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Pushover Analysis of Structures with Plan Irregularity

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Abstract: *Structural irregularities are one of the major causes of damage amplification under seismic action. Past earthquakes, indeed, have shown that buildings with irregular configuration or asymmetrical distribution of structural properties are subjected to an increase in seismic demand, causing greater damages. The sources of irregularity in a building configuration can be multiple and of different kinds and are usually classified in two major categories: irregularities in plan and in elevation [1].Both these types of irregularity often entail the development of brittle collapse mechanisms due to a local increase of the seismic demand in specific elements that are not always provided with sufficient strength and ductility. Among the two aforementioned types of structural irregularity, in-plan irregularity appears to have the most adverse effects on the applicability of the classical nonlinear static procedures (NSPs), precisely because such methods have been developed for the seismic assessment of structures whose behaviour is primarily translational. This is the reason why, in recent years, the extension of NSPs to plan irregular building structures has been widely investigated by specialists in this field [3]. Hence, this paper aims to study and understand the critical behaviour of plan irregular structures subject to seismic excitation. Lateral displacement, storey drift, base shear, storey displacement were the key parameters to ascertain performance point of all the 9 models, modelled in Etab 9.6.2 software. Output from software consisting of Pushover curve and hinge formation results of all 9 models are presented, which creates the awareness of planning simple planned structures in order to minimize the effect of earthquake.*
Keywords: *Pushover analysis, plan irregularity, pushover curve, performance point.*

I. Introduction

Irregularities in plan is related to in plan asymmetrical mass, stiffness and/or strength distributions, causing a substantial increase of the torsional effects when the structure is subjected to lateral forces, on the other hand irregularities in elevation involves variation of geometrical and/or structural properties along the height of the building, generally leading to an increase of the seismic demand in specific storey [4]. Empirical criteria for the classification of buildings into regular and irregular categories with reference to mass and lateral stiffness, variations in plan and in elevation (and related eccentricities),shape of the plan configuration, presence of set-backs, in-plan stiffness of the floors (rigid diaphragm condition), continuity of the structural system from the foundations to the top of the building. This list is not comprehensive of all the possible causes of irregularity and there is no definition for the degree of irregularity of the overall three-dimensional system. Code definitions fail to capture some irregularities, especially those resulting from the combination of both plan and vertical irregularities. Moreover, system irregularity does not solely depend on geometrical and structural properties of the building, but can also be induced by the features of the earthquake excitation and increased by the progressive damage of the structure [2].

The ATC-40 and FEMA-356 documents contain simplified nonlinear analysis procedures to determine the displacement demand imposed on a building expected to deform inelastically [6]. Nonlinear static analysis (pushover) utilized to estimate the seismic responses of structures have received considerable attention in last decades, relevant works are presented in literature and non linear static analysis has been largely used. Although an elastic analysis gives a good indication of the elastic capacity of structures and indicates where the elastic capacity of structures and indicates where first yielding will occur, it cannot predict failure mechanisms and account for redistribution of forces during progressive yielding [7]. Inelastic analysis procedures help demonstrate how buildings really work by identifying modes of failure and potential for progressive collapse.

II. Methodology

Pushover analysis is an analysis method in which the structure is subjected to increasing lateral forces with an invariant height-wise distribution until a target displacement is reached. Pushover analysis consists of a series of sequential elastic analysis, superimposed to approximate a force-displacement curve of the overall structure. A two or three dimensional model which includes bilinear or tri-linear load-deformation diagrams of all lateral force resisting elements is first created and gravity loads are applied initially. A predefined lateral load pattern which is distributed along the building height is then applied. The lateral forces are increased until some members yield. The structural model is modified to account for the reduced stiffness of yielded members and lateral forces are again increased until additional members yield. The process is continued until a control displacement at the top of building reaches a certain level of deformation or structure becomes unstable. The roof displacement is plotted with base shear to get the global capacity curve. Push over analysis is one of the most used non linear static procedure for seismic assessment of structure therefore now days it is extensively used by practicing engineers for the seismic analysis of virtually every type of building [5].

Considering this scenario, I have adopted pushover analysis method to define and measure structural irregularities also understand its effect on the seismic behaviourof plan and configuration of structure.

III. System Development

The expected behaviour of structures as observed in physical world cannot be replicated with the high degree of precision hence there is need to develop a system based on the classical approach which will establish a bridge between the physical and stimulated world.To solve the purpose I have developed 9 models in ETABs software. The geometrical loading data, support reactions adopted for both the models for each of the 9 models are kept same to achieve a behavior pattern.These 9 models are shaped by considering Plan irregularities i.e. the plan area for each structure is same only there is difference of geometry.

