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Analysis of Multistoried Infilled Steel Structure Subjected to Lateral Loading

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Abstract - *In the present study, an attempt is made to study the difference in structural behaviour of 3-dimensional (3D) 4 by 4 bays of 10 storey moment resisting steel frames when provided with different types of infill materials in the event of an earthquake. The detailed investigations are carried out as per IS 1893 (Part–1):2016, considering primary loads (dead, live and seismic loads) and their combinations with an appropriate load factor. The models analysed consist of one moment resisting steel frame (Bare frame), but also provided with masonry infills & ferro-cement panels. The above-mentioned models are analysed and designed for the static analysis case to obtain the beam and column sections for building with multiple iterations. So, we get the ISMC 200 double-channel section for beams and ISNB350-3 and ISHB250-2 with top and bottom plate of 320mm width and 25mm thick for columns and finally, two different models are made using two different column sections.*

In the present study different types of models are analysed using pushover analysis has been carried out using SAP2000 v22. The results of all models is analysed and compare in terms of base shear, storey displacement, modal time period, modal frequencies, pushover curve, spectrum curve, performance point of the structure. If the overall performance of the buildings has been found between O–CP (Operational to Collapse Prevent) stages, then the structure is safe. The hinges have been determined and it is noted that most of the hinges being to form in the B-IO range at the performance point.

***Key Words*: Pushover analysis, performance point, infills, displacement, base shear.**

1. INTRODUCTION

A large number of reinforced concrete and steel buildings are constructed with masonry infills. Masonry infills are usually used to fill the void between the vertical and horizontal resisting components of the building frames with the assumption that these infills won't participate in resisting any reasonably load either axial or lateral; thus its significance within the analysis of frame is mostly neglected. An infill wall enhances significantly the strength and rigidity of the structure. It has been recognised that frames with infills have additional strength and rigidity as compared to the bared frames and their ignorance has become the reason behind the failure of the many of the multi-storeyed buildings.

Infill walling is that the generic name given to a panel i.e, inbuilt between the floors of the primary structural frame of a building and provides support for the cladding system. Infill walls are considered to be non-load bearing, but they resist wind loads applied to the facade and also support their own weight and that of the cladding.

1.1 SEISMIC ANALYSIS METHODS [10, 11]

After selecting the structural model, it is possible to perform analysis to determine seismically induced forces in the structures. The analysis can be performed based on external action, the behaviour of structure or structural material, and the type of structural model selected.

Linear static analysis or equivalent static analysis is used for normal structures with restricted height. Linear dynamic analysis can be performed in two ways, response spectrum method or by elastic time history method. Non-linear static analysis is an improvement over linear static or dynamic analysis in the sense that it allows inelastic behaviour of the structure. A non-linear dynamic analysis or inelastic time-history analysis is the only method to describe the actual behaviour of a structure during an earthquake.

1.2 Performance-Based Design

Two key elements of a performance-based design procedure are demand and capacity. Capacity is a representation of the structure's ability to resist the seismic forces. Demand is a representation of earthquake ground motion. Two main methods to find the Performance of the structure is the capacity spectrum method (ATC 40) and displacement coefficient method (FEMA 356). In the capacity spectrum method, both the capacity and demand spectrum in ADRS (acceleration displacement response spectra) format are plotted onto a single graph. The point where the capacity curve meets the demand curve is the performance point which gives the overall performance of the building for the ground motion considered. In the displacement coefficient method, an equation with a set of coefficients is used to calculate the target displacement for the corresponding pushover curve. This target displacement is considered as the performance point. Depending on where the performance point lies in the capacity spectrum curve building's performance level is decided. They are Immediate Occupancy level, Life Safety level and Collapse Prevention level. Thus, an engineer gets an insight into the performance of the building for a particular ground motion and can decide on which safety level the structure is designed for the buildings.

Pushover analysis is an approximate analysis method in which the structure is subjected to monotonically increasing seismic forces with an invariant height wise distribution until a required displacement is achieved. Pushover analysis consists of a sequence of successive elastic analysis, superimposed to approximate a force-displacement curve of a complete structure.

2. LITERATURE REVIEW

Dr. S.S. Sankhla and Deepak Bhati (2016) [4] made a study on different theories (techniques for modeling the infill-frame interface) then one method has been applied to review the seismic response of in-filled frame structures. In this study infill walls are modeled as an equivalent diagonal strut while analysis. Work has been carried out for 20 storey infill structure in which the bottom storey height is varied and different combinations of infill wall are analyzed. All these models have been compared with bare frame structure. On the basis of this work results has been obtained. The results show that the influence of infill on the structural performance is significant. These results are going to be useful within the seismic design and understanding of in-filled frame structures.

Arafa Elhelloty (2017)[1] studied on the "Effect of Lateral Loads Resisting Systems on Response of Buildings Subjected to Dynamic Loads". In this paper, the modal and transient analysis is carried out to study the effect of lateral loads resisting systems on the response of buildings subjected to dynamic loads. Three and five stories steel frame buildings without and with three lateral loads resisting systems which are steel plate shear walls, steel bracings and laminated composite plate shear walls subjected to dynamic loads are investigated with reference to natural frequencies, mode shapes and time history graphs for total displacement and equivalent stresses. A comparative study is conducted to evaluate the effect of lateral loads resisting systems on the performance of buildings subjected to dynamic loads using the finite element system ANSYS16. From the results reported use of lateral load resisting systems in buildings increases the stiffness of buildings and the buildings form efficient under dynamic loads. The equivalent stresses for buildings with laminated composite plate shear walls system are higher than that for buildings with steel bracings and steel plate shear walls systems with the increase of the number of stories.

