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Seismic Vulnerability Assessment of Existing RC Building using Pushover Analysis

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***Abstract:-* The past earthquakes in which many reinforced concrete structures were severely damaged have indicated the need for evaluating the seismic adequacy of buildings. In particular, the seismic rehabilitation of older concrete structures in high seismicity areas is a matter of growing concern, since the structures which are vulnerable to damage must be identified and an acceptable level of safety must be established. To make such an assessment, simplified linear-elastic methods are not adequate. Thus, the structural engineering community has developed a new generation of design and seismic procedures that incorporate performance based design of structures. This approach moves away from simplified linear elastic methods and more towards non-linear techniques. The main focus of the present work is to carry out non-linear static pushover analysis to evaluate the capacity and performance of six storied , eight storied and ten storied reinforced concrete structures which are constructed on medium stiff soil in all seismic zones under seismic loading. The objective is to understand the nonlinear behavior of reinforced concrete frames under earthquake loading of much higher magnitude that takes the structural frame to a level much beyond the elastic limit and upto failure stage.**

Keywords- Earthquake, Pushover analysis,Performance levels, Capacity, Demand, Performance point.

I. INTRODUCTION

An earthquake is a manifestation of the rapid release of stress in the form of waves during the process of brittle rupture of rock. Earthquakes are the natural disasters of a generally unpredictable nature. A major earthquake is usually rather short in duration, often lasting only a few seconds and seldom more than a minute or so. During an earthquake there are usually one or more major peaks of magnitude of motion. These peaks represent the maximum effect of the earthquake. Although the magnitude of the earthquake is measured in terms of the energy released at the location of the ground fault, its critical effect on any given structure is determined by the ground movements at the location of that structure. The effect of these movements is affected mostly by the distance of the structure from the epicenter, but they are also influenced by the geological conditions prevalent directly beneath the structure and also by the nature of the entire earth mass between the epicenter and the structure.

The complexity of earthquake ground motion is primarily due to the factors such as the source effect, path effect and local site effect. Earthquake causes the ground to vibrate and in turn the structures supported on them are subjected to motion. Thus, the dynamic loading on the structure during an earthquake is not an external loading, but a loading arising due to the motion of support. Some of the factors contributing to the structural damage during earthquakes are plan and vertical irregularities, irregularity in strength and stiffness, mass irregularity, torsion irregularity etc.

Earthquake ground motion is one of the most dangerous natural hazards where both economic and life losses occur. Most of the losses are due to building collapses or damages. Therefore, it is very important to design the structure to resist moderate to severe earthquakes depending on its site location and importance. If the existing building is not designed to resist earthquakes, then its retrofitting becomes important.

II. HISTORICAL REVIEW

Kadid. A and A. Boumrkik [8] an experimental pushover analysis was carried out with an objective to evaluate the performance of framed buildings under future expected earthquakes. To achieve this objective, three framed buildings with 5, 8 and 12 stories respectively were analyzed. The buildings were symmetrical in plan and elevation and structures are designed according to the Algerian code RPA2003 and are located in high seismicity region with a peak ground acceleration of 0.32g. The results obtained in this paper shows that properly designed frames will perform well under seismic codes. Some of the conclusions made by the authors are: The pushover analysis is a relatively simple way to explore the non linear behaviour of Buildings. The results obtained in terms of demand, capacity and plastic hinges gave an insight into the real behaviour of structures. The behaviour of properly detailed reinforced concrete frame building is adequate as indicated by the intersection of the demand and capacity curves and the distribution of hinges in the beams and the columns. Most of the hinges developed in the beams and few in the columns but with limited damage.

R. Shahrin & T.R. Hossain [12] has overviewed the performance of bare, full infilled and soft ground storey buildings which is situated in Dhaka city. The building models have been designed according to BNBC (2006) and their performance based seismic investigation is assessed by pushover analysis. The performance of the buildings is assessed as per the procedure prescribed in ATC 40 and FEMA 273. For different loading conditions resembling

Syed Ahamed, DR. Jagadish.G.kori [14] presented an overview of the Performance based seismic analysis of an unsymmetrical building subjected to pushover analysis. wherein an investigation has been made to study behaviour of an unsymmetrical building (SMRF Type) situated in seismic zone -v of India, in accordance with IS:1893-2002 (part-1) and the various analytical approaches such as linear static and nonlinear static analysis are performed on the building to identify the seismic demand and also pushover analysis is performed to determine the performance levels, and Capacity spectrum of the considered, also Base shear is compared for 4 and 6 storied building models in both X and Y directions by linear static and pushover analysis.

3. MODEL DESCRIPTION

The plan layout and 3D view of the reinforced concrete moment resisting frame building of six storied, eight storied, ten storied building models is shown in *Fig.1, Fig.2, Fig.3 and Fig.4*. In this study, the plan layout is deliberately kept similar for all the buildings for the study. Each storey height is 3.0 m whereas ground floor height is 1.5 m for all the buildings models. The building is located in the seismic zone-2, zone-3, zone-4, zone-5 and intended for residential purpose. The input data given for all the different buildings is detailed below.