The specified shapes of models are as follows,

Regular Square Shape (S-1)	T-Shape (S-4)	Plus (+) Shape (S-7)
E-Shape (S-2)	L-Shape (S-5)	Square with Core (S-8)
H-Shape (S-3)	C-Shape (S-6)	Rectangle with core (S-9)

Specifications for all above mentioned structural models are same and are given as follows,

Table 1: Load Data

Live Load	3 kN/m2
Roof Live Load	1 kN/m2
Floor Finish	1 kN/m2

Table 2: Seismic Definition

Earthquake Zone	III
Damping Ratio	5%
Importance factor	1
Type of Soil	Medium Soil
Type of structure	All General RC frame
Response reduction Factor	5 [SMRF]
Time Period	Program Calculated
Foundation Depth	2 m
Poison's Ratio	0.15

Table 3: Geometric Data

Density of RCC considered:	25 kN/m3
Thickness of slab	160 mm
Depth of beam	380 mm
Width of beam	300 mm
Dimension of column	300 mm x 450 mm
Density of infill	20 kN/m3
Thickness of out wall	230 mm
Height of each floor	3.4 m
Poison's Ratio	0.15
Conc. Cube Comp. Strength, fck	20000 N/mm2
Bending Reinforcement yield strength , fy	415000 N/mm2
Shear Reinforcement yield strength , fys	415000 N/mm2

Beam Rebar Cover	30 mm
Column Bar Size	12 ϕ

Plan of each building considered in this research are shown below,

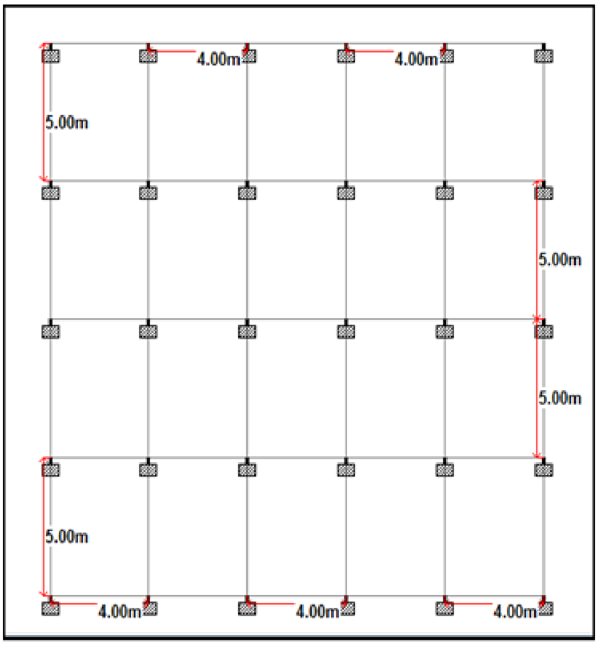

Fig. 1: Regular Square (S-1)

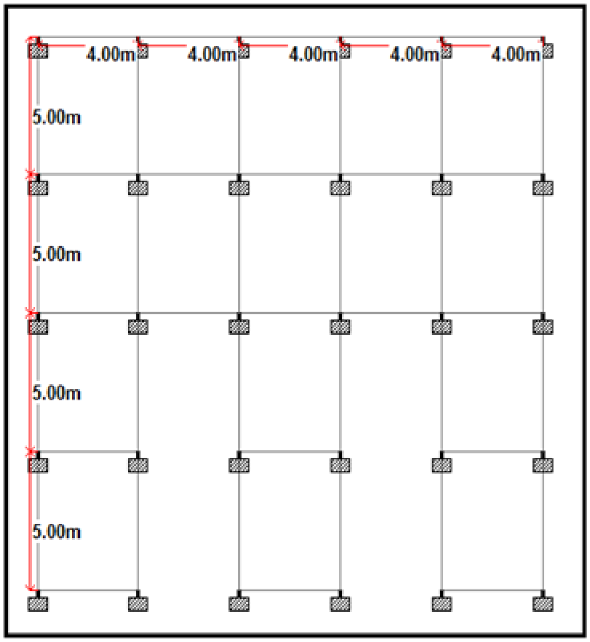

Fig 2: E Shape (S-2)

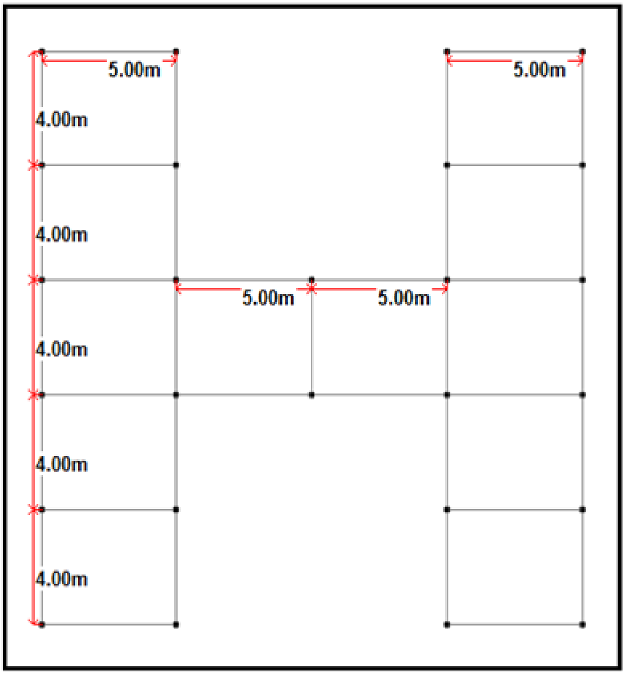

Fig. 3: H -Shape (S-3)

