Seismic Evaluation of Symmetric and Asymmetric Buildings by Pushover and Time History Analysis

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Abstract- *Most of the structures in urban areas are made up of RCC which are to be seismically analysed because of frequent earthquakes. Plan with irregularity of structures situated in earthquake prone areas are very important issue to be taken into account. In this study three new RCC buildings with unsymmetrical in plan (C-shape, L-shape, Square shape) of G+14 are considered. In this study it is considered that building is in type II soil (medium soil) and analysed. Different modelling issues were incorporated through three models for each building were; Bare Frame (without infill), Soft Storey (ground floor with no infill), with infill to all floors. The loading parameters are taken from IS1893-2002 Part-1 for seismic zone III. The modelling and analysis for Pushover analysis, Time History Analysis and Response Spectrum analysis, and these has been carried out using SAP-2000. The evaluation and comparison of the regular and irregular buildings has been done using the parameters- storey displacements, storey drifts, time period and base shear. The presence of wall in the building will reduce the lateral displacements so bare frame building will have more displacement of 24.52%,42.21% compared to soft storey and with wall building. The lateral displacements and storey drifts by response spectrum method are maximum in irregular buildings, i.e. C-shape, L-shape of 28.35%, 31.55%, and 9.1% minimum of Square shaped buildings. The building with wall have more base shear compared to bare frame and soft storey building of 57.76%,49.25% due to presence of wall.*

Key Words: Bare Frame, Soft Storey, Base Shear, Displacement, Storey Drift

1. INTRODUCTION

All over the world, there is high demand for the construction of high rise structures due to rapid urbanization and spiralling populations. In addition to this, new structural systems, design concepts, high strength materials, modern construction methods are playing important role to construction such sky scrapers by reinforced cement concrete. To ensure the performance based design it is required to know the behaviour of structure when earthquake happen. It is necessary to study the response of the structure subjected to earthquake excitation. Since seismic forces are random in nature and they are unpredictable, the use of engineering tools needs to be sharpened for analysing structures under the action of seismic forces. Earthquake loads are considered carefully during the modelling so as to assess the real behaviour of the structure with a clear understanding of the damage occur due to seismic forces as expected but then it should be regulated. Analysing these tall structures for various earthquake intensities and checking for multiple criteria at different level has become a most essential exercise for the last decades. India having different soil conditions and different earthquake intensity places with more than 60% area is prone to earthquake, should develop earthquake resistant structures in consideration to IS:1893(Part 1):2002. India classified into four seismic zones namely zone I, II, III, IV, V, having different types of soils which increases the importance of understanding of effect of base shear in consideration to various types of soils in same zone also. Response of structures to earth's surface vibrations is a function of type of soil available at site conditions. Response acceleration coefficient (Sa/g) for 5% damping is calculated for rock, medium, soft soils. Zone factor expected intensity of earthquake in different seismic zones.

2. SEISMIC ANALYSIS

To determine the seismic responses of the structure it is necessary to carry out the seismic analysis. The analysis can be carried out on the basis of the external action of structure, the type of structural model selected and the behaviour of structure or structural materials. Based on the type of external action and behaviour of structure the analysis can be classified as

1. Linear Static Analysis or Equivalent Analysis
2. Non- Linear Static Analysis
3. Non Linear Dynamic Analysis and
4. Linear Dynamic Analysis

2.1 Linear Dynamic Analysis by Response Spectrum Method

The performance of the structure can be analysed by one of the useful tools of earthquake engineering is analysis by response spectrum method, since many systems behave as single degree of freedom systems. Thus, if you can find out the natural frequency of the structure, then the peak response of the building can be estimated by reading the value from the ground response spectrum for the appropriate frequency. In most building codes in seismic regions, this value forms the basis for calculating the forces that a structure must be designed to resist (seismic analysis). A response spectrum is a plot of the maximum response amplitude (displacement, velocity or acceleration) versus time period of many linear single degree of freedom oscillators to a give component of ground motion. The resulting plot can be used to select the response of any linear SDOF oscillator, given its natural frequency of oscillation. One such use is in assessing the peak response of buildings to earthquakes. In this method the peak response of structure during an earthquake is obtained directly from the earthquake response, but this is quite accurate for structural design applications.

2.2 Pushover Analysis

The Pushover Analysis or Non–Linear Static analysis Procedure is defined in the Federal Emergency Management Agency document 356 (FEMA 356) as a non–linear static approximation of the response a structure will undergo when subjected to dynamic earthquake loading. 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 vs. roof displacement plot.

2.3 Time History Analysis

It is also known as nonlinear dynamic analysis. This is an important technique for seismic analysis of structure especially when the evaluated structural response is non-linear. This method is not used frequently as compared to other conventional methods because of lack availability of actual ground motion data. However it is most accurate method of all other methods. In this method structures response history is evaluated by subjecting to a designed earthquake. The structure is subjected to the actual ground motion which is the representation of the ground acceleration versus time. The ground acceleration is determined at small time step to give the ground motion record. To perform such an analysis, a representative earthquake time history data is required to evaluate the structure. This time history analysis method is step by step analysis of the dynamic response of a structure to a specified loading that may vary with time. This method is used to determine the seismic response of the structure under dynamic loading of representative earthquake.

3.0 METHODOLOGY AND MODELLING

3.1 SAP 2000

The SAP 2000 is structural and earthquake engineering software and built in database founded by "Ashraf Habibullah" in 1975. It can be used for simple and complex projects. The important thing to create only one model which includes the ground techniques and the vertical and lateral framing programs to study and design the whole structures. This topic briefly describes the new features in the program and directs you to manual and technical support to help you get started using this latest version of the program.

3.2 Description of Models

Plan (m^2)

1. C- Shaped Building- 20x25
2. L- Shaped Building- 20x20
3. Square Shaped Building- 20x20

Grade of concrete	M30
Grade of steel	HYSD 500
Column size (mm)	400x900
Beam size (mm)	300x450
Column cover (mm)	40
Beam cover (mm)	30
Slab thickness (mm)	150
Storey height (m)	3.6
Dead load (kN/m^2)	2.5
Live load (kN/m^2) (IS 875-1987,P-2)	3
Roof live load (kN/m^2)	1.5
Floor finish (kN/m^2)	1.5
Wall load (kN/m) (IS 875-1987,P-1)	12.6
Brick Density (kN/m^3)	20
Type of soil(IS 1893-2002)	Medium
Seismic zone(IS 1893-2002)	3
Response reduction factor (R) (IS 1893-2002)	5 For SMRF
Importance factor(I) (IS 1893-2002)	1
Damping ratio (%)	5