3.1 Building Models:

Model 1: G+5 storied Building model analysed in zone-2, zone-3, zone-4, zone-5

Model 2: G+7 storied Building model analysed in zone-2, zone-3, zone-4, zone-5

Model 3: G+9 storied Building model analysed in zone-2, zone-3, zone-4, zone-5

the practical solutions of Dhaka city, the performances of these structures are analyzed with the help of capacity curve, capacity spectrum, deflection, drift and seismic performance level. For the bare frame structure they kept regular throughout its height and bay length to concentrate on the effects caused by the distribution of infill. The structure is six storeys high with a storey height of 3 meters. In order to investigate the effect of infill distribution they have considered 3 geometrical cases: The first case comprises a fully infilled structure resembling the regular structures representing a regular distribution of stiffness throughout the height. Second case examined the effects of omitting infills from ground floor only, such as with infamous soft ground storey configuration. On the other hand third case specifically dealt with the consequences of omitting the infills of the third floor of the building and observed the influences on structural performances. It has been concluded that the performance of an infilled frame is found to be much better than a bare frame structure and also the consideration of effect of infill leads to significant change in the capacity.

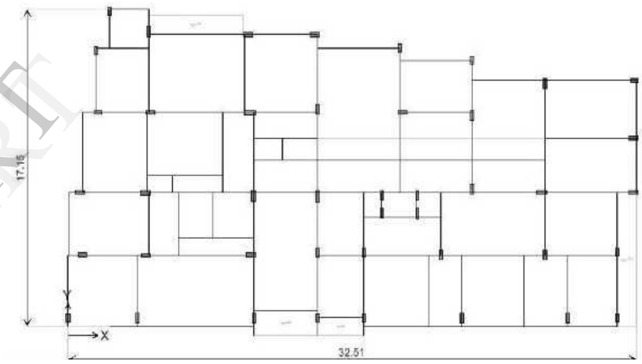

Fig.1 Plan layout of residential building model

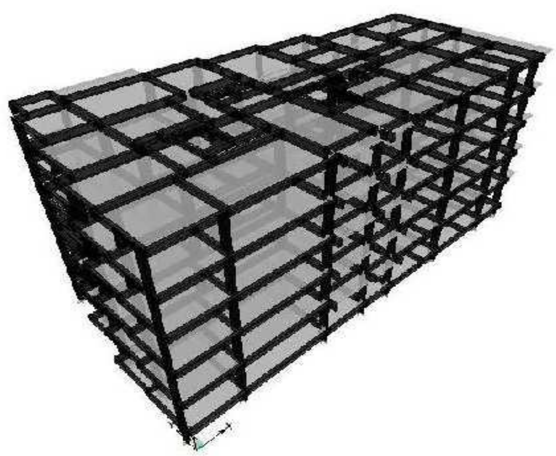

Fig. 2 3-D view of G+5 storied building model

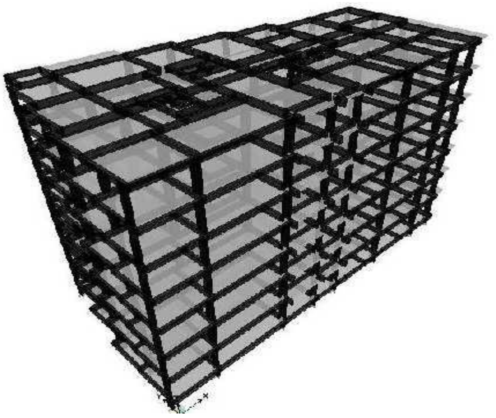

Fig.3 3-D view of G+7 storied building model

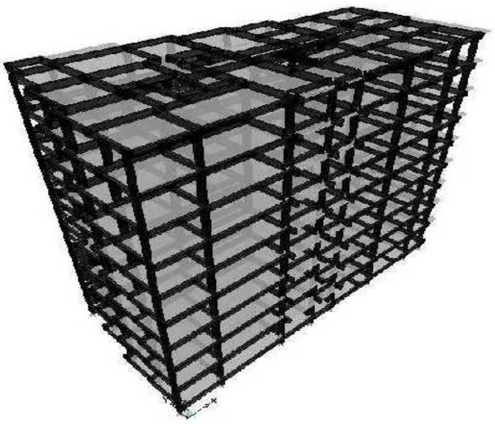

Fig.4 3-D view of G+9 storied building model

3.2 Design data:

TABLE I.