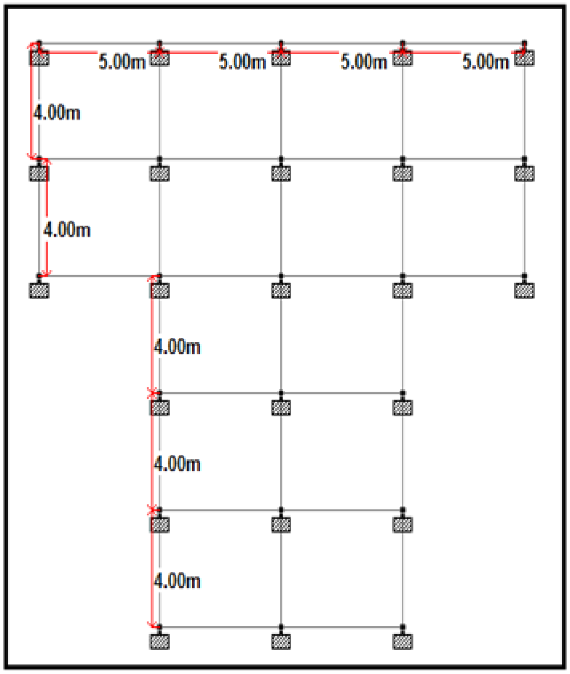

Fig. 4: T - Shape (S-4)

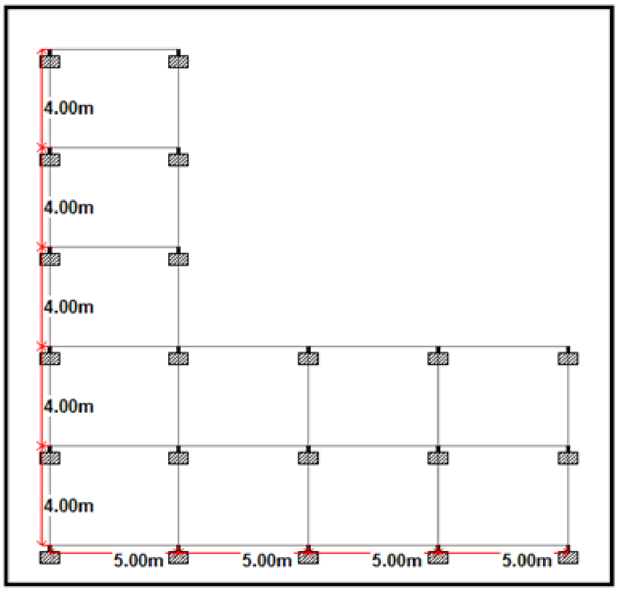

Fig.5: L – Shape (S-5)

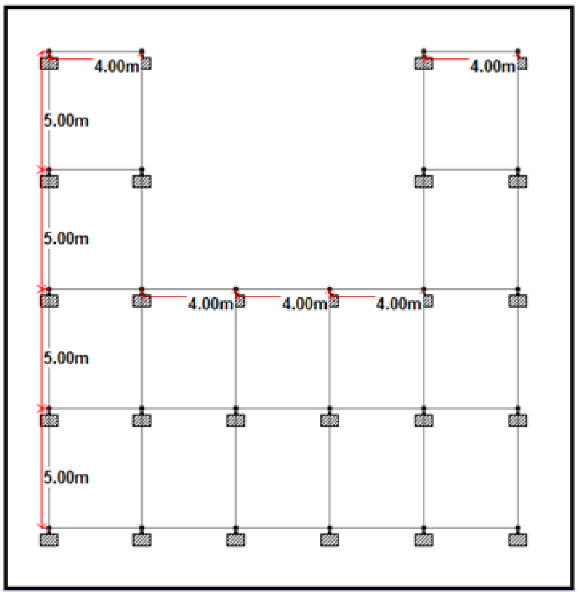

Fig.6: C - Shape (S-6)

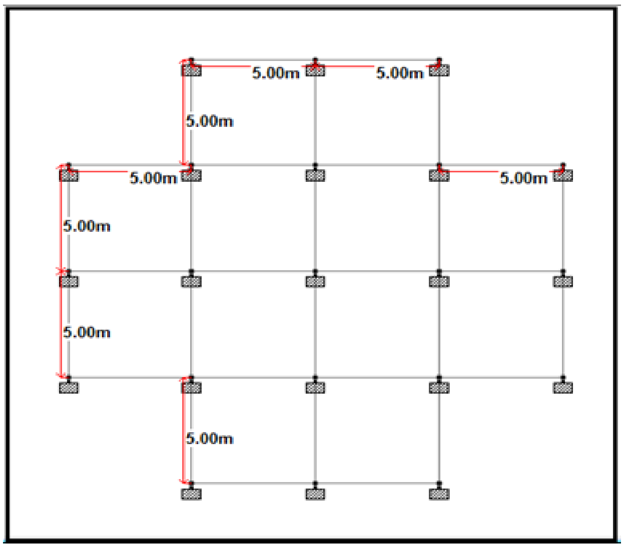

Fig.7: Plus (+) Shape (S-7)

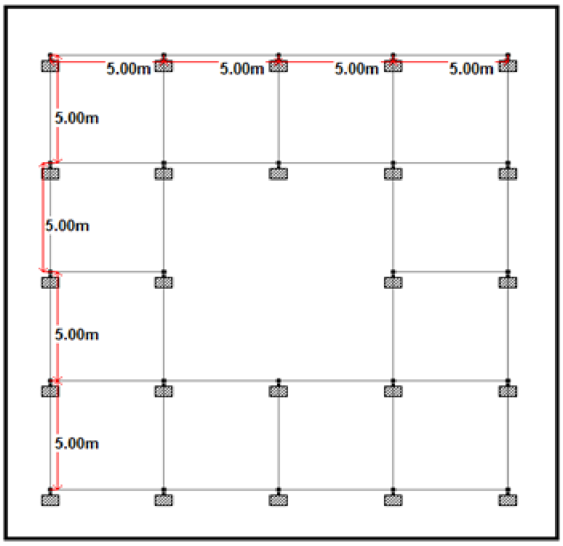

Fig.8: Square with Core (S-8)