3.3 Plan and 3D view of models

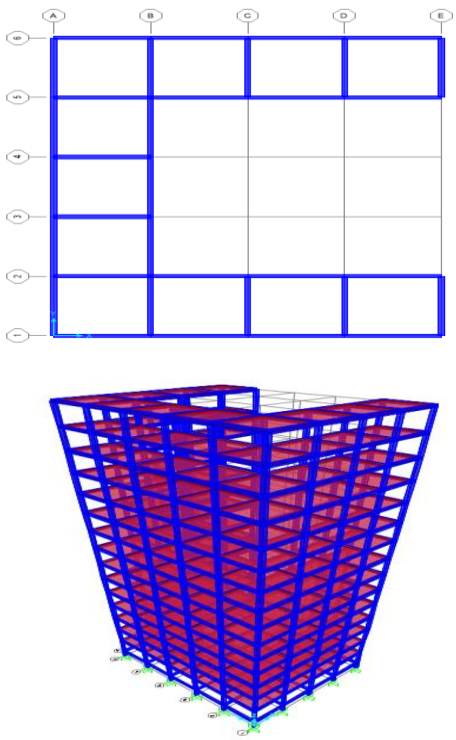

Fig 1: Plan and 3D view of C-Shaped Building

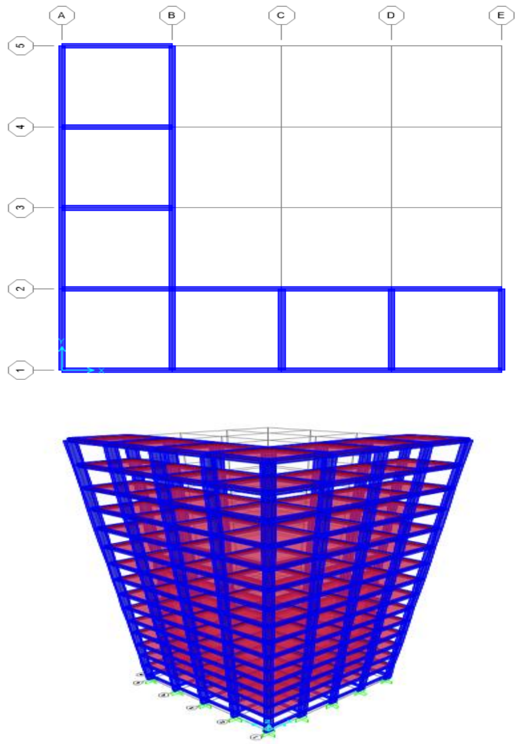

Fig 2: Plan and 3D view of L-Shaped Building

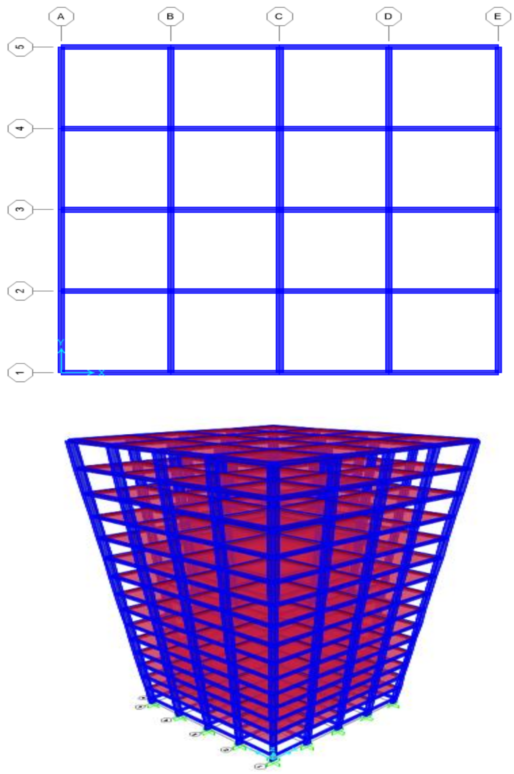

Fig 3: Plan and 3D view of Square Shaped Building

4.0 RESULTS AND DISCUSSIONS

4.1 Natural Time Period

Table 1: Natural time period

Shapes of building	Time period in X direction in seconds			Time period in Y direction in seconds		
	Bare frame building	Soft storey building	Building with wall	Bare frame building	Soft storey building	Building with wall
C- Shape	1.525	1.159	1.180	0.999	0.854	0.798
L- Shape	1.598	1.402	1.668	1.583	1.468	1.321
Square - Shape	1.503	1.465	1.225	1.392	1.338	1.203

The above table show the variation of time period for C, L and Square shapes of G+14 storied buildings of bare frame, soft storey and with wall without for first modes of vibration in seconds. From these tables it is evident that the natural time peri0d g0es 0n increasing as the building height g0es on increasing and als0 when we provide wall in the building the natural time peri0d 0f the building decreases. As the time peri0d decreases the stiffness 0f the structure increases, hence it is concluded that building with walls are more stable than bare frames (without walls).

4.2 Base Shear by Response Spectrum Method

Table 2: Base shear in X and Y directions

Shapes of Buildings	Bare Frame Building		Soft Storey Building		Building with wall	
	RSAX (kN)	RSAY (kN)	RSAX (kN)	RSAY (kN)	RSAX (kN)	RSAY (kN)
C-Shaped	408.34	317.45	634.09	514.124	639.71	512.64
L-Shaped	504.341	418.62	628.56	578.41	638.12	592.46
Square Shaped	654.45	584.87	779.254	758.56	740.11	710.98

In dynamic response spectrum, all the modes of the building are considered, and first mode governs in the shorter buildings and as the story increases for tall buildings, the flexibility increases and higher modes come in to picture. Hence base shear obtained from the analysis it is evident that bare frame buildings experience more base shear compare to soft storey and building with wall models. From the above tables it is evident that the structure experiences less shear in Y direction compare to X direction.

4.3 Lateral Displacement and Storey Drift by Response Spectrum Method

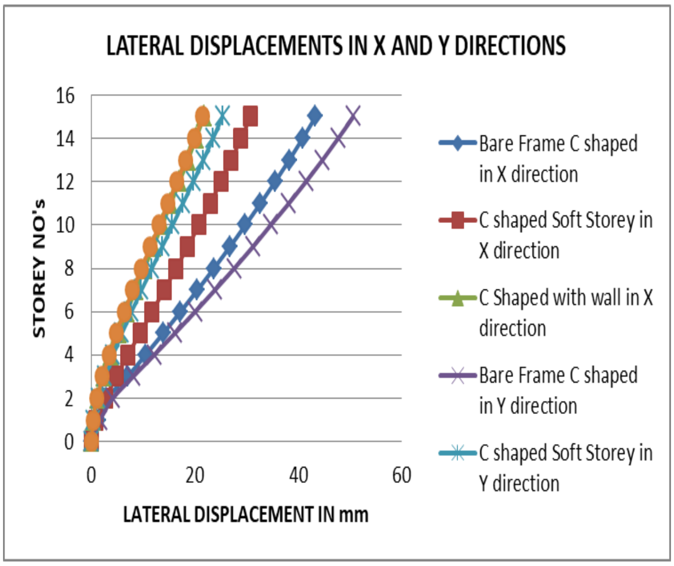

Chart 1: Variation of Lateral Displacement in X and Y Direction for C-Shaped Building