Basavaraj M. Malagimani *et.al* (2017) [2] studied an effort is made to study the behaviour of RC frame structure using conventional bricks, CC blocks, hollow blocks and lightweight bricks infill. Linear static and non-linear static pushover analysis has been carried out for fixed and flexible support in different types of soil condition, to know the effect of earthquake loading. The various results such as base shear, top storey displacement, natural period and pushover results are compared to know the suitable infill material in seismic prone zones. From the results obtained the lightweight brick system gives better performance than the other infill materials.

3. OBJECTIVES

1. To assess the suitability of the beams and columns sections for the building in the SAP2000.
2. To analyse the behaviour of steel frame with masonry infill versus ordinal ferro-cement panels under seismic loading.
3. Finite Element Analysis on Steel Frames using modal analysis by Equivalent Static Method, Response Spectrum with different infill materials.
4. Pushover analysis is carried out to evaluate the performance of the building according to ATC 40.

4. STRUCTURAL MODELING AND ANALYSIS

As trial and error analytical model of G+9 storey was used in the analysis. In this study, bare frame, framed with both masonry infills and ferro-cement panels and also two different column sections have taken for pushover analysis. Typically, no. of bays and bay width in both X and Y directions are 4 and 4m respectively. The total height of the building is 40 m. Storey height is 4 m were considered in this study. All columns are fixed from the base for foundations. The models are analysed as per Indian Standard Code and ATC – 40 and FEMA356.

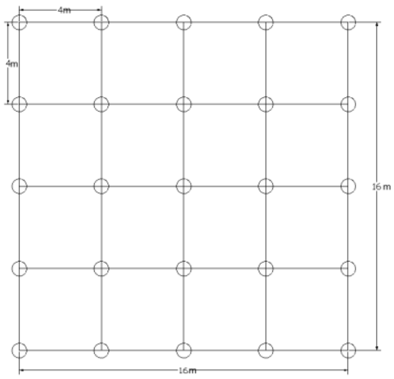

Fig -1: Common plan for all the building models

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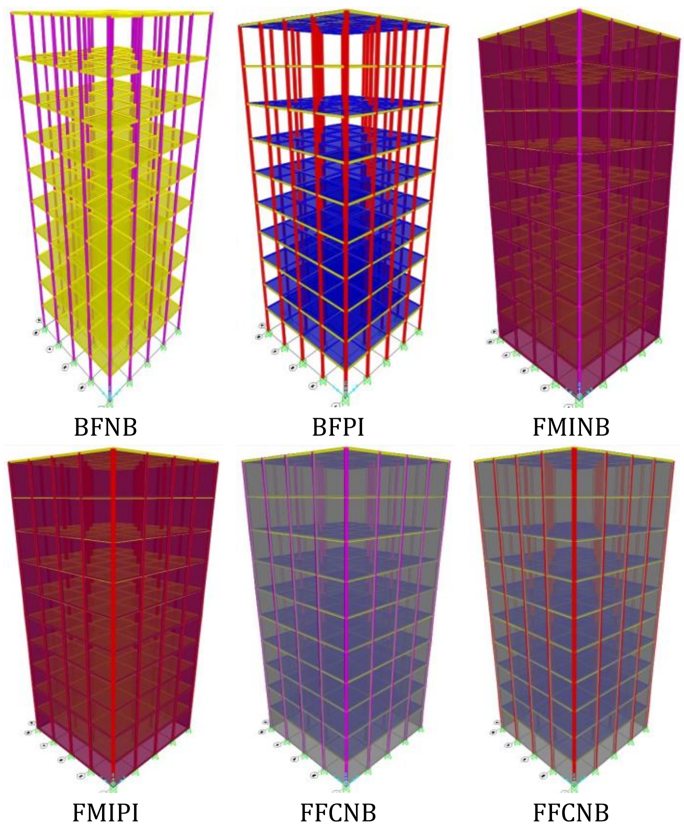


Fig -2: 3D view of all the model buildings

Table-1: Models considered for the analysis

Model	Nomenclature
Bare Framed Building with ISNB350-3 as a column	BFNB
Bare Framed Building with ISHB250–2 with Top and Bottom Plate of 320mm width and 25mm thick as a column	BFPI
Framed Building with Masonry Infills and ISNB350-3 as a column	FMINB
Framed Building with Masonry Infills and ISHB250–2 with Top and Bottom Plate of 320mm width and 25mm thick as a column	FMIPI
Framed Building with Ferro-cement Panels and ISNB350-3 as a column	FFCNB
Framed Building with Ferro-cement Panels and ISHB250–2 with Top and Bottom Plate of 320mm width and 25mm thick as a column	FFCPI

5. MATERIAL PROPERTIES

The material used in the structure is steel and concrete for beam and column members and slab respectively. Fe345 grade of steel and M20 grade of concrete are used for all the models used in this study. Parameters considered for this study is given below.

