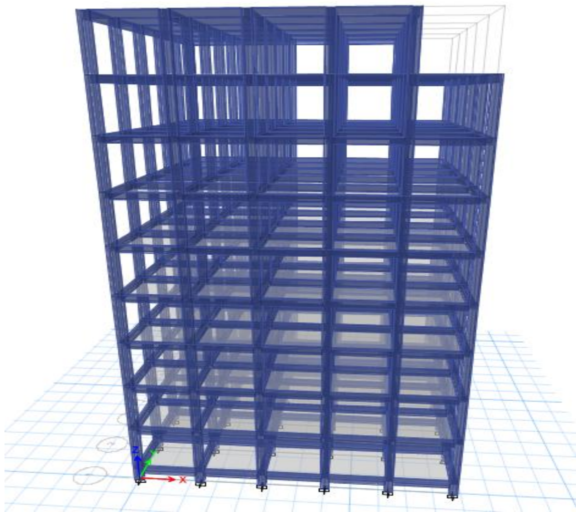

Figure-4: 3D view for setback building model-1 (A/L = 2.0)

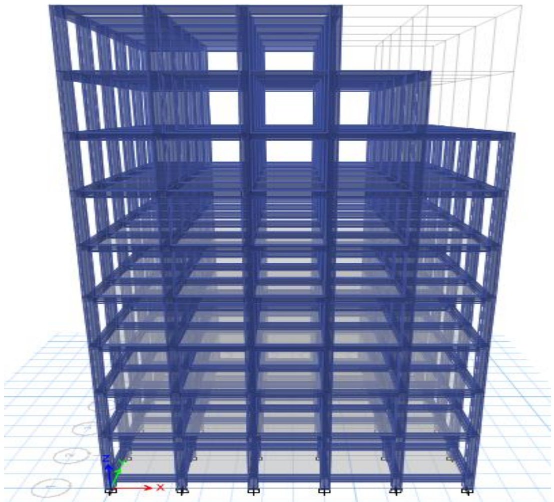

Figure-5: 3D view for setback building model-3 (A/L = 6.0)

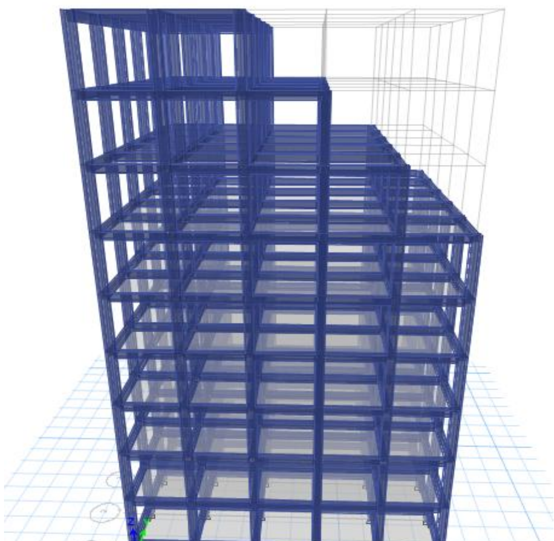

Figure-6: 3D view for setback building model-4 (A/L = 12.0)