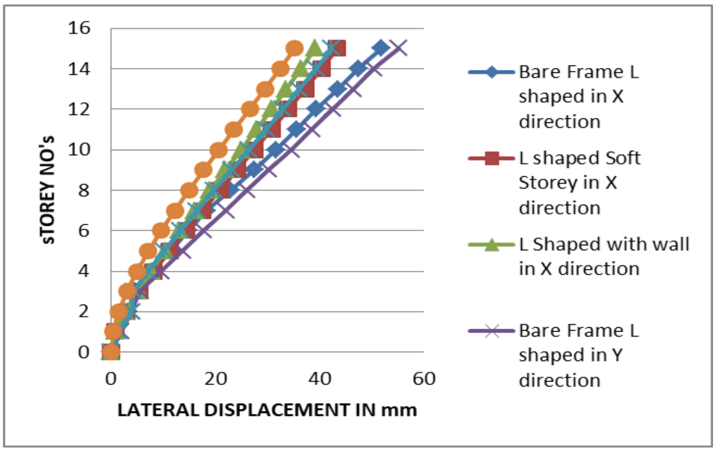

Chart 2: Variation of lateral displacement in X and Y direction for l-shaped building

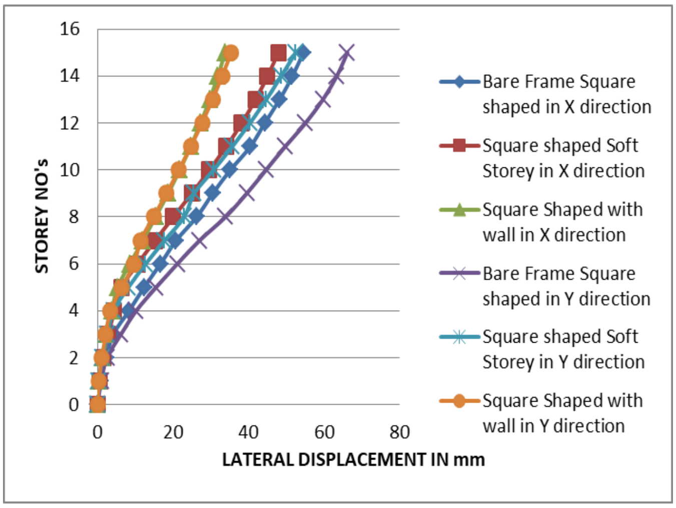

Chart 3: Variation of lateral displacement in X and Y direction for square-shaped building

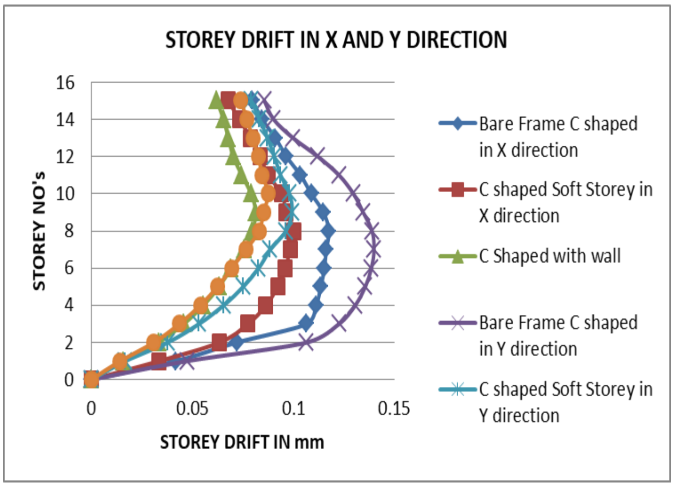

Chart 4: Variation of storey drift in X and Y direction for C-Shaped Building

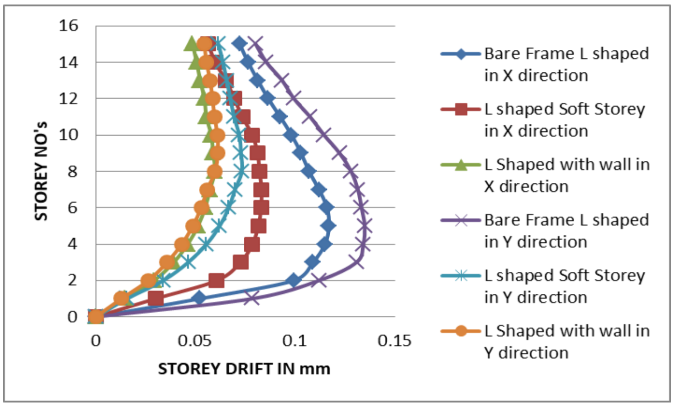

Chart 5: Variation of storey drift in X and Y direction for L-Shaped Building

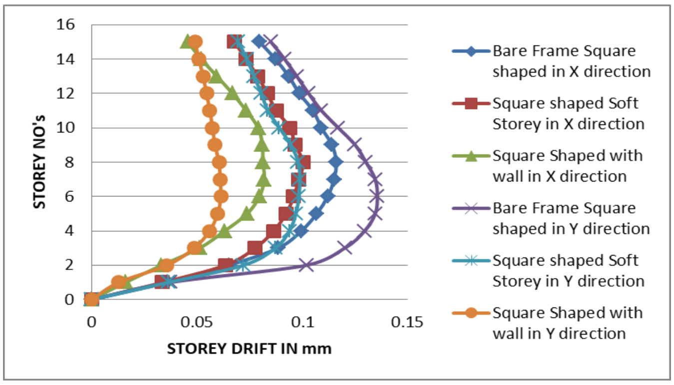

Chart 6: Variation of storey drift in X and Y direction for Square Shaped Building

4.4 Pushover Curves

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 vs. roof displacement plot.