Table-2: Building parameter considered in this study

Particular	Details
Slab (thickness)	150 mm
Beams	ISMC 200 D Steel Section
Column	ISNB350-3 Steel Section
	ISHB 250-2 with top and bottom plate of 320 mm width and 25 thick Steel Section
Masonry Infill (thickness)	230 mm
Ferro cement Panels (thickness)	50 mm
Dead Load	Automatically calculated by the program
Live Load	4 kN/m² for all the floors
Earthquake Load	As per IS 1893 (Part – 1): 2016
Type of Soil.	Type II, Medium
Importance Factor	1
Response Reduction Factor	5

6. PROCEDURE OF PUSHOVER ANALYSIS

- Define all the materials properties, frame and area sections, load patterns, cases, combinations, mass source and functions.
- Model the structure and assign supports and above mentioned definitions.
- Once the steel design is done, the model is unlocked. Define gravity and pushover load cases in both directions to the model.
- Assign the pushover hinges to selected frame objects using Assign > Frame > Hinges. Hinges is also defined manually or by using one of several default specifications which are available.
- Select Analyze > Run Analysis to run the static-pushover analysis.
- Review the results and display the static pushover curve and displacement and the step-by-step sequence of hinge formation.

7. ANALYSIS AND RESULTS

7.1 Base Shear

Base shear is an estimate of the maximum expected lateral force that will occur due to seismic ground motion at the base of a structure. The structure is analysed with gravity load, static earthquake loading method and the resulting base shear is tabulated in the table below.

Table-3: Base Shears along X and Y – direction

Structure Type	EQx (kN)	EQy (kN)
BFNB	592.149	592.149
BFPI	612.067	612.067
FMINB	1486.355	1486.355
FMIPI	1526.205	1526.205
FFCNB	1041.785	1041.785
FFCPI	1081.639	1081.639

From Table 3 it is observed that the base shear is more for framed building with different materiel infills compared to bare framed buildings.

7.2 Time Period

The fundamental natural frequency of a structure at which structure may resonate is known as modal frequency. Modal frequencies for first mode are obtained by performing modal analysis is tabulated in the table below.

Table-4: Time Period and its frequency

Structure Type	Period	Frequency
	sec	cycle/sec
BFNB	2.112	0.473
BFPI	2.199	0.454
FMINB	0.331	3.024
FMIPI	0.322	3.098
FFCNB	0.437	2.284
FFCPI	0.419	2.382

From Table 4 it is observed that the time period is more for bare framed buildings compared to framed building with different materiel infills. It is also observed that the frequency is more for framed building with different materiel infills compared to bare framed buildings.

7.3 Storey Displacement

The storey displacement is the lateral displacement of the storey with respect to the ground. The maximum storey displacement along X and Y direction obtained from the equivalent static force method and response spectrum method is shown in below table.

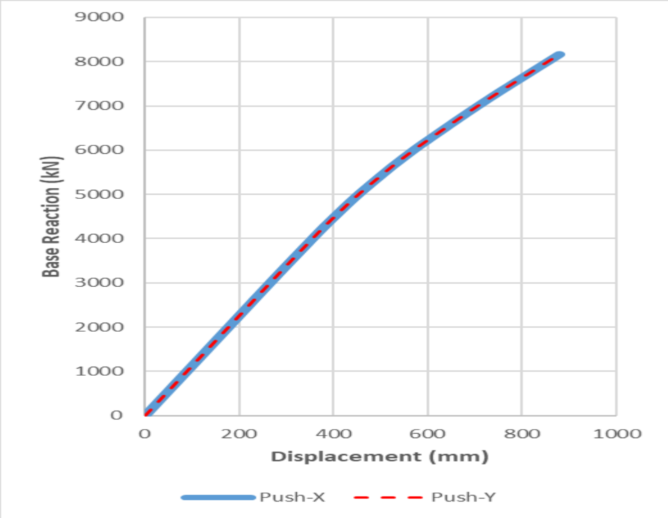
Table-5: Maximum Storey Displacement for Earthquake Static Load and Response Spectrum analysis

Structure Type	EQx	EQy	RSx	RSy
	Along X-direction	Along Y-direction	Along X-direction	Along Y-direction
BFNB	73.755	73.755	58.431	58.431
BFPI	61.345	79.167	48.727	62.944
FMINB	3.147	3.147	2.815	2.804
FMIPI	2.976	2.981	2.674	2.668
FFCNB	5.405	5.405	4.753	4.753
FFCPI	4.877	4.900	4.257	4.276

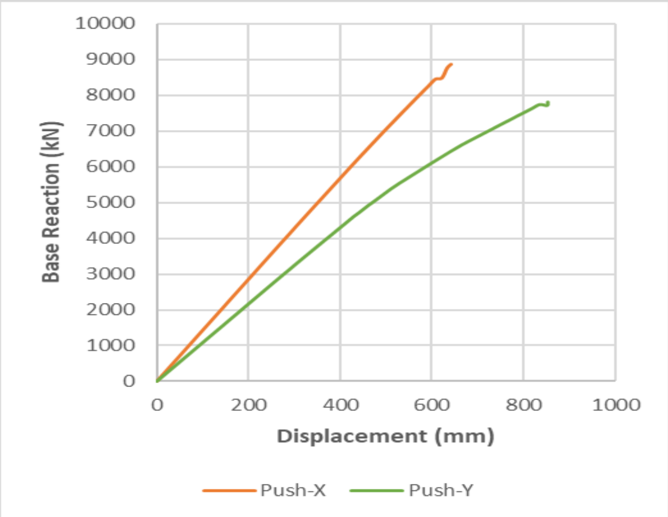
7.4 Pushover Curves

The curve shows a linear behaviour of structure until the elastic limit and then shows nonlinear behaviour. In this stage the structure forms hinges which gradually fails and finally the structure collapses.