ITEM	DESCRIPTION	
Structure Type	SMRF	
Response Reduction Factor	3	
Seismic Zone and Zone factor(Z)	a) ZONE-2, Z=0.10 b) ZONE-3, Z=0.16 c) ZONE-4 Z=0.24 d) ZONE-5 Z=0.36	
Height of The Building	3.0 m	
Height of ground floor	1.5m	
Soil Condition	Medium Stiff	
Plan Size	32.51mX17.15m	
Thickness Of Slab	0.12 m	
Beam Size	0.2mX0.45m	
	0.15mX0.45m	
	0.2mX0.6m	
Column	SIZE	NUMBER
	0.2mX0.6m	5
	0.2mX0.53m	20
	0.2mX0.45m	14
	0.15mX0.53m	4
Live Load on floor slab	$3kN/m^2$	
Live Load on roof slab	$1.5kN/m^2$	
Floor Finish	$1\ kN/m^2$	
Density of RCC	$25\ kN/m^3$	
Density of infill	$20\ kN/m^3$	
Material Properties	Concrete grade	Steel grade
	M25	Fe415

3.4 Results and Discussions

3.5 Analysis results of base shear and performance poin
t

TABLE II.Analysis results of base shear and performance point for G+5, G+7 and G+9 storey building model in zone-2

Model No.	Pushover Base shear (Vpo)	Elastic Base shear (Ve)	Collapse Disp.	Performance point			
				Base Shear (V)	***Roof Disp (D)***	***Sa***	***Sd***
Model_1	1614.4912	449.38	0.0988	1443.845	0.086	0.109	0.077
Model_2	1261.3189	605.06	0.109	1236.545	0.105	0.078	0.109
Model_3	1181.9337	760.70	0.1340	945.807	0.104	0.062	0.144

TABLE III. Analysis results of base shear and performance point for G+5, G+7 and G+9 storey building model in zone-3

Model No.	Pushover Base shear (Vpo)	Elastic Base shear (Ve)	Collapse Disp.	Performance point			
				Base shear (V)	***Roof Disp (D)***	***Sa***	***Sd***
Model_1	1614.4962	717.32	0.0988	1443.872	0.086	0.109	0.077
Model_2	1261.6912	968.10	0.109	1236.760	0.105	0.078	0.109
Model_3	1181.8341	1214.48	0.134	966.627	0.108	0.063	0.147

Table IV. Analysis results of base shear and performance point for G+5, G+7 and G+9 storey building model in zone-4

Model No.	**Pushover Base shear(Vpo)**	**Elastic Base shear(Ve)**	**Collapse Disp.**	**Performance point**			
				Base shear (V)	***Roof Disp (D)***	***Sa***	***Sd***
Model_1	1614.5029	1078.31	0.0988	1443.862	0.086	0.109	0.077
Model_2	1261.6947	1449.00	0.109	1257.729	0.108	0.08	0.111
Model_3	1181.9885	1825.67	0.1340	945.814	0.104	0.062	0.144

TABLE V. Analysis results of base shear and performance point for G+5, G+7 and G+9 Storey building model in zone-5

Model No.	**Pushover Base shear(Vpo)**	**Elastic Base shear(Ve)**	**Collapse Disp.**	**Performance point**			
				Base shear (V)	***Roof Disp (D)***	***Sa***	***Sd***
Model_1	1614.8123	1614.5043	0.0988	1443.880	0.086	0.109	0.077
Model_2	1261.6962	2178.22	0.1090	1242.140	0.107	0.077	0.109
Model_3	1181.9892	2732.58	0.1340	966.624	0.108	0.063	0.147

DISCUSSION OF RESULT

1) The elastic base shear for all the three models of G+5, G+7 and G+9 storey building model in zone- 2,zone-3,zone-4,zone-5 is obtained from the equivalent static analysis as per IS-1893-Part I: 2002 and compared with the pushover analysis base shear and the results are presented in Table II, Table III, Tabel IV and Table V respectively.
2) The ratio of pushover base shear to elastic base shear gives an indication of the amount of reserve strength being unutilized. The ratio of pushover base shear to elastic base is highest for model_1 in all the zones and least for model_3 in all the seismic zones.
3) The amount of reserve strength being unutilized for model_1, model_2 and model_3 is 3.59, 2.08 and 1.55 respectively in zone-2.
4) The amount of reserve strength being unutilized for model_1, model_2 and model_3 is 2.2507, 1.30 and 0.973 respectively in zone-3.
5) The amount of reserve strength being unutilized for model_1, model_2 and model_3 is 1.497, 0.871 and 0.647 respectively in zone-4.
6) The amount of reserve strength being unutilized for model_1, model_2 and model_3 is 1.00, 0.579 and 0.433 respectively in zone-5.
7) As the height increases the ratio of pushover base shear to elastic base is decreasing for model_1 to model_3 in all the zones.
8) The bigger the magnitude of spectral acceleration and smaller the magnitude of spectral displacement, better will be the performance of the structure.