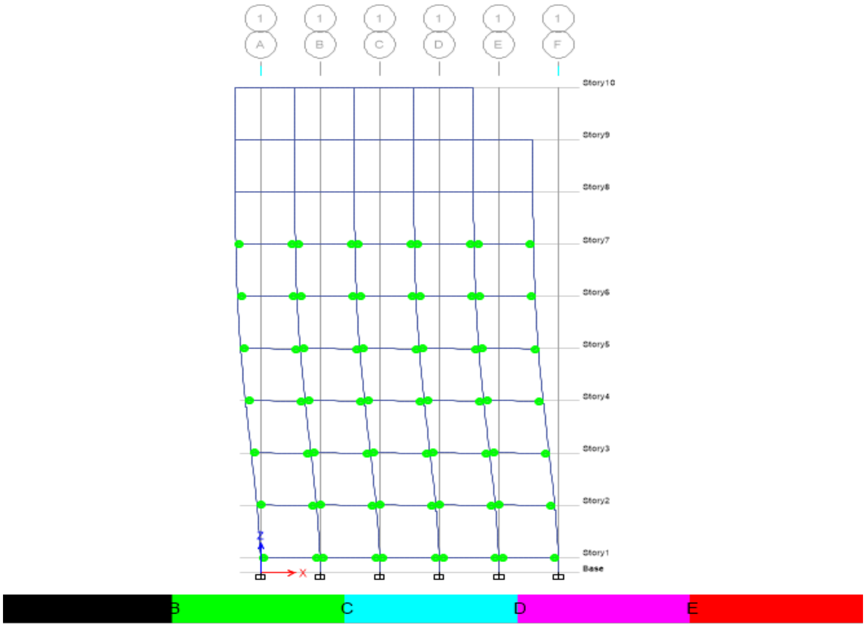

Figure-7: Performance point at step 4 for model-1 due to push X

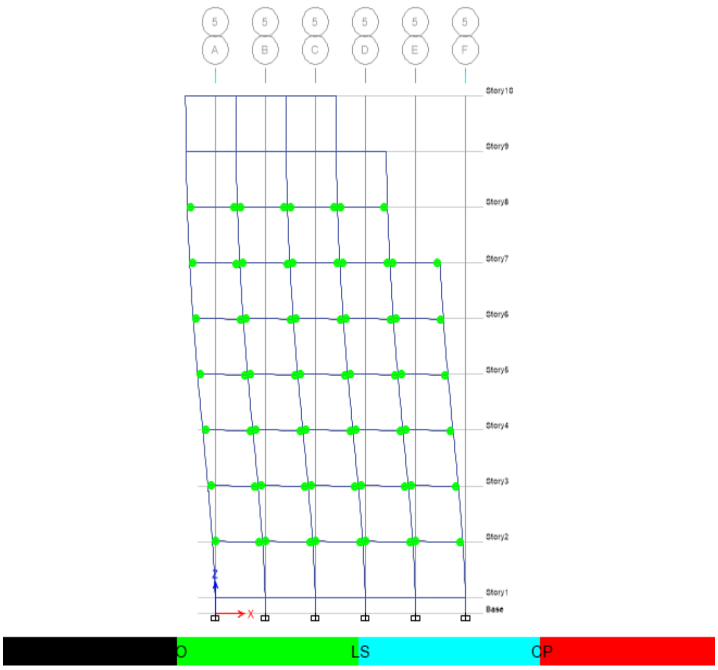

Figure-8: Hinge formation due to push X for model-3 (Step 11 out of 11)