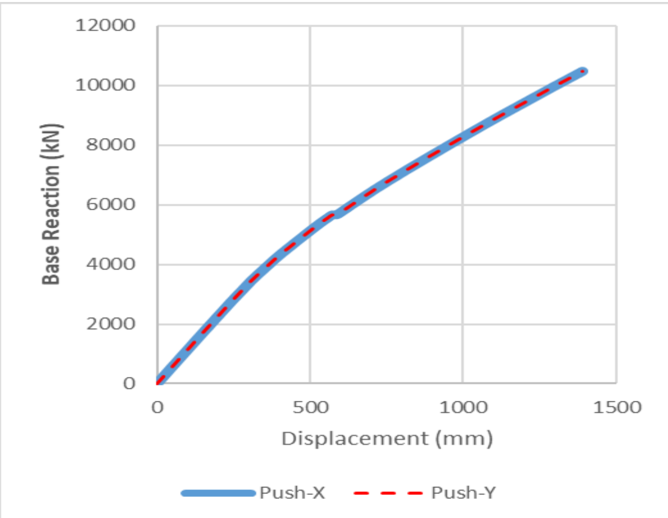
In below figures from the pushover curves of all buildings the data about displacement and base shear have obtained.



(a) Pushover Curve of BFNB in both X and Y direction.

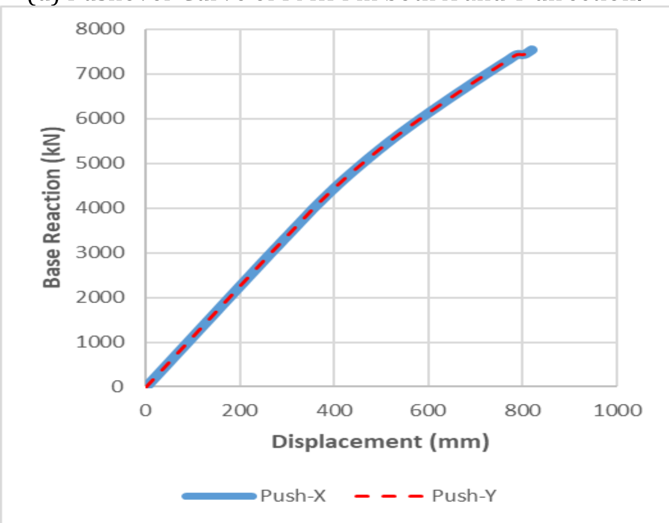


(b) Pushover Curve of BFPI in both X and Y direction.

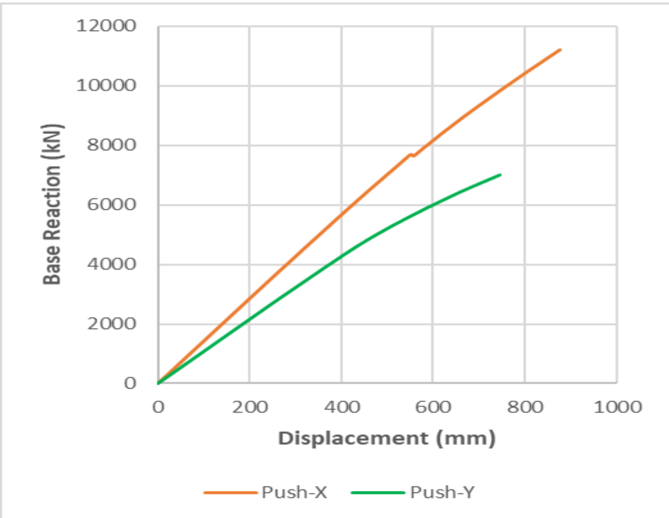


(c) Pushover Curve of FMINB in both X and Y direction.

(d) Pushover Curve of FMIPI in both X and Y direction.



(e) Pushover Curve of FFCNB in both X and Y direction.



(f) Pushover Curve of FFCPI in both X and Y direction.

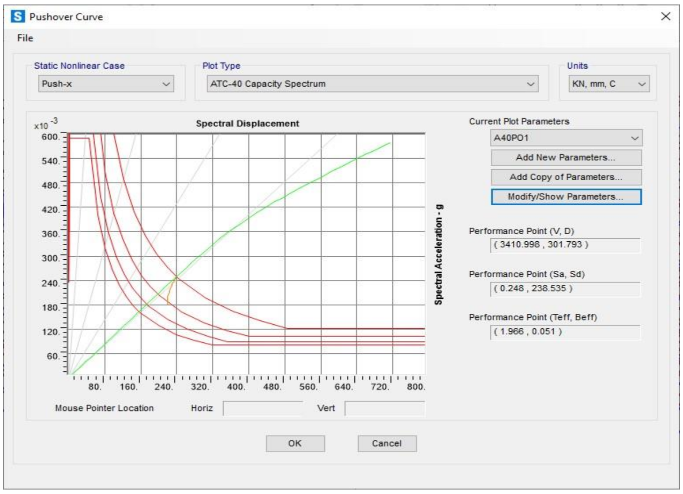
Fig -3: Pushover Curves for all the buildings