3.6 Pushover curve variation

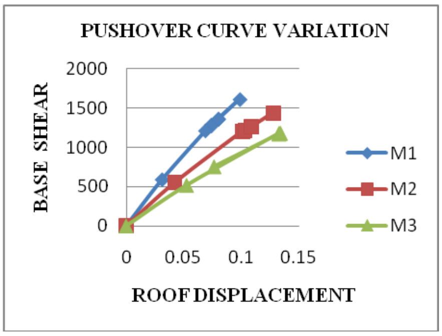

Fig.6 Pushover curves for G+5, G+7 and G+9 storey building model in zone-2

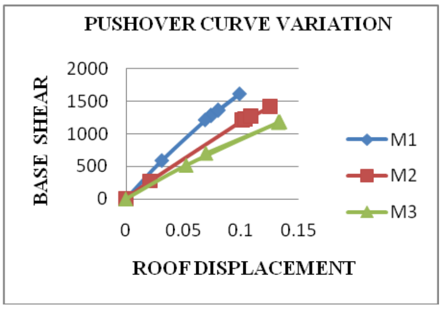

Fig.7 Pushover curves for G+5, G+7 and G+9 storey building model in zone-3

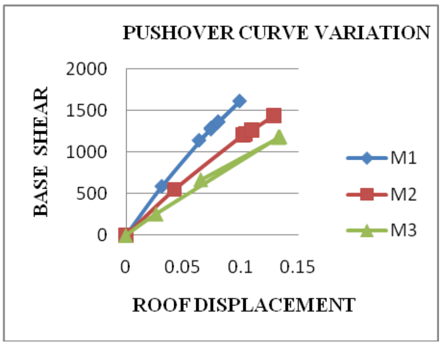

Fig.8 Pushover curves for G+5, G+7 and G+9 storey building model in zone-4

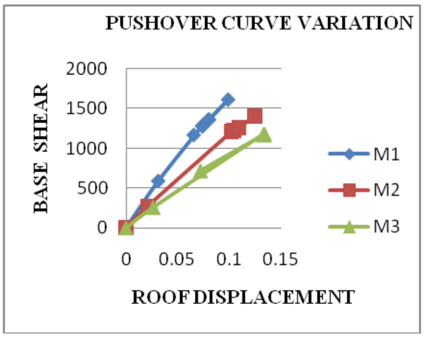

Fig.9 Pushover curves for G+5, G+7 and G+9 storey building model in zone-5.

DISCUSSION OF RESULT

1) The pushover (capacity) curves for the three models of G+5, G+7 and G+9 storey building in zone-2, zone-3, zone-4, zone-5 are shown in *Fig.6, Fig.7, Fig.8 and Fig.9* respectively. The three pushover curves shown in *Fig.6, Fig.7, Fig.8 and Fig.9* could be approximated by a bi-linear relationship.
2) For model_1, model_2 and model_3 the collapse displacement of 0.0988 m, 0.109 m and 0.1340 m respectively remaining the same in the seismic zone-2, zone-3, zone-4 and zone-5.
3) The roof displacement remains the same for model_1 in the seismic zone-2, zone-3, zone-4 and zone-5 whereas the roof displacement is increasing for model_2 and model_3 in the seismic zone-2, zone-3, zone-4 and zone-5.
4) The pushover curve of model_1 and model_2 is showing linear behaviour in the seismic zone-2, zone-3, zone-4 and zone-5
5) The pushover curve of model_3 is showing nonlinear behaviour in the seismic zone-2, zone-3, zone-4 and zone-5
6) From the three pushover curves shown in Fig.6, Fig.7, Fig.8 and Fig.9 it is observed that they are initially linear but start to deviate from linearity consequently from model_1 to model_3 in all seismic zones- zone-2, zone-3, zone-4 and zone-5.As the beams and the columns undergo inelastic actions.
7) From *Fig.6, Fig.7, Fig..8 and Fig.9* it is observed from the 3- models that lateral load carrying capacity reduces as the building height increases wherein the displacement increasing from zone to zone and also displacement increasing from Model 1 to Models 3.

3.7 Performance point variation

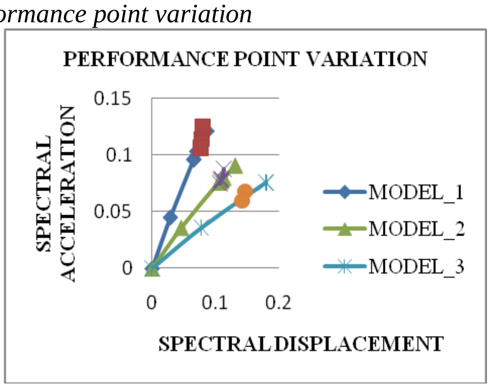

Fig.10 Performance point variation for G+5, G+7 and G+9 storey building model by combining capacity curve and demand spectrum curvein zone-2