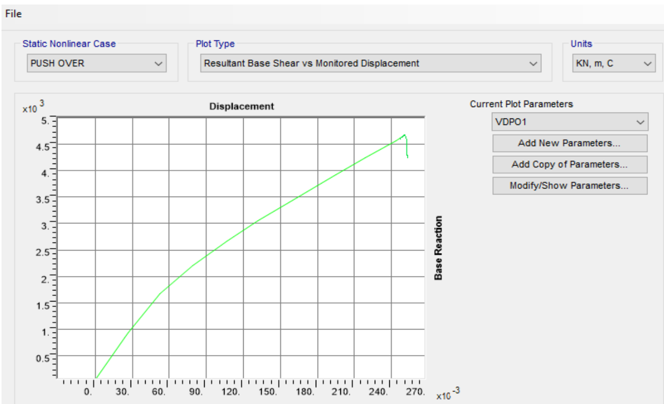

Fig 4: Pushover curve for C-shaped Bare Frame building

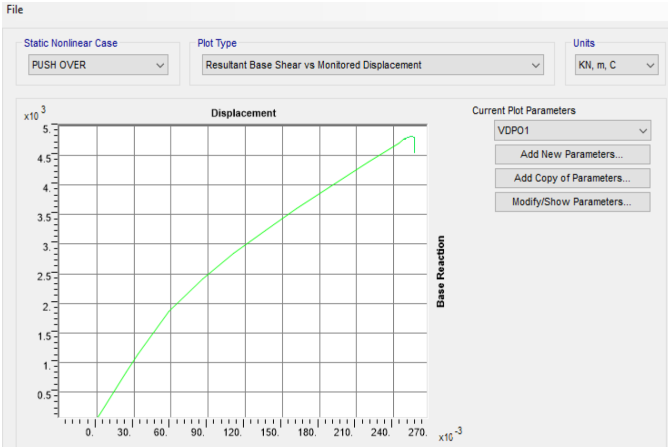

Fig 5: Pushover curve for C-shaped soft storey building

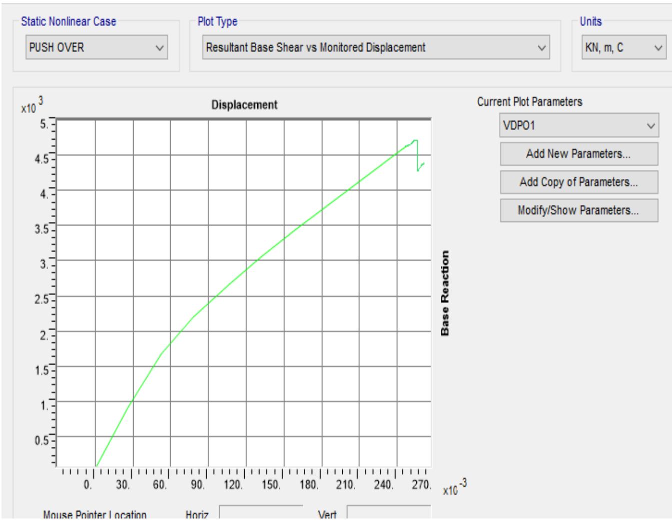

Fig 6: Pushover curve for C-shaped with wall building

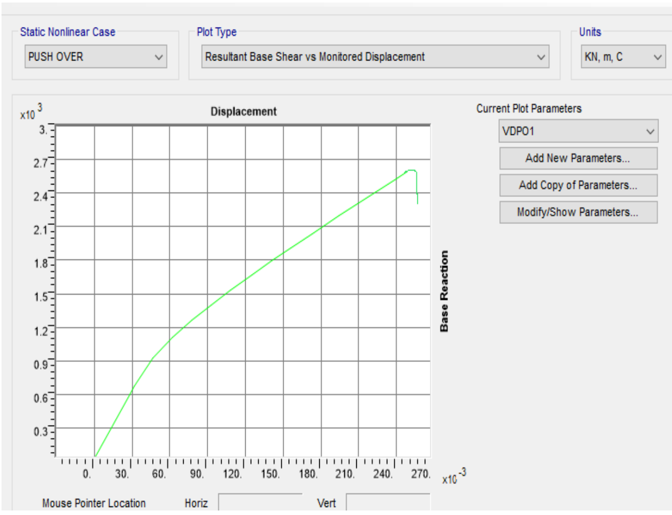

Fig 7: Pushover curve for L-shaped bare frame building

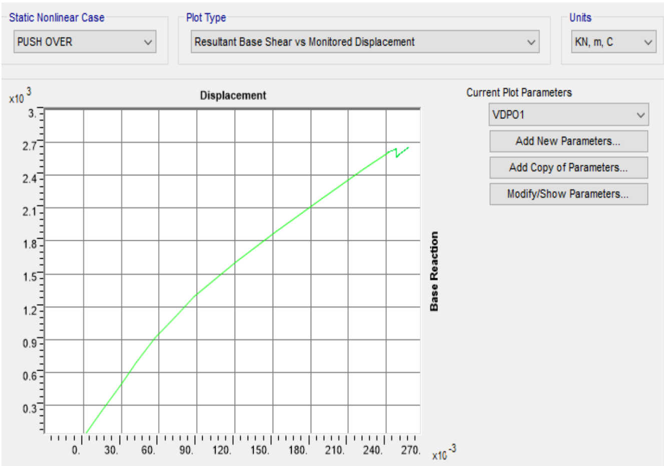

Fig 8: Pushover curve for L-shaped Soft Storey building

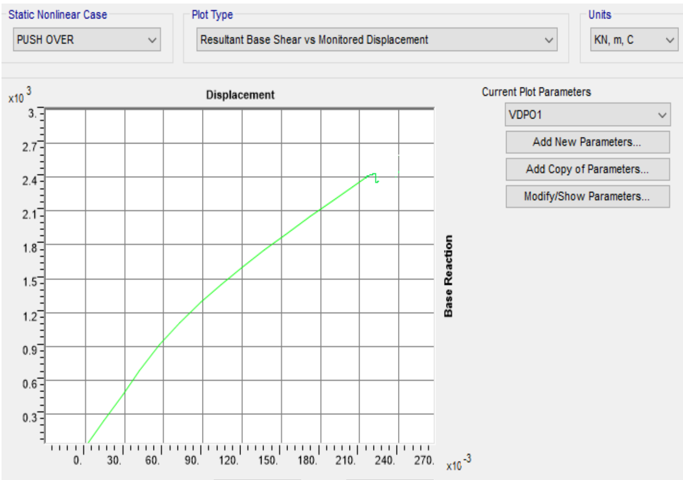

Fig 9: Pushover curve for L-shaped With Wall building

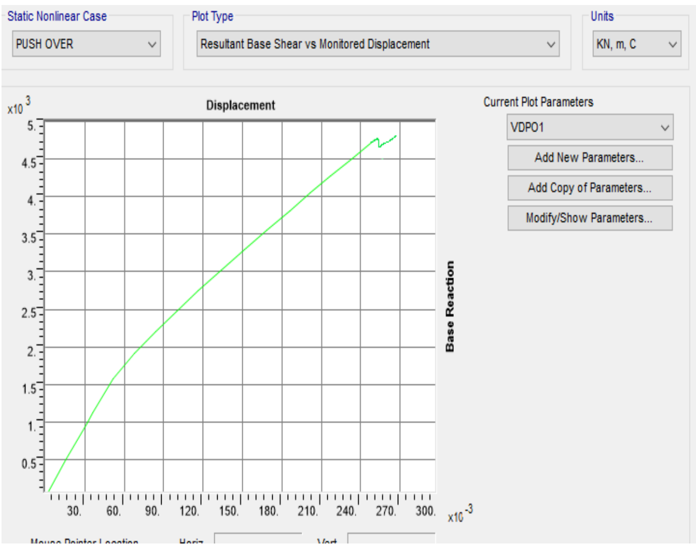

Fig 10: Pushover curve for Square shaped Bare Frame building

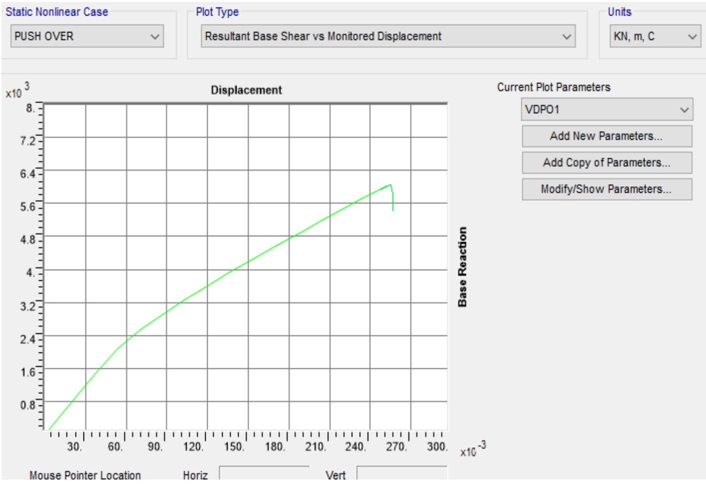

Fig 11: Pushover curve for Square shaped Soft Storey building