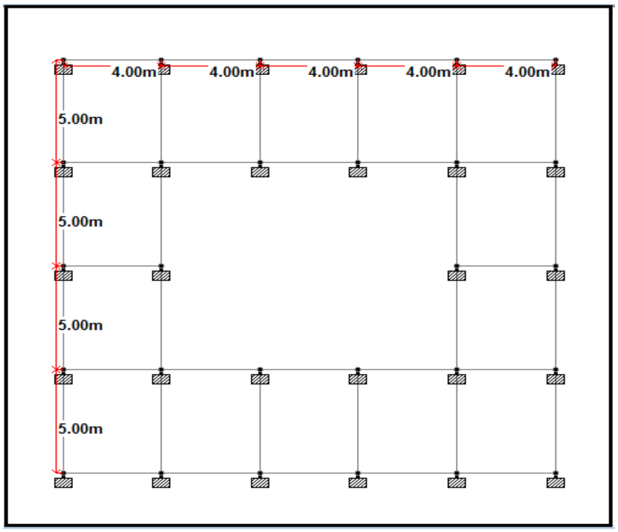

Fig.9: Rectangle with Core (S-9)

The Pushover Analysis is expected to provide information on many response characteristics that cannot be obtained from a linear elastic static or dynamic analysis. The pushover analysis is most useful for the evaluation at performance levels that are associated with large inelastic deformations (e.g. collapse prevention level). The method is applicable and useful, however for evaluation at any performance level at which inelastic deformation will occur.

IV. Results And Discussion

Behavior of structure subjected to earthquake loading is a complicated phenomenon. There are several numbers of factors affecting the behavior of building out of which of storey drift, lateral displacement, Base shear and performance point are consider for study in this paper. For this, building model in zone III is considered seismic definitions are provided in Table No.2. Response spectrum analysis and pushover analysis are adopted to obtain required parameters for study with the help of Etab Software. Analysis results are demonstrated with the help of tables and charts.

1. Lateral Displacement And Storey Drift:

Lateral displacement and storey drift of all the 9 models are presented in graphical form specifically each quantity in X and Y direction,