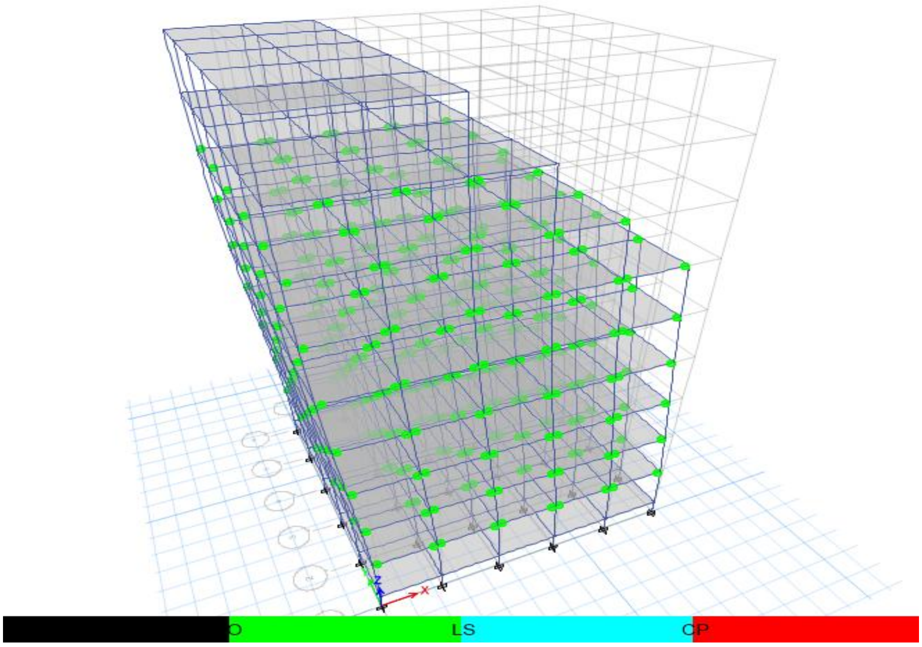

Figure-9: Hinge formation due to push X for model-4

V. Analysis Results

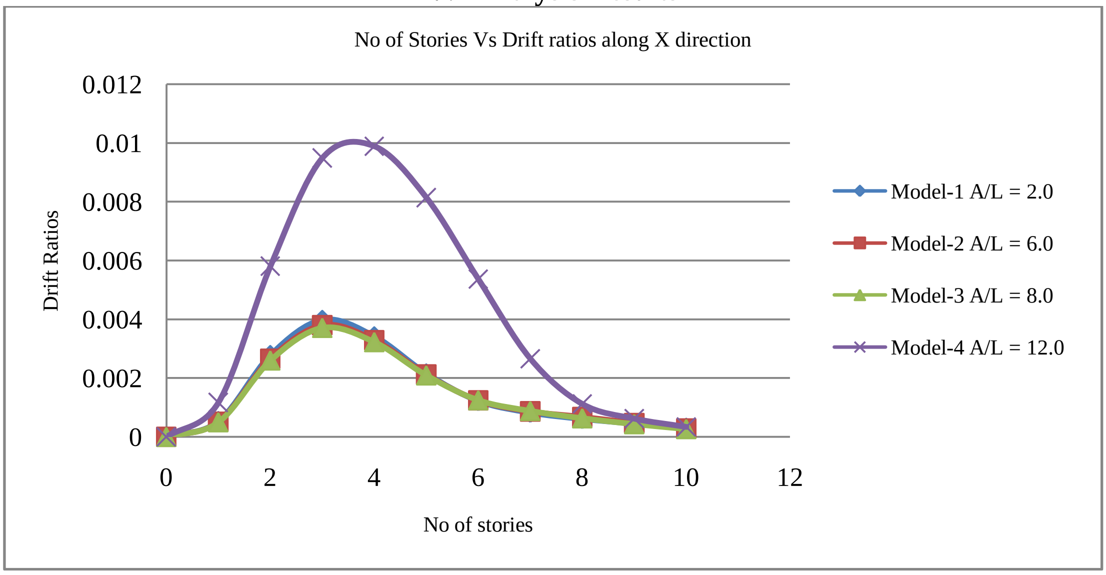

Figure-10: Comparison of drift ratios for four different setback buildings along X direction.

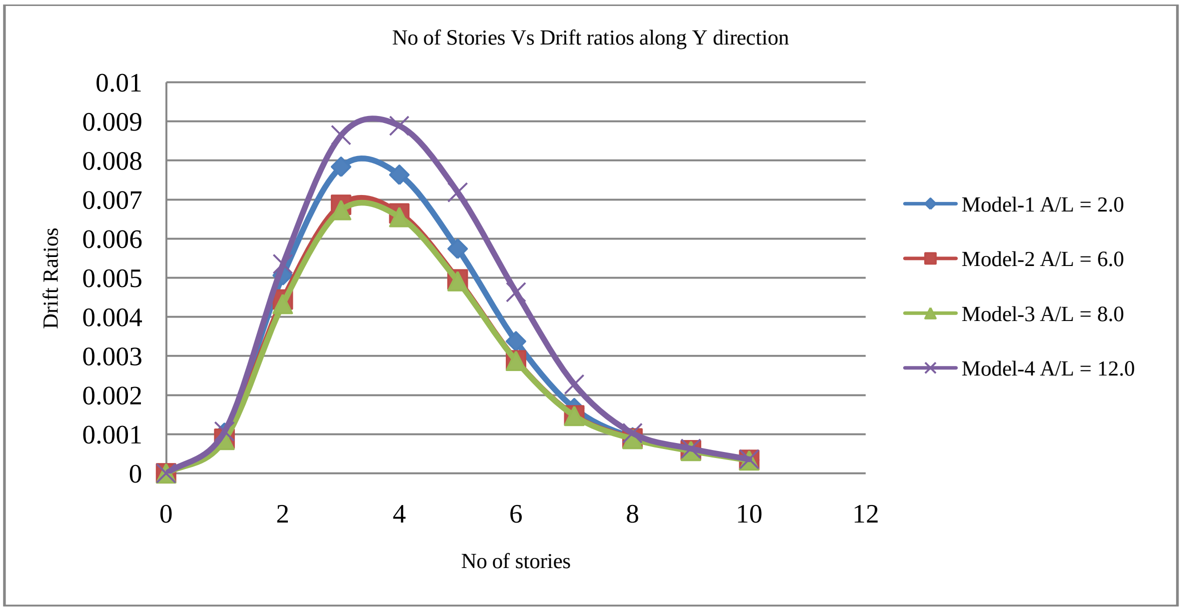

Figure-11: Comparison of drift ratios for four different setback buildings along Y direction