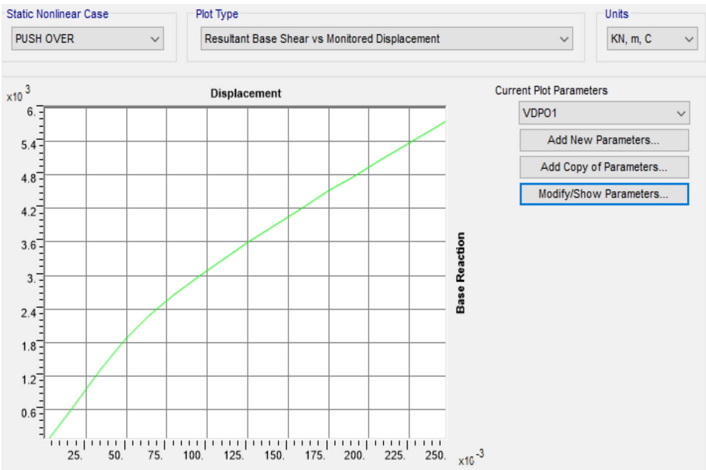

Fig 12: Pushover curve for Square shaped With Wall building

4.5 Capacity Curves

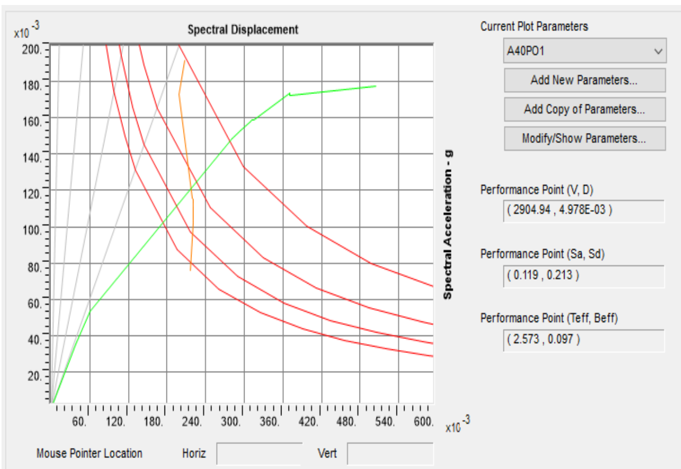

Fig 13: Capacity curve for C-shaped Bare Frame building

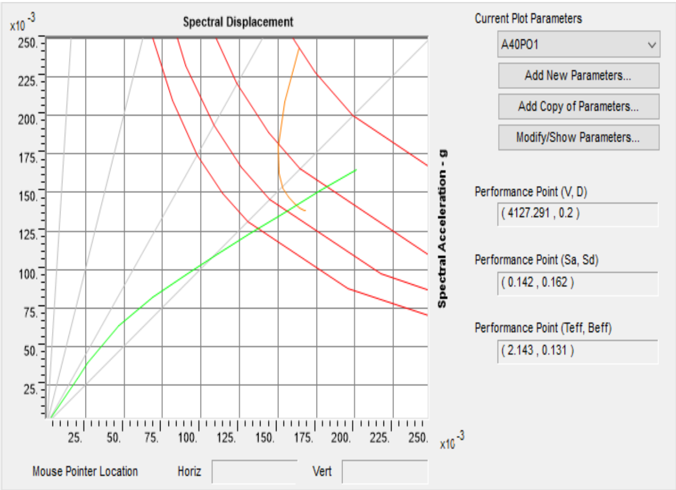

Fig 14: Capacity curve for C-shaped Soft Storey building

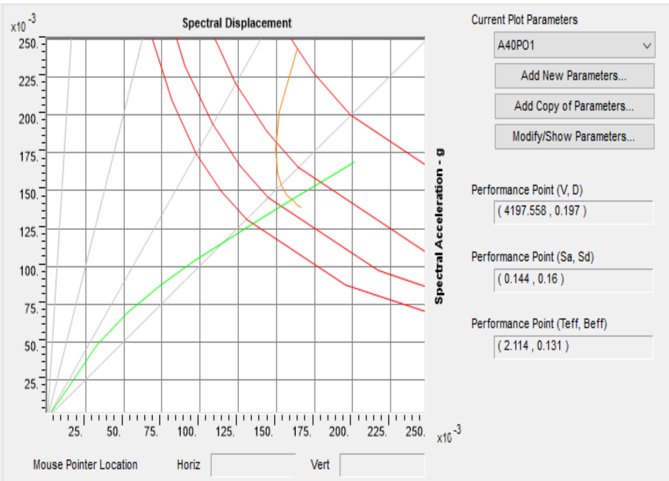

Fig 15: Capacity curve for C-shaped With Wall building

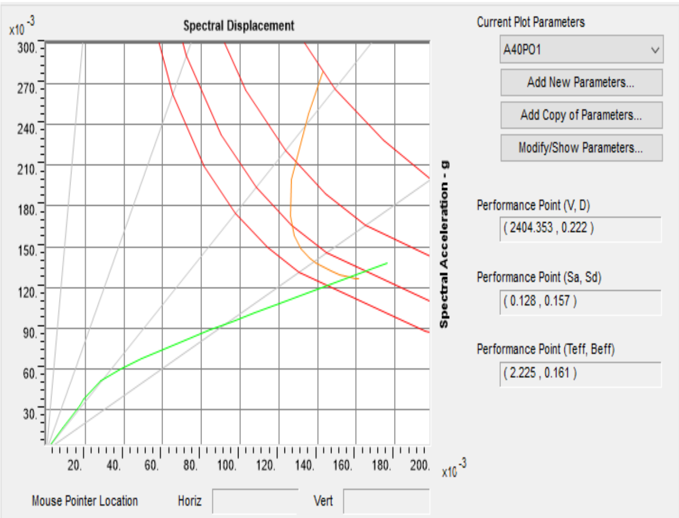

Fig 16: Capacity curve for L-shaped Bare Frame building

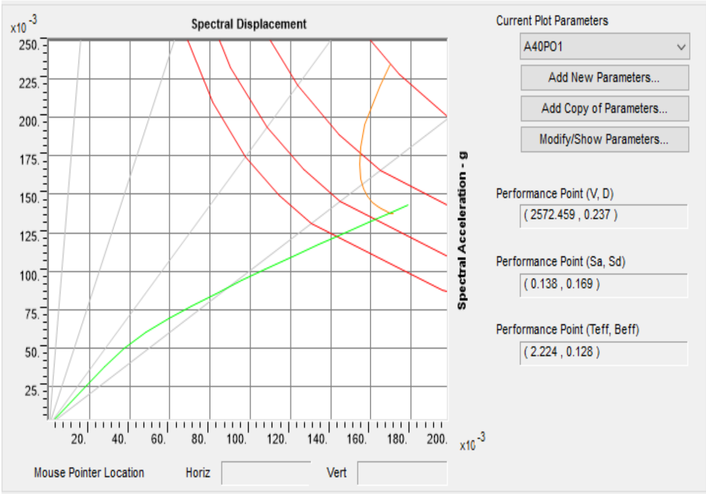

Fig 17: Capacity curve for L-shaped Soft Storey building

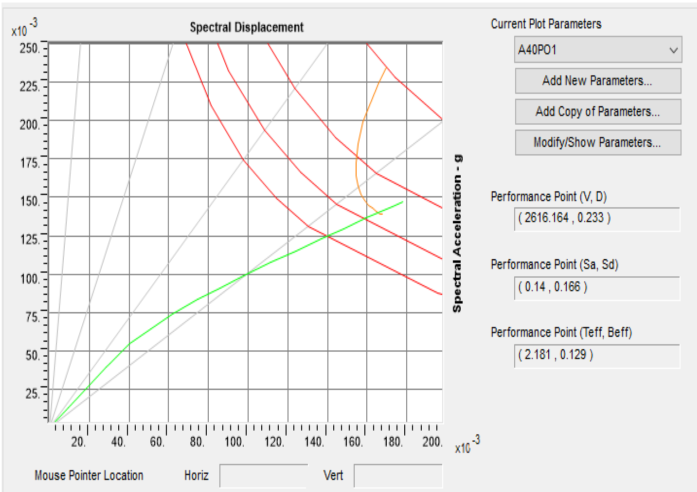

Fig 18: Capacity curve for L-shaped With Wall building

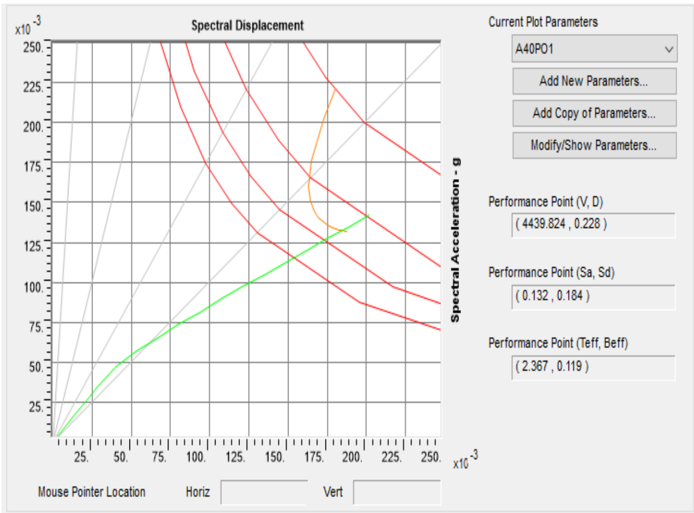

Fig 19: Capacity curve for Square shaped Bare Frame building