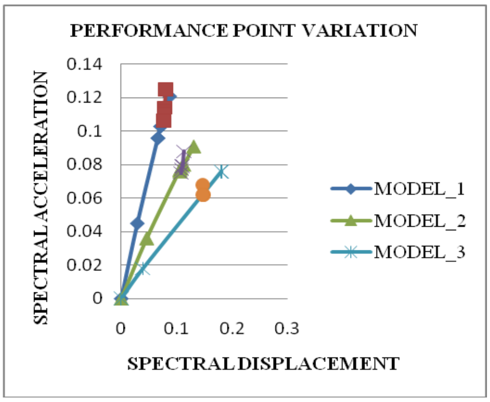

Fig.11 Performance point variation for G+5, G+7 and G+9 storey building model by combining capacity curve and demand spectrum curve in zone-3

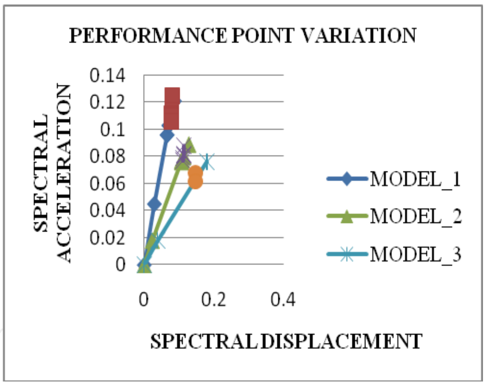

Fig.12 Performance point variation for G+5, G+7 and G+9 storey building model by combining capacity curve and demand spectrum curve in zone-4

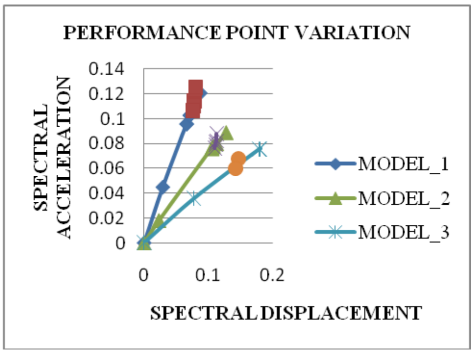

Fig.13 Performance point variation for G+5, G+7 and G+9 storey building model by combining capacity curve and demand spectrum curve in zone-5

DISCUSSION OF RESULT

1) *Fig.10, Fig.11, Fig.12 and Fig.13* show the variation of performance point for the three building models of G+5, G+7 and G+9 storey building model in zone-2, zone-3, zone-4 and zone-5 respectively.
2) From model_1 it can be noted that the variation in seismic zone does not have much influence on the variation of performance point.
3) From model_2 and model_3 it can be noted that the variation in seismic zone influences on the variation of performance point.
4) From model_1, model_2 and model_3, in the seismic zones-zone-2, zone-3, zone-4 and zone-5 it can be noted that the increase in height of the building increases the severity of lateral forces on the buildings.
5) From model_1, model_2 and model_3, in the seismic zones-zone-2, zone-3, zone-4 and zone-5 it is observed that the demand curve tends to intersect the capacity curve in the elastic range and the margin of safety against collapse is sufficient.
6) From model_1, model_2 and model_3, in the seismic zones-zone-2, zone-3, zone-4 and zone-5 it is observed that the performance point gets shifted slightly from model_1 to model_3 as the height of the building increasing.
7) Also, the strength and displacement reserves in the three building models are sufficient with a slight decrease seen from model_1 to model_3.

3.8 Number and status of plastic hinges for G+5, G+7 and G+9 storey building model

TABLE VI. Number and status of plastic hinges for G+5, G+7 and G+9 storey building model in zone-3

Types of Hinges	**Model_1**	**Model_2**	**Model_3**
A-B(Operational)	3748	5043	6366
B-IO(Operational – Immediate occupancy)	92	114	107
IO-LS(Immediate Occupancy-Life safety)	2	0	1
LS-CP(life safety-collapse prevention)	0	0	0
CP-C(Collapse prevention-Collapse)	0	0	0
C-D(Collapse-Reduced hazard)	0	1	0
D-E(Reduced hazard-Non structural damage)	0	0	0
>E(Non structural damage)	4	4	4
Total number of hinges	3846	5162	6478

TABLE VII. Number and status of plastic hinges for G+5, G+7 and G+9 storey building model in zone-3

Types of Hinges	**Model_1**	**Model_2**	**Model_3**
A-B(Operational)	3748	5034	6366
B-IO(Operational – Immediate occupancy)	92	114	107
IO-LS(Immediate Occupancy-Life safety)	2	0	1
LS-CP(life safety-collapse prevention)	0	0	0
CP-C(Collapse prevention-Collapse)	0	0	0
C-D(Collapse-Reduced hazard)	0	1	0
D-E(Reduced hazard-Non structural damage)	0	0	0
>E(Non structural damage)	4	4	4
Total number of hinges	3846	5162	6478