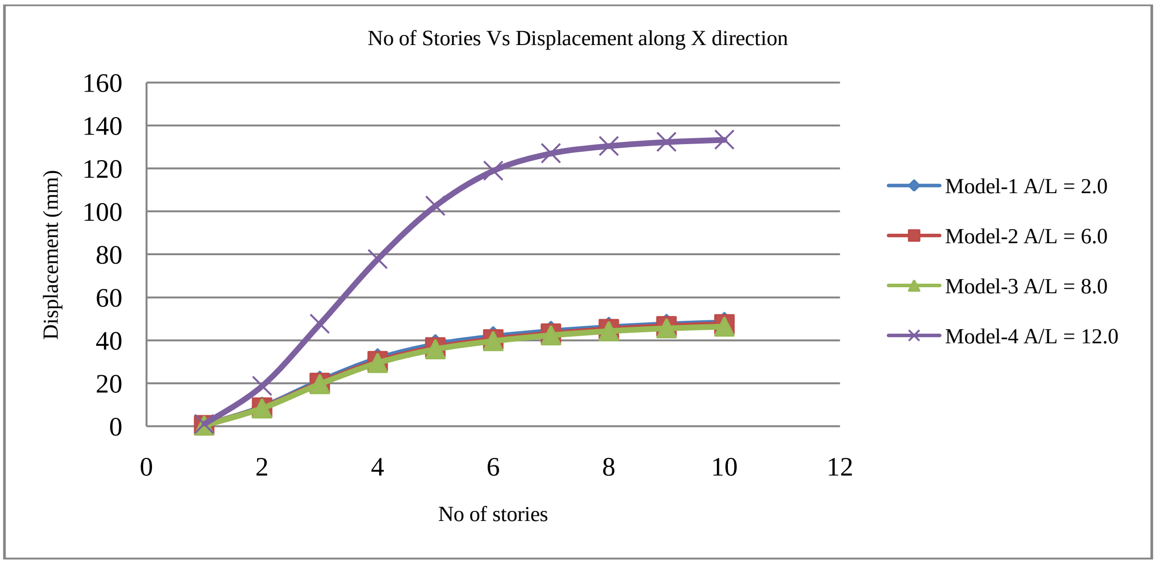

Figure-12: Comparison of displacement for four different setback buildings along X direction

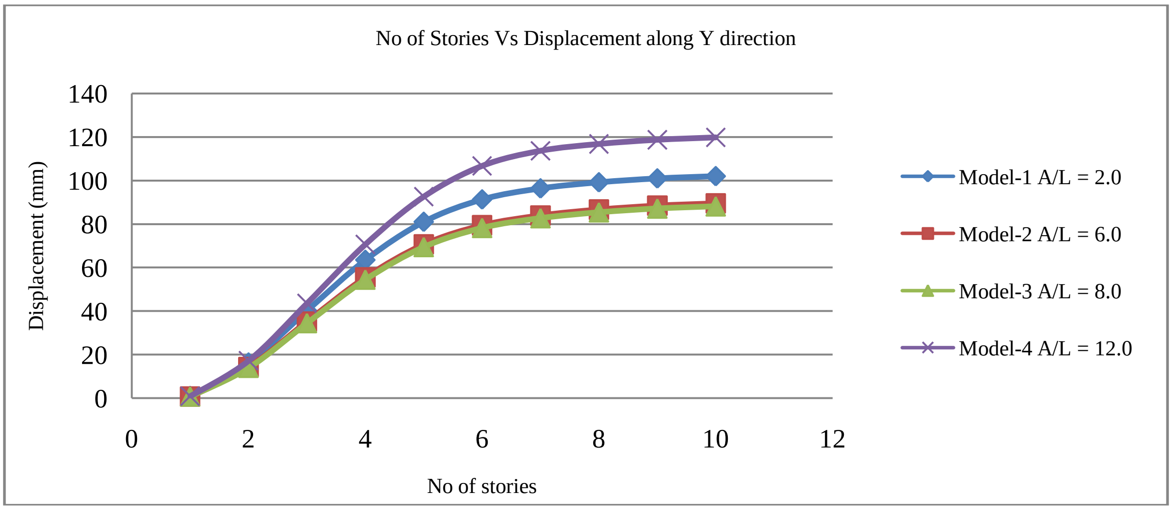

Figure-13: Comparison of displacement for four different setback buildings along Y direction