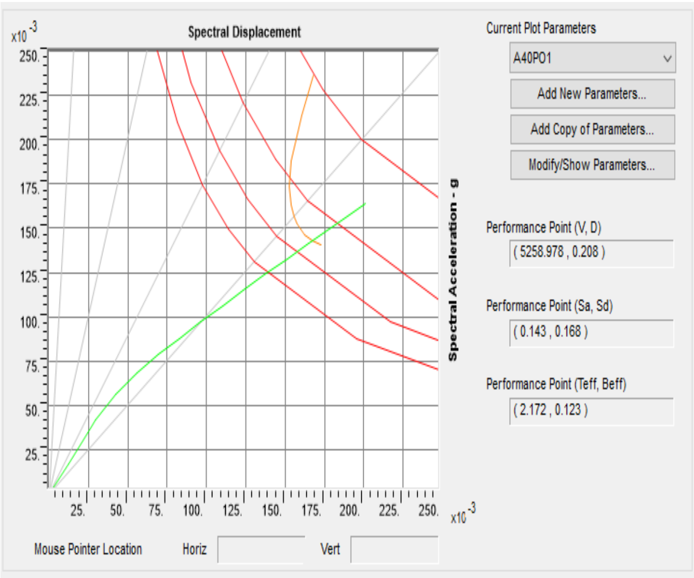

Fig 20: Capacity curve for Square shaped Soft Storey building

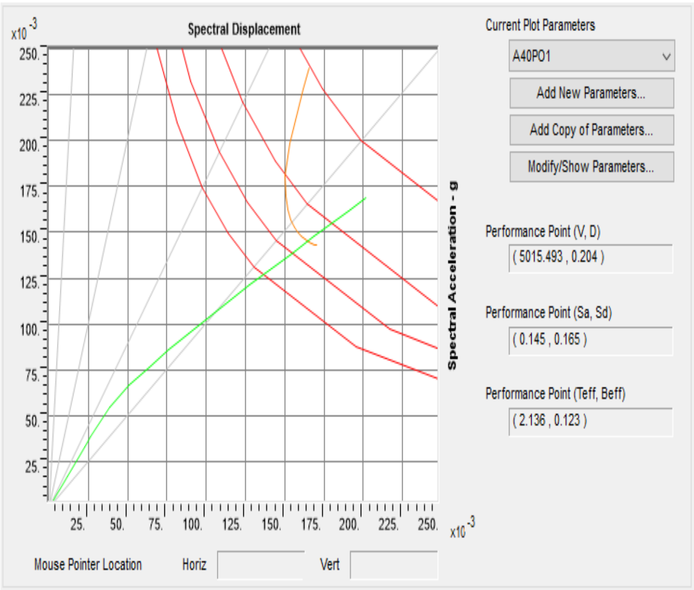

Fig 21: Capacity curve for Square shaped With Wall building

The Capacity and Demand graphs obtained in Non-linear static Pushover Analysis for different plan shapes for different soil strara are shown in figures above. If the demand curve intersects the capacity envelope near the elastic range, then the structure has a good resistance. If the demand curve intersects the capacity curve with little reserve of strength and deformation capacity, then it can be concluded that the structure will behave poorly during the imposed seismic excitation and need to be retrofitted to avoid future major damage or collapse.