TABLE VIII. Number and status of plastic hinges for G+5, G+7 and G+9 storey building model in zone-4

Types of Hinges	Model_1	Model_2	Model_3
A-B(Operational)	3748	5047	6367
B-IO(Operational – Immediate occupancy)	92	110	106
IO-LS(Immediate Occupancy-Life safety)	2	0	1
LS-CP(life safety-collapse prevention)	0	0	0
CP-C(Collapse prevention-Collapse)	0	1	0
C-D(Collapse-Reduced hazard)	0	0	0
D-E(Reduced hazard-Non structural damage)	0	0	0
>E(Non structural damage)	2	4	4
Total number of hinges	3846	5162	6478

TABLE IX. Number and status of plastic hinges for G+5, G+7 and G+9 storey building model in zone-5

Types of Hinges	Model_1	Model_2	Model_3
A-B(Operational)	3748	5049	6368
B-IO(Operational – Immediate occupancy)	92	108	105
IO-LS(Immediate Occupancy-Life safety)	2	1	1
LS-CP(life safety-collapse prevention)	0	0	0
CP-C(Collapse prevention-Collapse)	0	0	0
C-D(Collapse-Reduced hazard)	0	0	0
D-E(Reduced hazard-Non structural damage)	0	0	0
>E(Non structural damage)	4	4	4
Total number of hinges	3846	5162	6478

DISCUSSION OF RESULT

1) TABLE VI, TABLE VII, TABLE VIII and TABLE IX Presents the status of plastic hinges in different states for the three building models in zone-2, zone-3, zone-4 and zone-5.
2) The hinges change their states namely- Operational, Immediate occupancy, Life safety, Collapse prevention, Collapse, Reduced hazard and Non-structural damage depending on the severity of the ground motion.
3) Most of the designs are carried out such that the plastic hinges do not exceed the elastic limit.
4) From model_1 it can be noted that the variation in seismic zone does not have much influence on the status of plastic hinges.
5) From model_2 and model_3 it can be noted that the variation in seismic zone influences the status of plastic hinges.
6) From model_1, model_2 and model_3 it can be noted that the increase in height of the building increases the severity of lateral forces on the buildings.
7) In the present work it can be noted that all the frame models are within the B-IO (Operational –Immediate Occupancy) performance level and safe from damage.

3.9 Base shear results

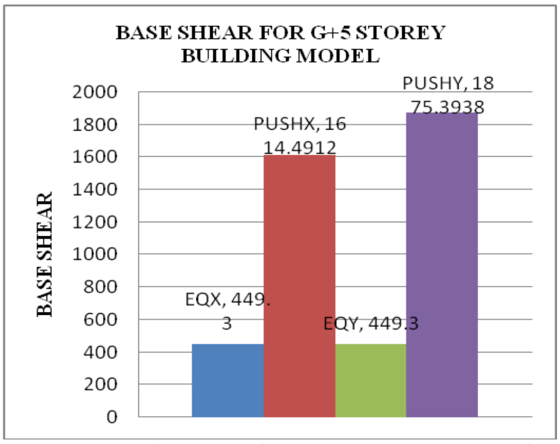

Fig.14 Comparison of Base shear for G+5 storey building model for both linear static and model and non-linear static analysis in zone-2

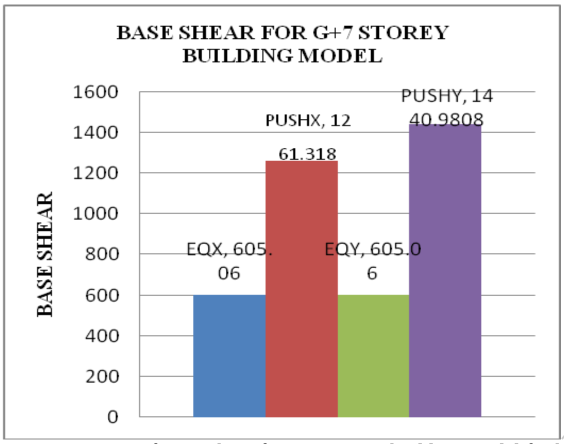

Fig.15 Comparison of Base shear for G+7 storey building model for both linear static and model and non-linear static analysis in zone-2

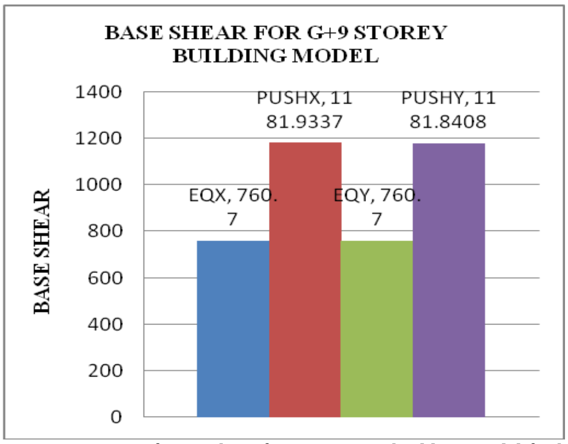

Fig.16 Comparison of Base shear for G+9 storey building model for both linear static and model and non-linear static analysis in zone-2