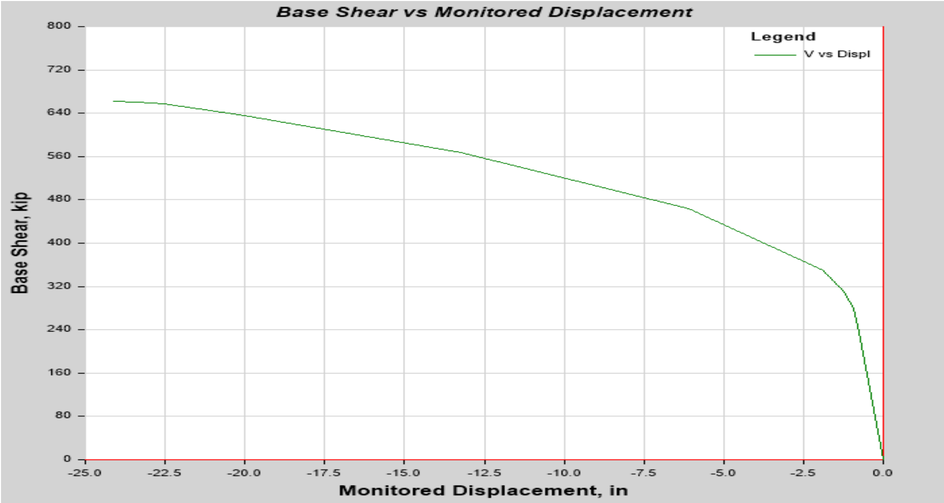

Figure-14: Push over curve for model-1 (A/L =2) due to Push X

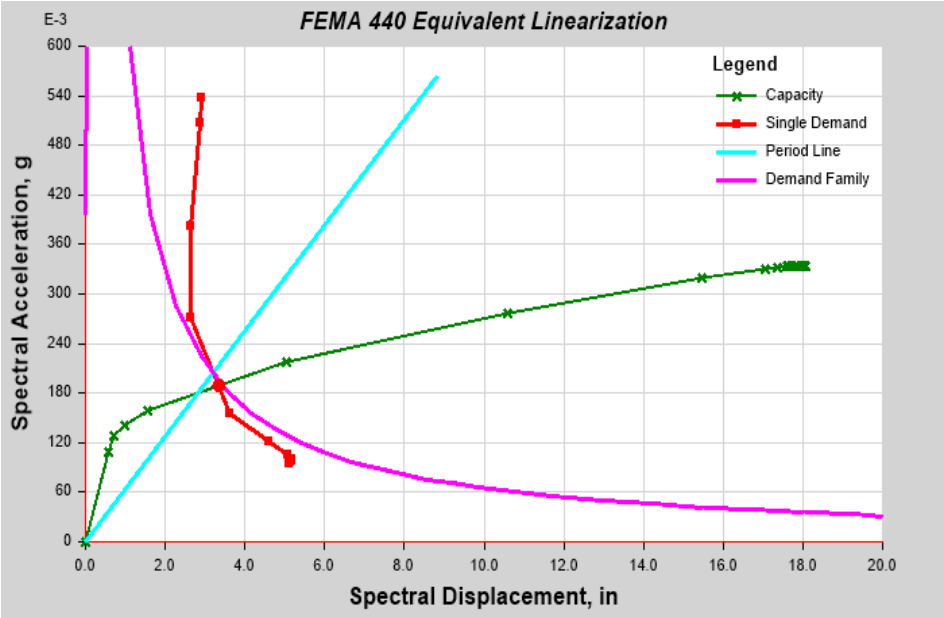

Figure-15: Performance point for model-1 (A/L =2) due to Push X

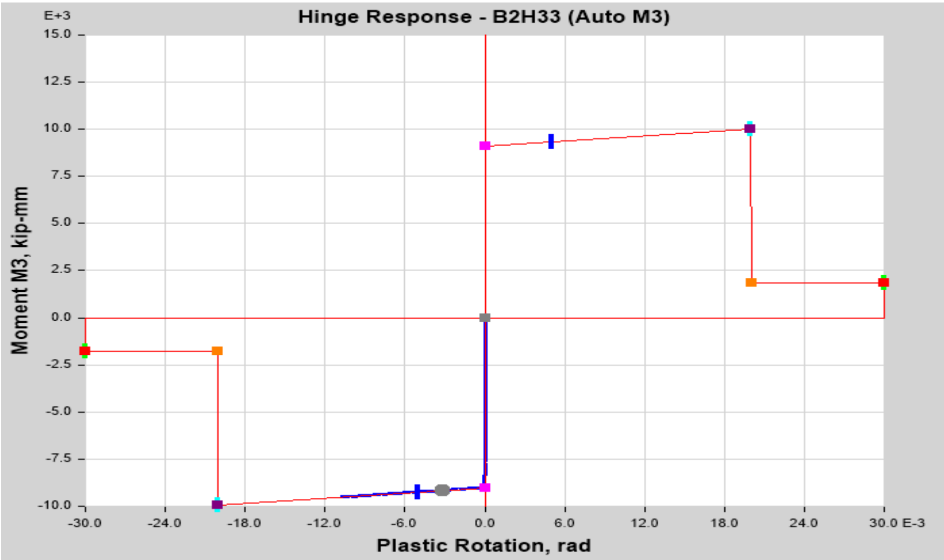

Figure-16: Hinge rotation at performance point for model-1 (A/L =2) due to Push Y

Table -2: Performance points and number of plastic hinges in different performance levels

Model No	A/L	Direction	Base shear (kip)	Displacement at performance point in (in)	Number of plastic hinges in			Total number of plastic hinges
					B-IO	IO-LS	LS-CP	
Model-1	2	X	408.30	4.04	504	0	0	504
		Y	406.64	0.30	720	0	0	720
Model-2	6	X	399.6	4.07	708	120	0	828
		Y	404.21	0.25	712	0	0	712
Model-3	8	X	396.72	4.14	720	120	0	840
		Y	400.36	0.17	734	0	0	734
Model-4	12	X	390.6	4.22	816	24	0	840
		Y	392.5	0.06	732	0	0	732

Table -3: Allowable inter storey drift ratios according to FEMA-273 & 356

Structural Systems	IO	LS	CP
Masonry shear wall system	0.007	0.007	0.009
Others	0.010	0.020	0.025

Table -4: Maximum Inter storey drifts ratios of setback buildings

Model No	Direction	IO	LS	CP
Model-1	X	0.003977 (Ok)		
	Y	0.007839 (Ok)		
Model-2	X		0.0038 (Ok)	
	Y	0.006869 (Ok)		
Model-3	X		0.003715 (Ok)	
	Y	0.006735 (Ok)		
Model-4	X		0.009886 (Ok)	
	Y	0.008889 (OK)		

Table -5: Allowable plastic rotations (in radians) according to FEMA-273 & 356

Structural Systems	IO	LS	CP
Beams	0.005	0.02	0.025
Columns	0.005	0.01	0.02

Table -6: Maximum plastic rotations of beams for setback buildings