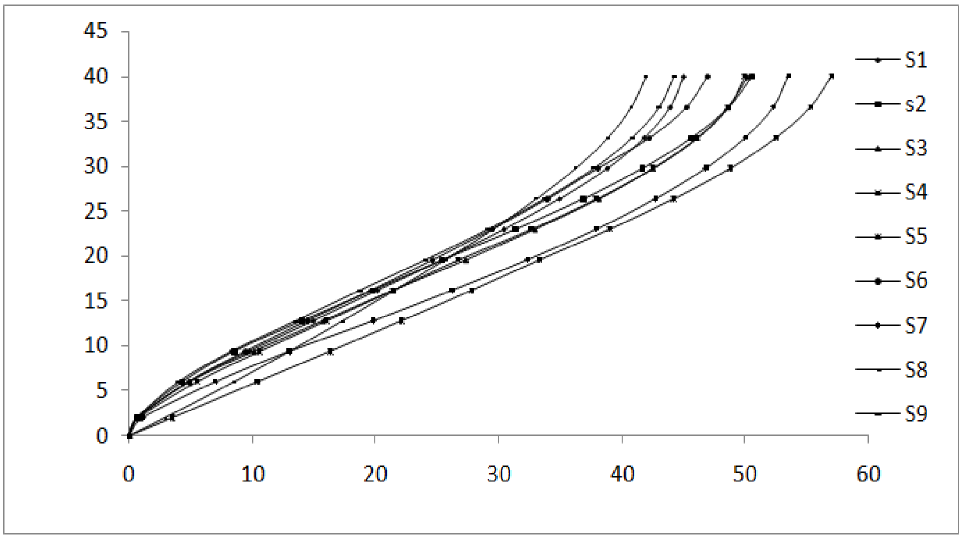

Fig. 1 Lateral Displacement in X direction

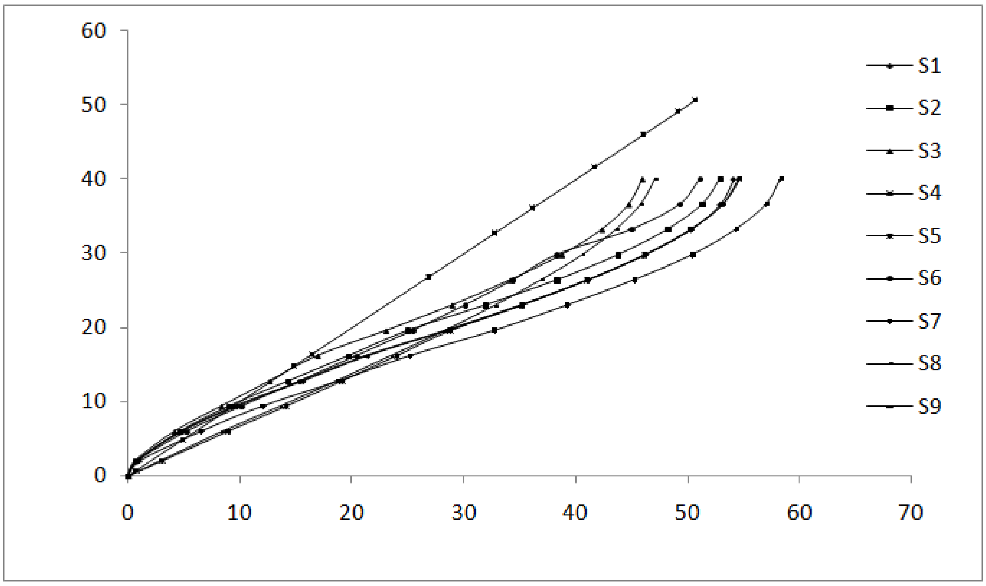

Fig. 2 Lateral Displacement in Y direction

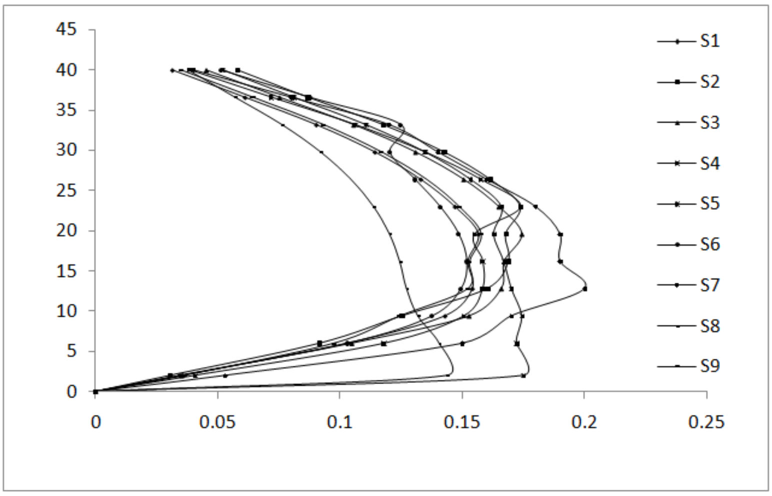

Fig. 3 Lateral Drift in X direction

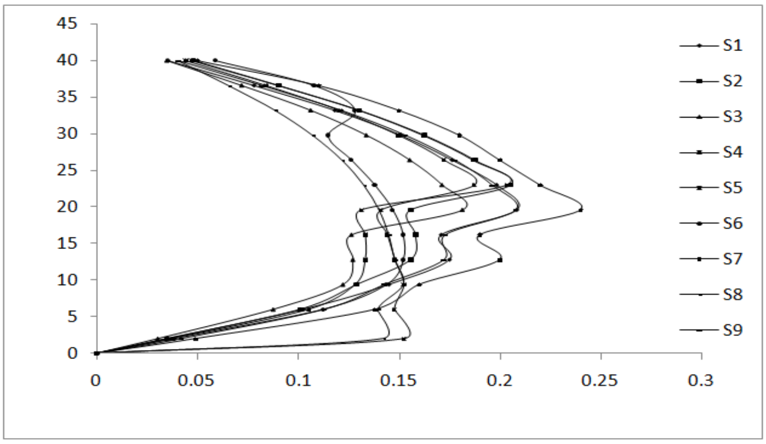

Fig. 4 Lateral Drift In X Direction

2. Pushover Curve And Base Shear

Performance point for all the 9 models along with pushover curve and comparative statement of base shear is presented in suitable format,

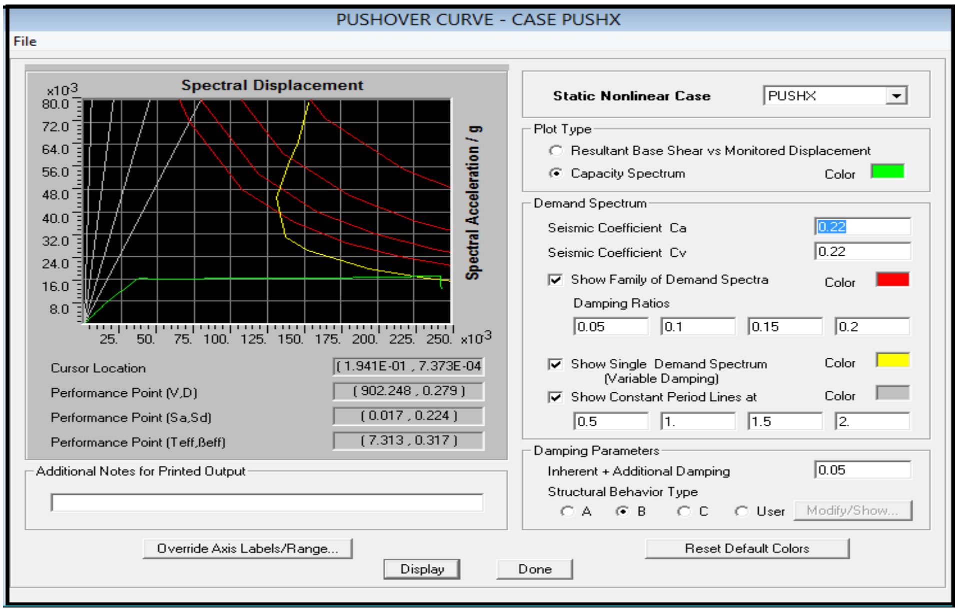

Fig.5: Pushover curve X-Direction for regular square shape (S1)