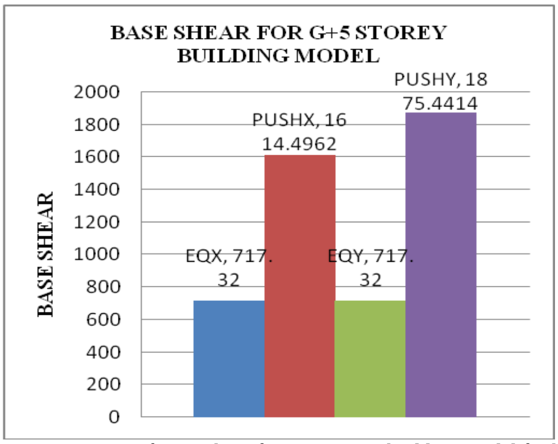

Fig.17 Comparison of Base shear for G+5 storey building model for both linear static and model and non-linear static analysis in zone-3

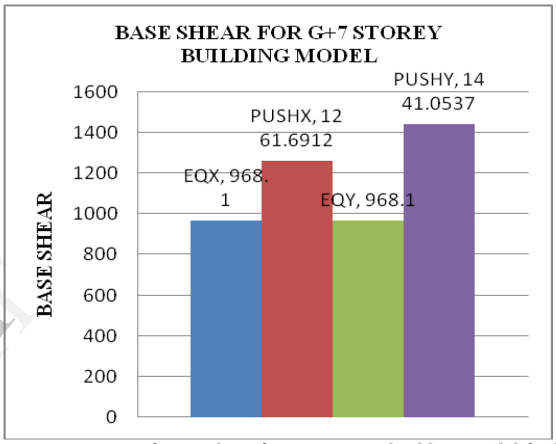

Fig. 18 Comparison of Base shear for G+7 storey building model for both linear static and model and non-linear static analysis in zone-3

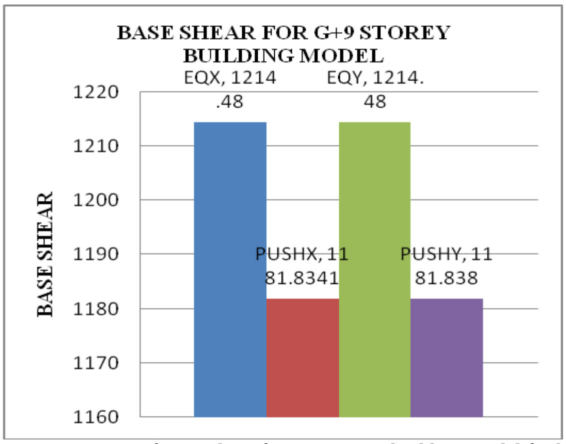

Fig.19 Comparison of Base shear for G+9 storey building model for both linear static and model and non-linear static analysis in zone-3

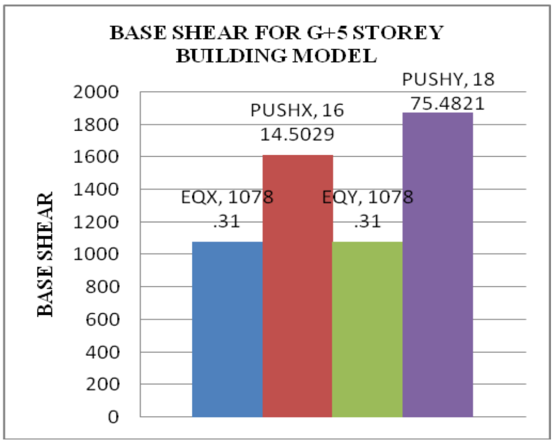

Fig.20 Comparison of Base shear for G+5 storey building model for both linear static and model and non-linear static analysis in zone-4

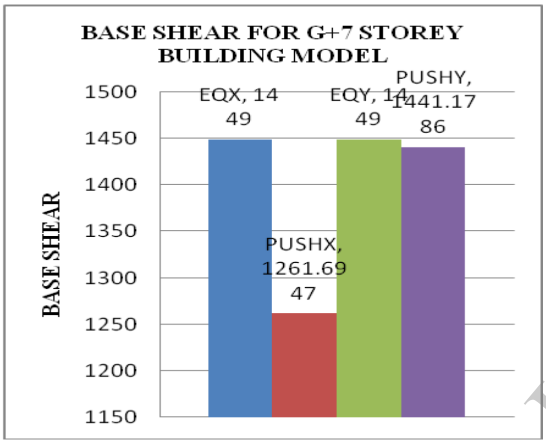

Fig.21 Comparison of Base shear for G+7 storey building model for both linear static and model and non-linear static analysis in zone-4