Table-6: Maximum Base Shear for Pushover load cases and all modelled buildings

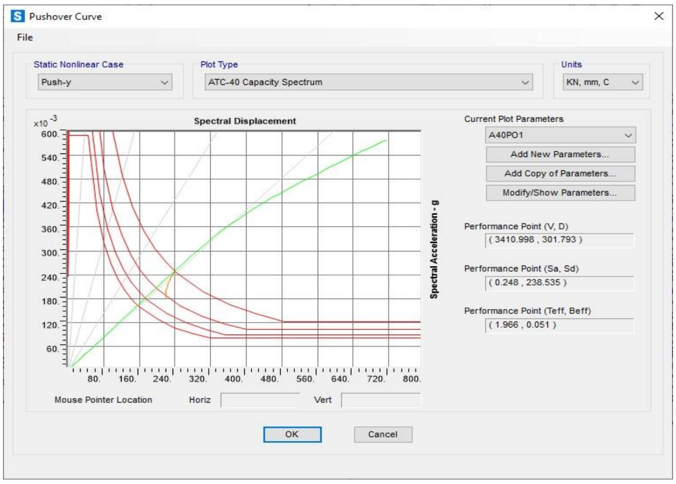
Structure Type	Maximum Base Shear (kN)		Displacement (mm)	
	Along X-direction	Along Y-direction	Along X-direction	Along Y-direction
BFNB	8165.148	8165.148	879.529	879.529
BFPI	8869.941	7821.122	641.494	854.531
FMINB	10466.721	10466.721	1388.699	1388.699
FMIPI	5821.161	4910.796	428.504	520.570
FFCNB	7531.302	7531.302	819.375	819.375
FFCPI	11219.694	6991.375	876.855	744.057

7.5 Spectrum Curves

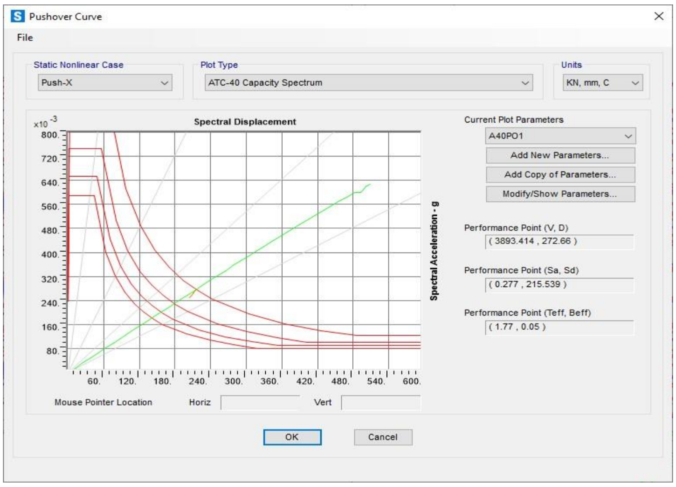
Performance point of the structure is calculated by two methods. ATC 40 capacity spectrum method and FEMA 356 Displacement coefficient method. In this study, capacity spectrum method is followed. Capacity spectrum curve is useful for calculate the overall demand and capacity of the structure. It is useful to get the performance point of the structure. Spectrum curve of all buildings are shown in below figures.



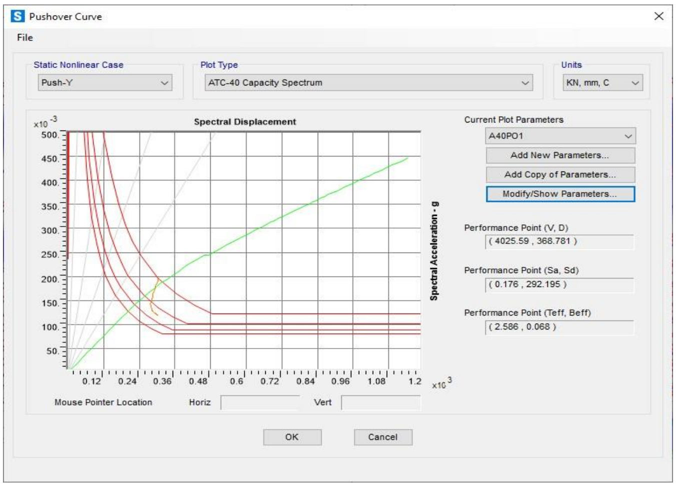
(a) Spectrum Curve of BFNB in X direction.



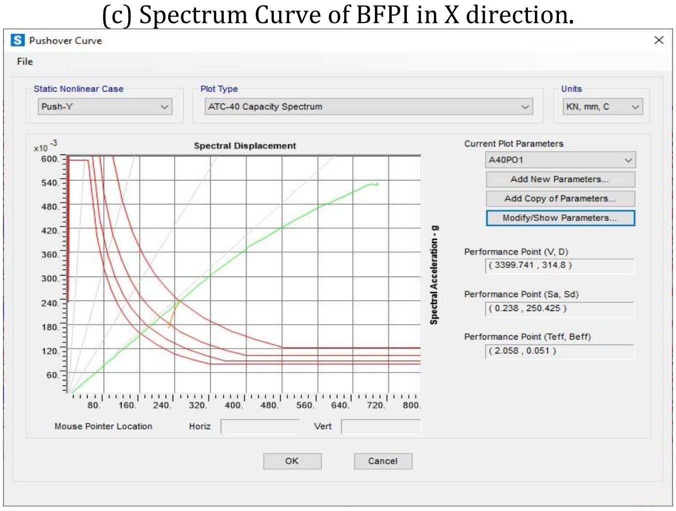
(b) Spectrum Curve of BFNB in Y direction.