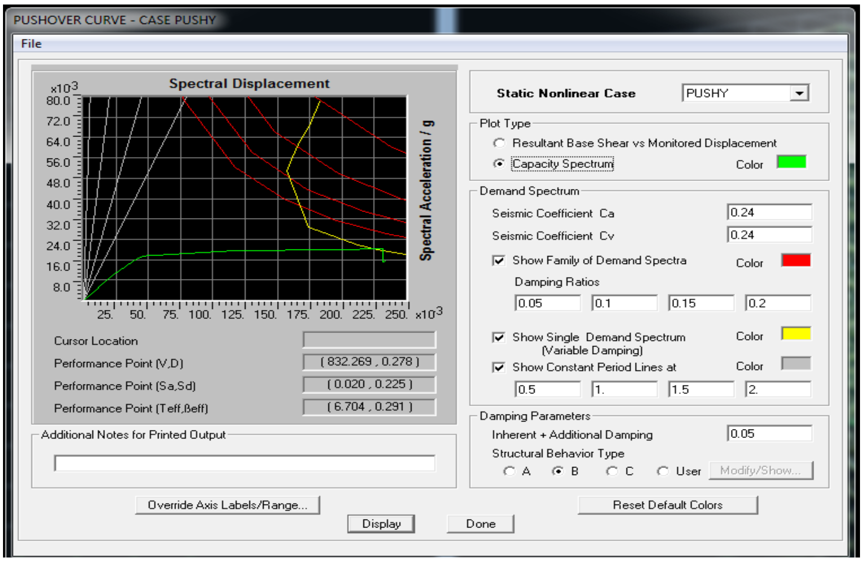

Fig.6: Pushover curve y-Direction for E shape (S2)

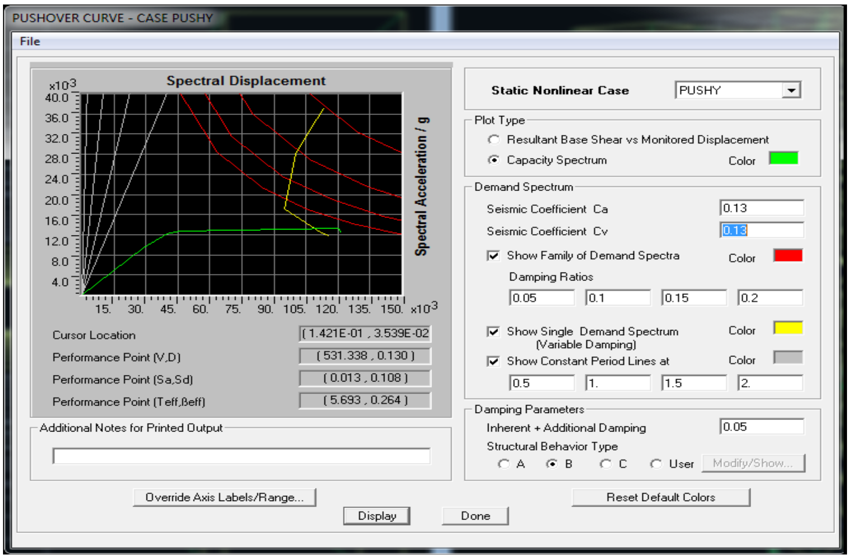

Fig.7: Pushover curve y-Direction for H shape (S3)

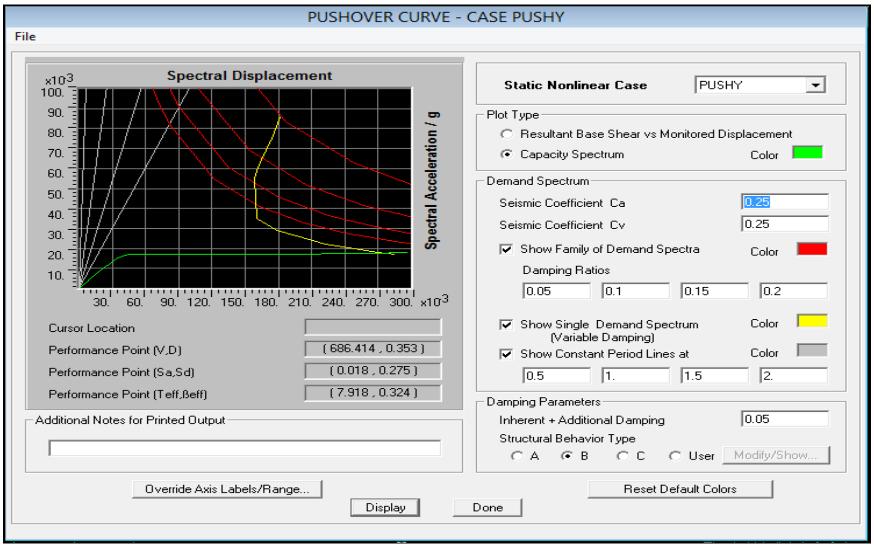

Fig.8: Pushover curve y-Direction for T shape (S4)