Model No	Direction	IO	LS	CP
Model-1	X	0.0014 (Ok)		
	Y	0.003 (Ok)		
Model-2	X		0.004 (Ok)	
	Y	0.0046 (Ok)		
Model-3	X		0.0044 (Ok)	
	Y	0.0025 (Ok)		
Model-4	X		0.0049 (Ok)	
	Y	0.0034 (Ok)		

VI. Conclusion on Results

Ratio of A/L has much significant effect on performance levels of buildings and seismic behavior of buildings. From the obtained results it can be said that all the buildings performed well since their performance levels within the limit of life safety.Among all of the setback buildings, model-1 (A/L = 2) performs well since the performance point is slightly higher in both X and Y direction comparing to other models.Performance levels lies in immediate occupancy level for model-1 (A/L = 2) which indicates A/L ratio of building should be kept low.All the building models drift ratios and plastic rotations (radians) are within allowable limit according to FEMA 273 and FEMA-356. All the plastic hinges developed in the buildings are within life safety performance level which indicates all the setback buildings are safe. Also the building showed a weak beam and strong column behavior. In both X and Y directions model-4 (A/L = 12) shows higher drift ratios and displacements comparing to other models. Drift ratios are higher in middle storey buildings.

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Md. Mohiuddin Ahmed. “Seismic Response of Setback RCC Buildings under Revised BNBC Code by Pushover Analysis.” IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 16, no. 5, 2019, pp. 19-28.