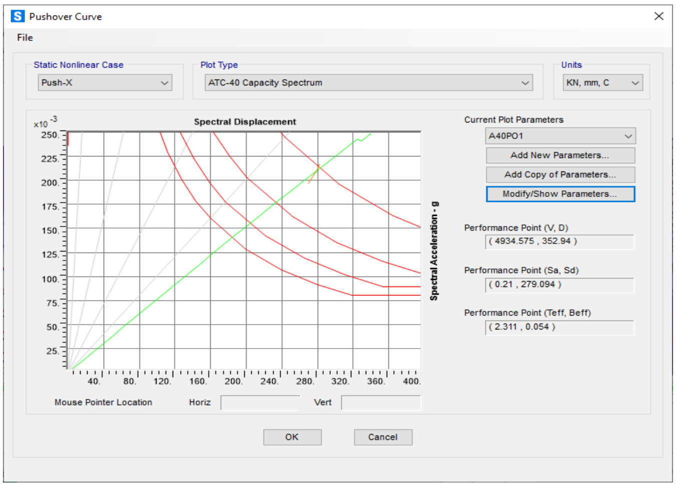
(c) Spectrum Curve of BFPI in X direction.



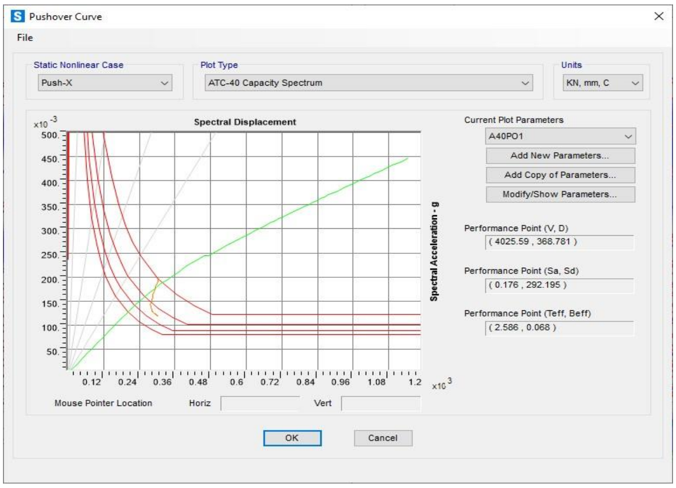
(f) Spectrum Curve of FMINB in Y direction.



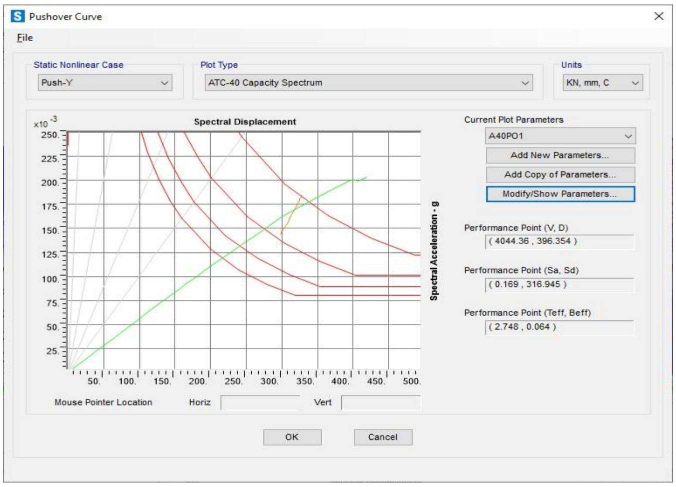
(d) Spectrum Curve of BFPI in Y direction.



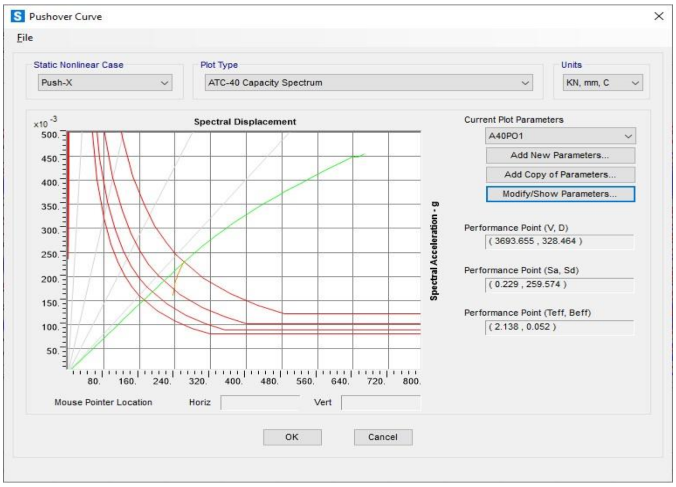
(g) Spectrum Curve of FMIPI in X direction.



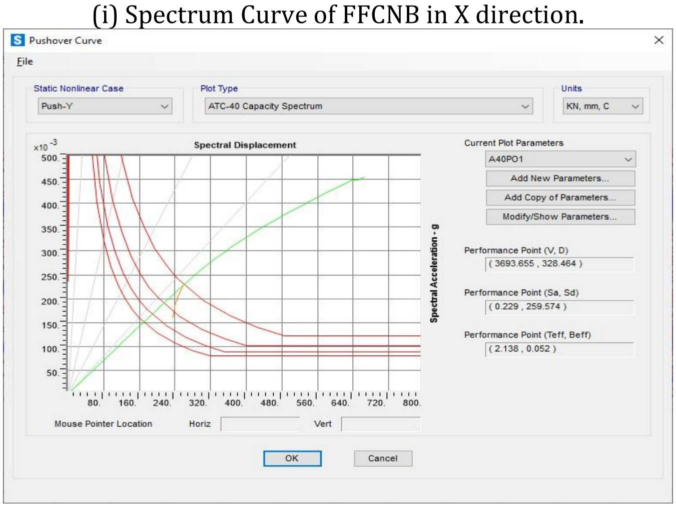
(e) Spectrum Curve of FMINB in X direction.