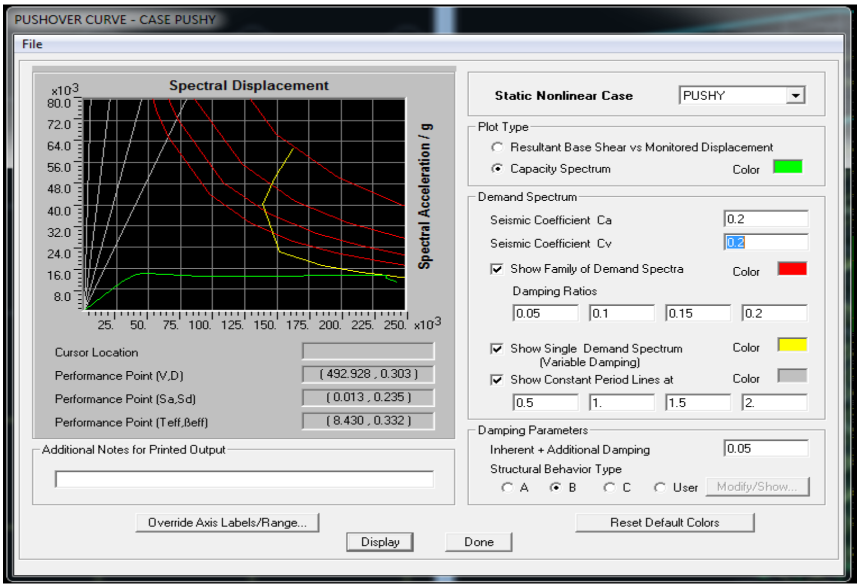

Fig.9: Pushover curve y-Direction for L shape (S5)

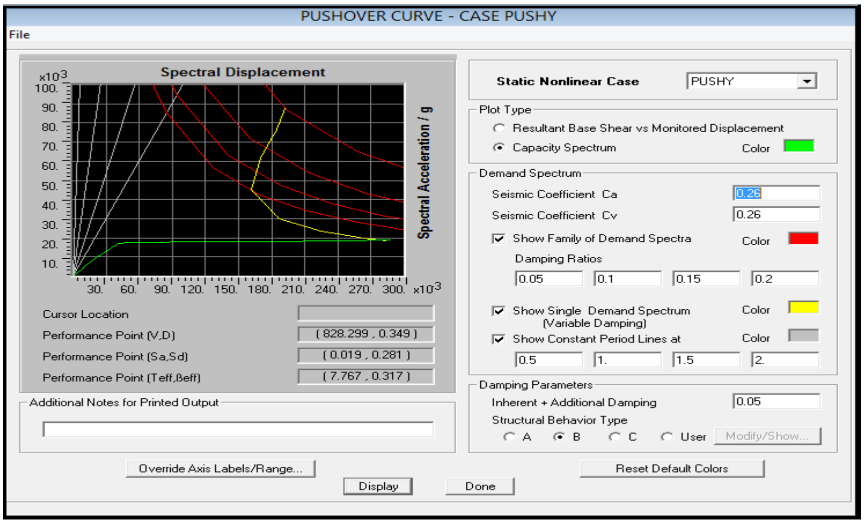

Fig.10: Pushover curve y-Direction for C shape (S6)

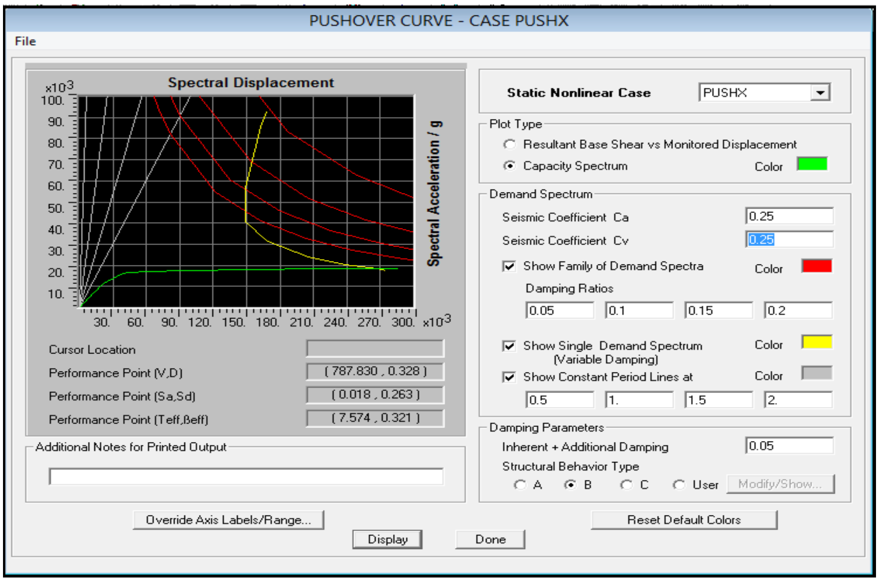

Fig.11: Pushover curve X-Direction for Plus (+) shape (S7)