4.6 Base Shear by Time History Analysis

Table 3: Base shear in X and Y directions

Shapes of Buildings	Bare Frame Building		Soft Storey Building		Building with wall	
	Base shear in (kN)		Base shear (kN)		Base shear (kN)	
	X direction	Y direction	X direction	Y direction	X direction	Y direction
C-Shaped	3693.58	3756.21	5246.58	5415.69	8785.92	8854.21
L-Shaped	2698.32	2872.65	6895.47	7154.52	8125.98	8625.85
Square Shaped	3692.82	3956.19	7853.25	7945.28	9915.28	9562.45

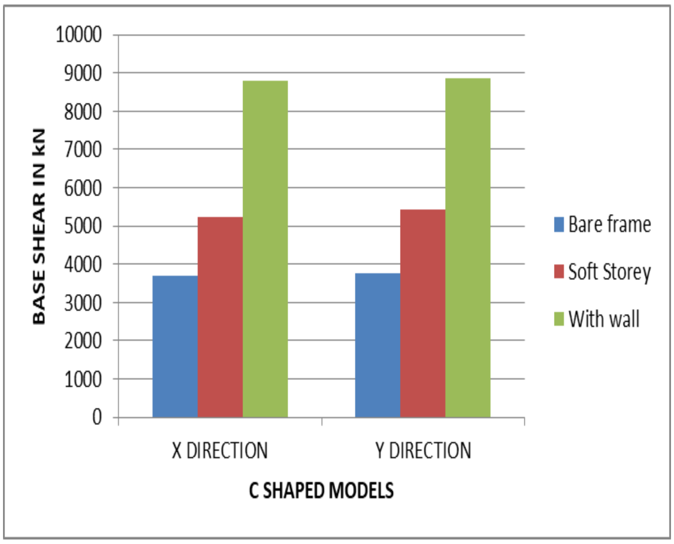

Chart 7: Baseshear for C-Shaped building

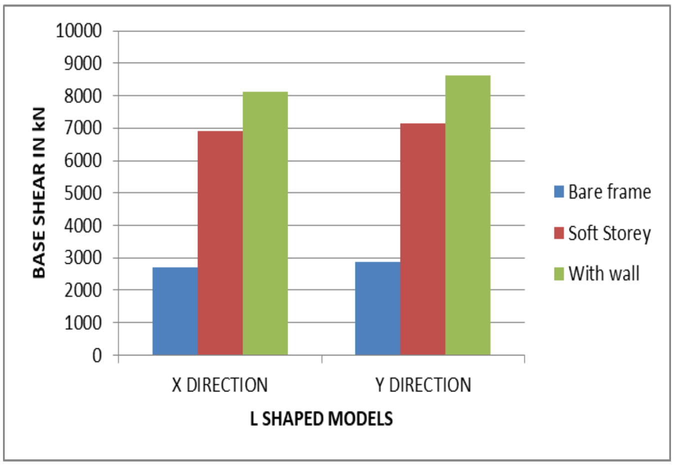

Chart 8: Baseshear for L-Shaped building

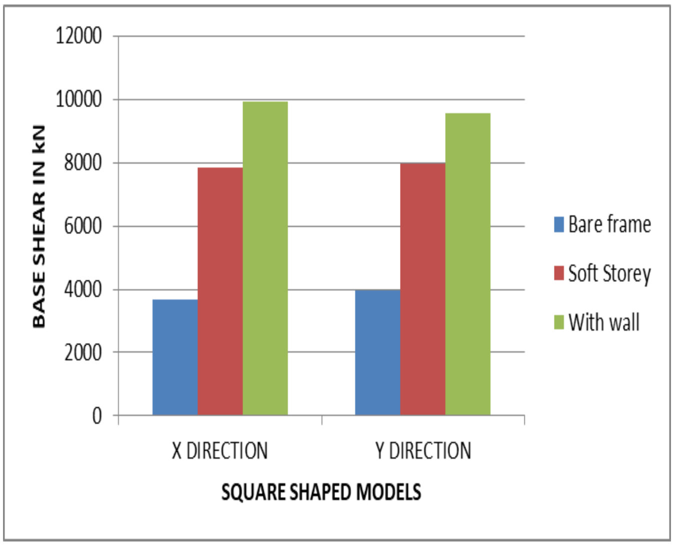

Chart 9: Base shear for Square Shaped building

The above table and fig show that the base shear of buildings for C,L,Square shaped buildings with and without wall in X and Y directions for time history analysis method. The Base Shear is a function of mass, stiffness, height and natural period of building structure. From the above tables and graphs it is evident that base shear is directly proportional to the stiffness of the building. As the stiffness of the building increases the base shear of building also increases and also the lateral load taking capacity of the building increases. The buildings with wall will have more stiffness compared to bare frame and soft storey buildings, then irregular shape building will experience less base shear compared to regular buildings because of greater stiffness.

4.7 Lateral Displacement and Storey Drift by Time History Analysis

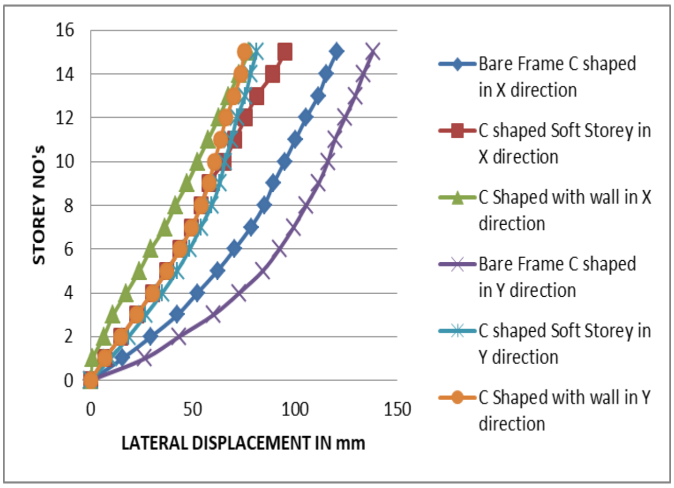

Chart 10: Variation of lateral displacement for C-Shaped building in X and Y direction

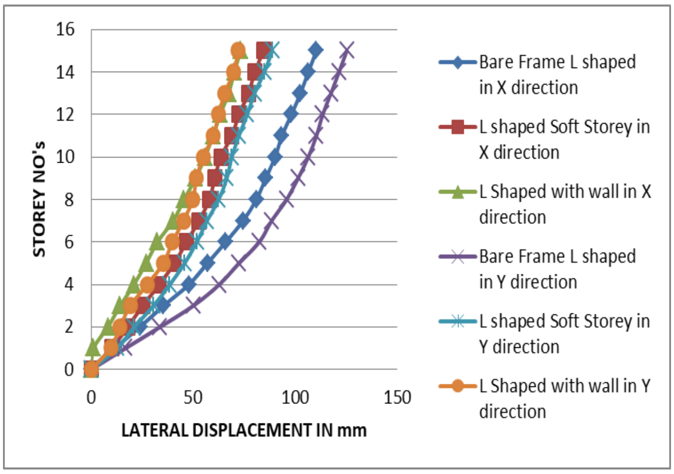

Chart 11: Variation of lateral displacement for L-Shaped building in X and Y direction