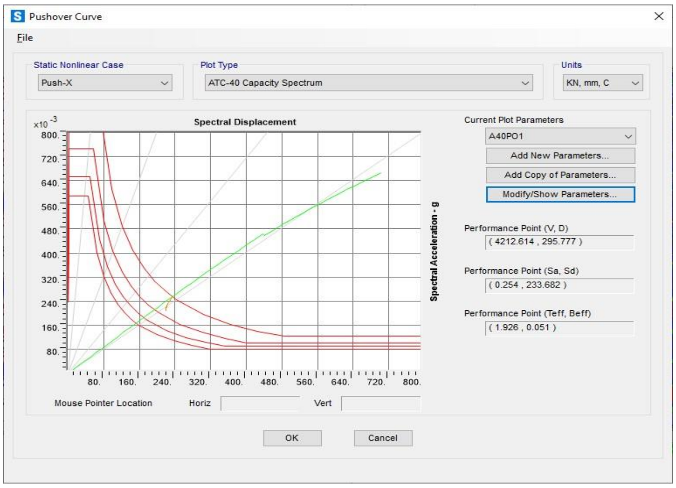
(h) Spectrum Curve of FMIPI in Y direction.



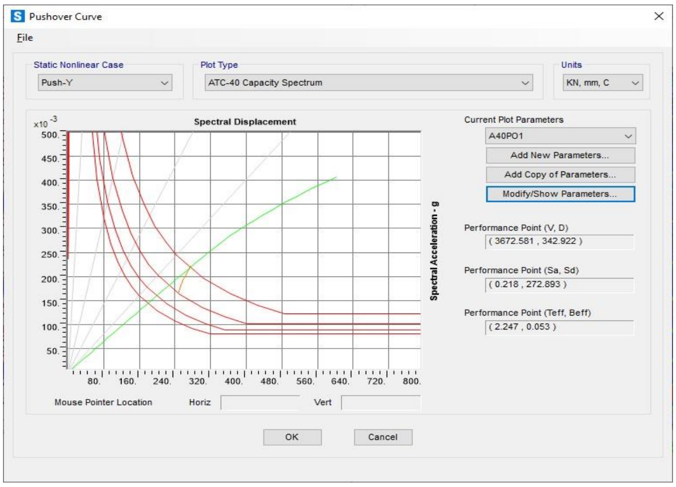
(i) Spectrum Curve of FFCNB in X direction.



(j) Spectrum Curve of FFCNB in Y direction.



(k) Spectrum Curve of FFCPI in X direction.



(f) Spectrum Curve of FFCPI in Y direction.

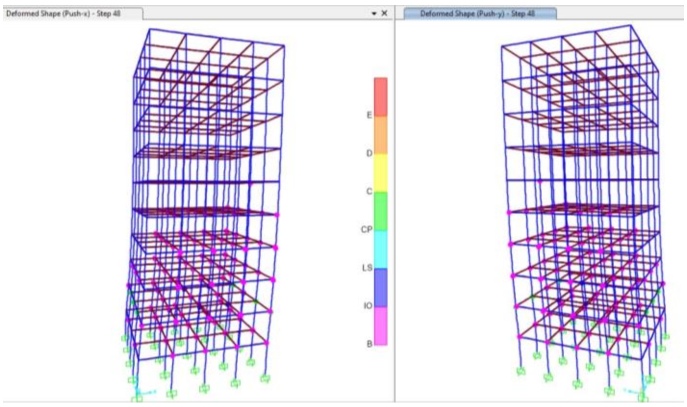
Fig -4: Performance Point for all modelled buildings

Table-7: Performance Point for all modelled buildings

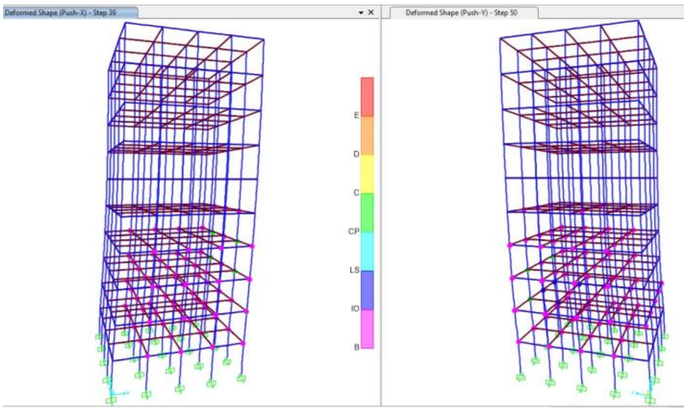
Structure Type	Performance Point (kN)		Displacement (mm)	
	Along X-direction	Along Y-direction	Along X-direction	Along Y-direction
BFNB	3410.998	3410.998	301.793	301.793
BFPI	3893.414	3399.741	272.660	314.800
FMINB	4025.590	4025.590	368.781	368.781
FMIPI	4934.575	4044.360	352.940	396.354
FFCNB	3693.655	3693.655	328.464	328.464
FFCPI	4212.614	3672.581	295.777	342.922

7.6 Hinges Result

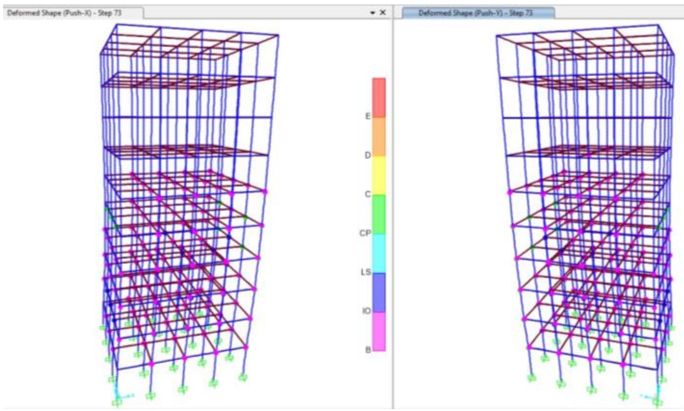
In the following figures shown that the location of hinges formed for maximum base shear levels in their final steps of analysis for Push – X and Push – Y direction. If hinges are in O–CP (Operational to Collapse Prevent) stage, we can say that overall structure is safe.