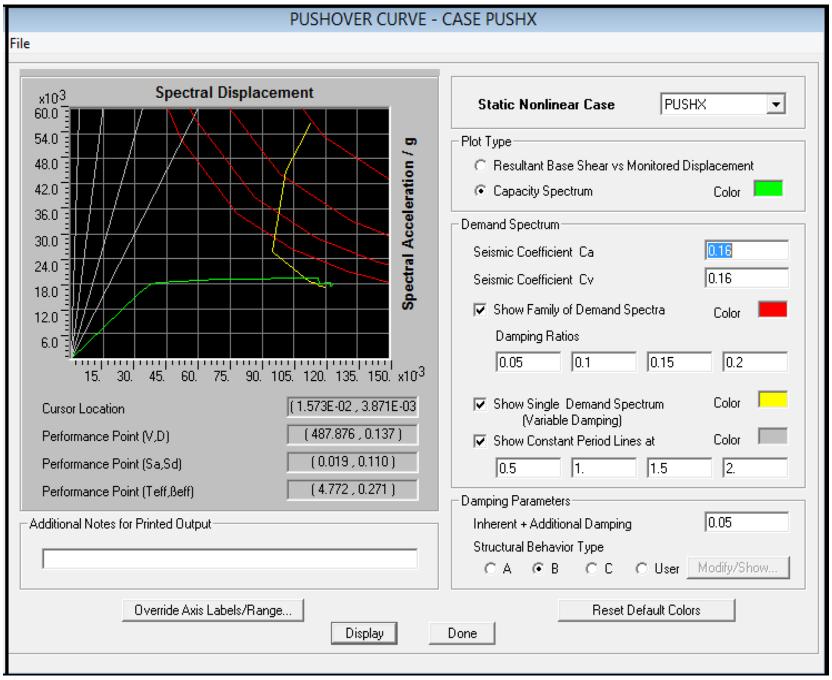

Fig.12: Pushover curve X-Direction for Square shape with core (S8)

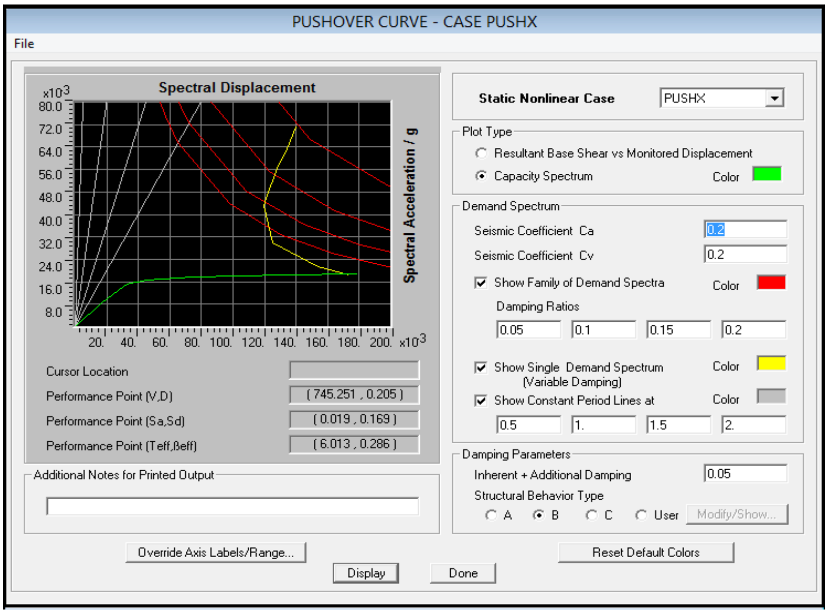

Fig.13: Pushover curve X-Direction for Rectangular shape with core (S9)

V. Discussion

With reference to the results collected from all the 9 models considering response spectrum method and pushover analysis by using Etab software, it has been observed that complex plan geometries attract more forces which make them vulnerable under the effect of seismic action. Lateral displacement and storey drift has been shown graphically in Fig. 1 to Fig. 4 which clearly depicts the need of simpler plan of the structure at planning stage itself. Complex geometries can be resolved into simple shapes by provision of seismic gaps as per the requirement. Thorough analysis must be done to ascertain the width of seismic gap.

Pushover curves plotted for all the 9 models shows variation of base shear with reference to storey displacement. Performance levels as per ATC 40 and FEMA 356 are observed and identified in all the 9 models. As per ATC 40 structures subjected to earthquake forces must obey the yielding capacity for a given section till Life safety (LS) level. Hence, base shear and storey displacement observed at this level predicts the performance of the particular structure/model. Performance point is shown for all the models in Fig.5 to Fig.13.

VI. Conclusion

Effects on chosen models have been shown in the form of graph in successive part of results and discussions, by comparing various parameters such as nodal displacements, base shear, storey drifts and performance point. Hence from the obtained results the following conclusions are made,

1. Considering the effect of lateral displacement on different shapes of the building of the structure. it has been observed that, Plus-shape, L-shape, C-shape H-shape, E-shape and T-shape building have displaced more in both direction (X and Y) in comparison to other remaining simple shaped building (Core-rectangle, Core-square, Regular building,)
2. The storey drift being the important parameter to understand the drift demand of the structure is considered while collecting the results from both the software as per (IS 1893-2002), limiting value of drift for the given structure as per (7.11.1) is not exceeded in any of the structure but L-shaped and C-shaped models showed larger drift than other shaped models.
3. To critically analyse irregular structure, results obtained from pushover analysis have been adopted. Basically base shear and roof displacement plays a vital role in obtaining performance point of the given structure, while comparing base shear for different shaped buildings it has been observed that complex plan buildings more base shear as in comparison to simple planned geometries.
4. Pushover analysis provides various performance levels for the given structure under the effect of lateral loads, it is admissible for a given structure to obey these performance levels and perform till the safety performance levels are achieved. It has been observed that most of the models have achieved performance point at lower time steps.

Considering all these above discussion made on analysis of irregular structures, I finally say that simple geometry attracts less force and perform well during the effect of earthquake. It is inevitable to omit complex geometries but complex shapes can be reduced to the simple ones and adopted from the planning stage.

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