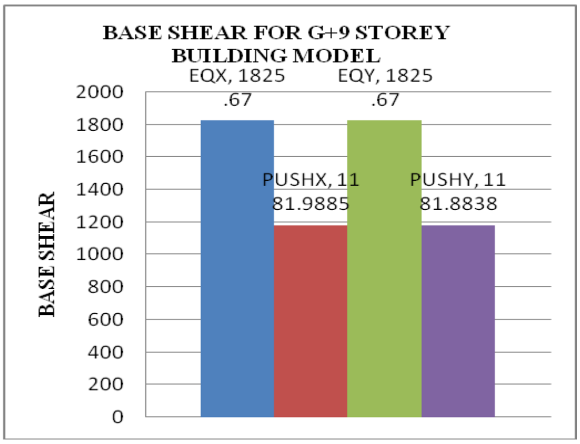

Fig.22 Comparison of Base shear for G+9 storey building model for both linear static and model and non-linear static analysis in zone-4

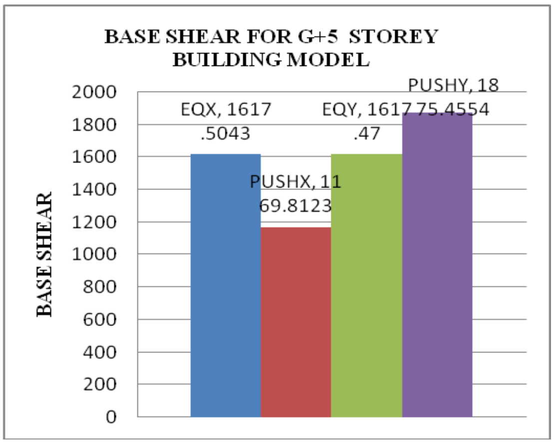

Fig.23 Comparison of Base shear for G+5 storey building model for both linear static and model and non-linear static analysis in zone-5

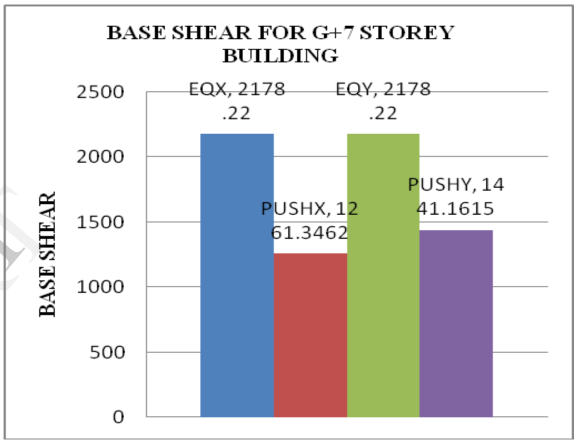

Fig.24 Comparison of Base shear for G+7 storey building model for both linear static and model and non-linear static analysis in zone-5

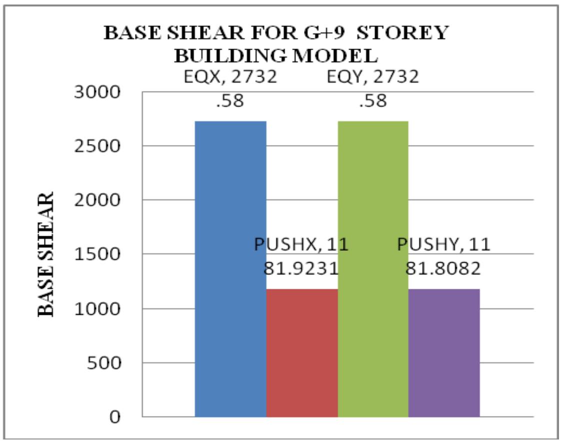

Fig.25 Comparison of Base shear for G+9 storey building model for both linear static and model and non-linear static analysis in zone-5

CONCLUSION

1) The results obtained in terms of pushover demand, capacity spectrum and plastic hinges gave an insight into the real behavior of structures.
2) Plastic hinges formation for the building mechanism has been obtained at different displacement levels. Plastic hinges formation started with beam ends and base columns of lower stories, then propagates to upper stories and continue with yielding of interior intermediate columns in the upper stories. The overall performance level for G+5, G+7 and G+9 storey building models were found between B-IO (Operational level–Immediate occupancy) and the amount of damages in the buildings are limited.
3) The performance point is determined for G+5, G+7 and G+9 storey building models in PUSH X direction.
4) The capacity curve is intersecting the demand curve in the elastic range for G+5, G+7 and G+9 storey building models in all the seismic zones, which indicates that the performance level of the building is good.
5) Base shear increases with the increase in mass and number of stories of building in case of linear static analysis.
6) Base shear decreases with the increase in mass and number of stories of building in case of nonlinear static analysis.

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