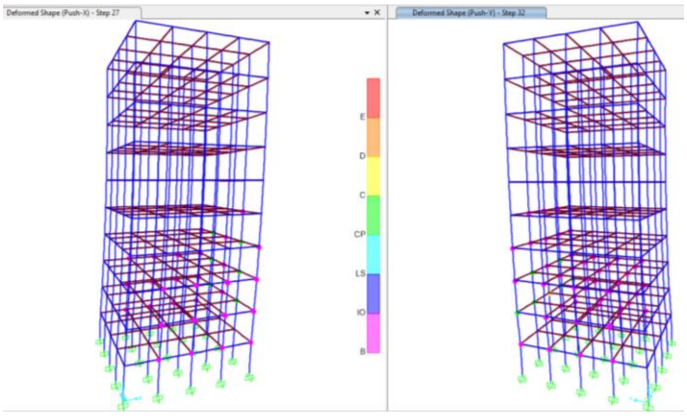
(a) Hinges Status at maximum base shear of BFNB in both X and Y direction.



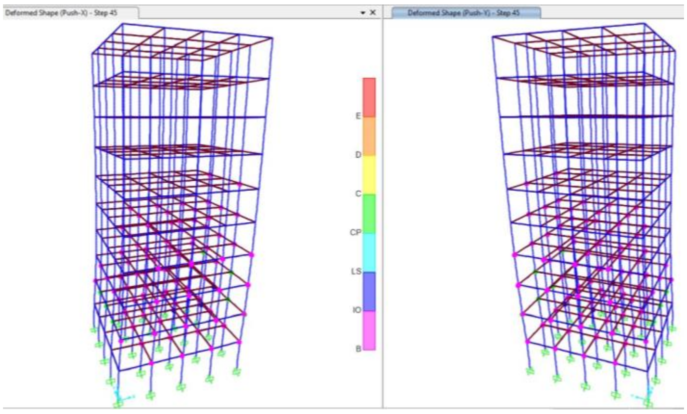
(b) Hinges Status at maximum base shear of BFPI in both X and Y direction.



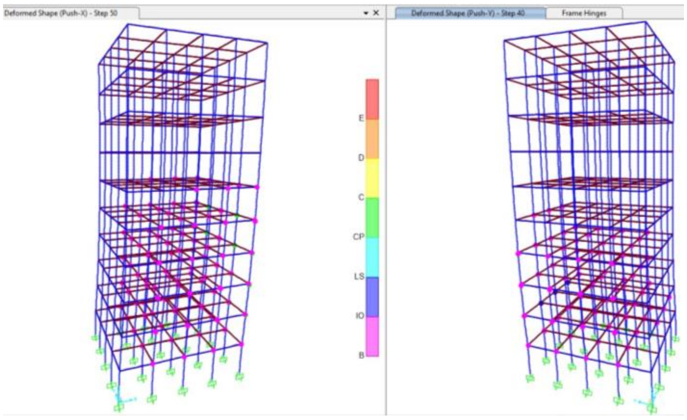
(c) Hinges Status at maximum base shear of FMINB in both X and Y direction.



(d) Hinges Status at maximum base shear of FMIPI in both X and Y direction.



(e) Hinges Status at maximum base shear of FFCNB in both X and Y direction.



(f) Hinges Status at maximum base shear of FFCPI in both X and Y direction.

Fig -5: Hinges Status for all the buildings

Formation of the hinges starts at the supports and progressively moves towards the upper stories with the increment of load. Step by step development of hinges is observed in results.

8. CONCLUSIONS

1. The base shear was observed that maximum for Framed Building with Masonry Infills and reduced for Framed Building with Ferro-cement Panels and further reduced for Bare Framed Building.
2. The maximum displacement was observed in Bare Framed Building for both equivalent static condition and response spectrum condition.
3. The displacement was observed to be decreasing for Framed Building with Ferro-cement Panels. It was further observed further decent in the displacement for Framed Building with Masonry Infills for both equivalent static condition and response spectrum condition.
4. Pushover analysis results shows that hinges formed in members at performance point are under immediate occupancy level in SAP2000 software.

5. Results obtained from the Framed Building with Masonry Infills and ISHB250–2 with Top and Bottom Plate of 320mm width and 25mm thick as a column gives the minimum displacement of 272.660mm at performance point of 3893.414 kN along X-direction.
6. The maximum value of performance point for the structure having masonry infills and ISHB250–2 with Top and Bottom Plate of 320mm width and 25mm thick as a column is 4934.575 kN and 4044.360 kN along X and Y direction respectively.
7. The results obtained from Framed Building with Masonry Infills and ISHB250–2 with Top and Bottom Plate of 320mm width and 25mm thick as a column gives the maximum displacement of 396.354mm at performance level.

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