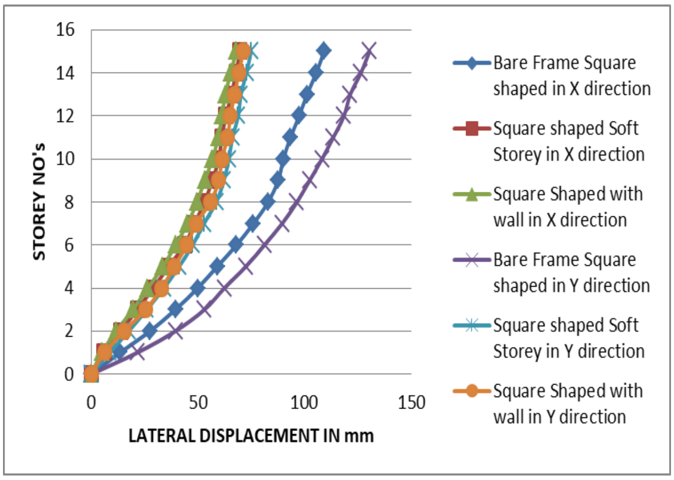

Chart 12: Variation of lateral displacement for Square Shaped building in X and Y direction

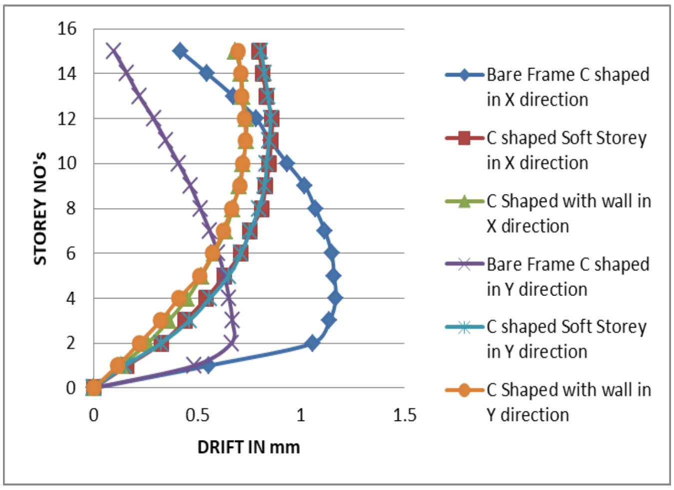

Chart 13: Variation of storey drift for C-Shaped building in X and Y direction

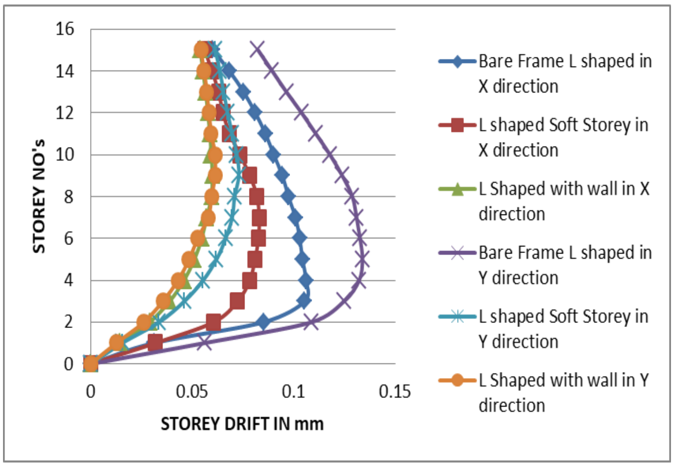

Chart 14: Variation of storey drift for L-Shaped building in X and Y direction

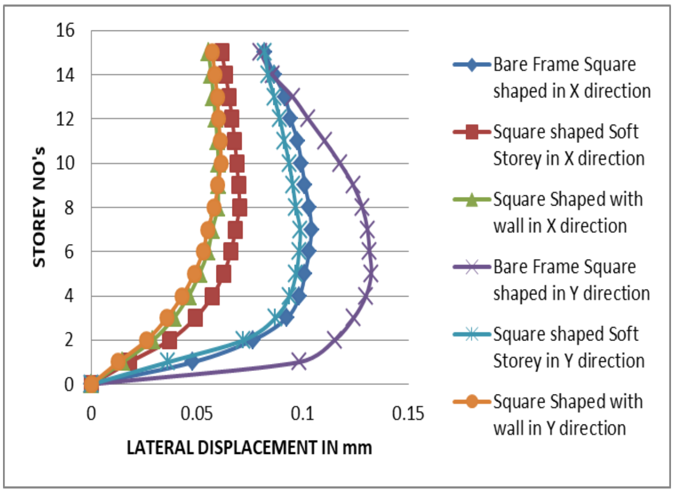

Chart 15: Variation of storey drift for Square Shaped building in X and Y direction

The lateral displcement for C, L, and Square shaped buildings for bare frame, soft storey and with wall buildings along X and Y direction are presented in tabular and graphs form.From above figures it is observe that the presence of wall in the building the lateral displacement and storey drift is got reduced, this indicates the stiffness of the buildings.And also the irregular shape buildings have more displacements compare to regular buildings.

5. CONCLUSIONS

1. The natural time period goes in increasing as the height if building goes on increases, the time period is more in irregular shape of buildings, this indicates that the irregular shape building have less stiffness compared to regular shape buildings.
2. Due to the presence of wall in the building will reduce the lateral displacements so bare frame building will have more displacement of 24.52%,42.21% compared to soft storey and with wall building.
3. The lateral displacements and storey drifts by response spectrum method are maximum in irregular buildings, i.e. C-shape, L-shape of 28.35%, 31.55%, and 9.1% minimum of Square shaped buildings (regular building).
4. Due to less area and mass, the irregular shape buildings will have least base shear, then regular shape buildings will have greater base shear this indicates the greater stiffness.
5. The results obtained from push over analysis interms of performance point gave an insight about the actual behaviour of the buildings.
6. The main output of pushover analysis in terms of response demand versus capacity. Buildings with wall will experience greater base forces compared to bare frame and soft storey buildings.
7. The seismic responses namely base shear, lateral diplacement, storey drift varies in similar pattern in both X and Y directions for regular and irregular buildings.
8. The lateral displacement and storey drift in irregular buildings is more compared to regular buildings for the given time history.
9. The building with wall have more base shear compared to bare frame and soft storey building of 57.76%,49.25% due to presence of wall.
10. As Time History Analysis is realistic method used for seismic analysis of buildings will give a better check to the saftey of building analysis.

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