

Performance of Steel Frame by Pushover Analysis for Solid and Hollow Sections

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Abstract:- The research concentrates on a computer based push-over analysis technique for performance-based design of steel building frame works subjected to earthquake loading. Through the use of a plasticity-factor that measures the degree of plasticisation, the standard elastic and geometric stiffness matrices for frame elements (beams, columns, etc.) are progressively modified to account for nonlinear elastic-plastic behaviour under constant gravity loads and incrementally increasing lateral loads. The analysis is performed for two steel frameworks of solid and hollow members. This investigation aims to analyse the difference in structural behaviour between hollow and solid frames. The technique adopted in this research is based on the conventional displacement method of elastic analysis.

Keywords:- Seismic Performance, Pushover, Non-linear, performance levels, Steel frame, Capacity Curves.

I. INTRODUCTION

Pushover analysis is a static, nonlinear procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern. With the increase in the magnitude of the loading, weak links and failure modes of the structure are found. The loading is monotonic with the effects of the cyclic behaviour and load reversals being estimated by using a modified monotonic force-deformation criteria and with damping approximations. Static pushover analysis is an attempt by the structural engineering profession to evaluate the real strength of the structure and it promises to be a useful and effective tool for performance based design.

II. PUSHOVER ANALYSIS

Pushover analysis is a performance based analysis. According to ATC 40, there are two key elements of a performance-based design procedure - demand and capacity. Demand is the representation of earthquake ground motion or shaking that the building is subjected to. In nonlinear static analysis procedures, demand is represented by an estimation of the displacements or deformations that the structure is expected to undergo. Capacity is a representation of the structure's ability to resist the seismic demand. The performance is dependent on the manner that the capacity is able to handle the demand. In other words, the structure must have the capacity to resist demands of the earthquake such that the performance of the structure is compatible with the objectives of the design.

Pushover analysis is an approximate analysis method in which the structure is subjected to monotonically 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 trilinear 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.

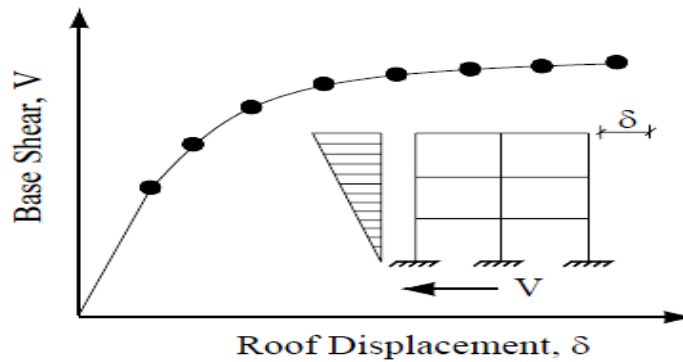


Figure 1. Design capacity curve

Objectives of this study:

1. To study the structural performance of solid and hollow steel frames when subjected to seismic loads.

Scope of the study:

1. Determination of performance level of solid and hollow frames
2. To predict peak response of building and components for a given seismic loads.

Modelling:

The STAAD Pro V8i software is utilized to create 2D model and carry out the Pushover analysis. The buildings are modelled as a series of stories from 5 to 40 with same bay width and storey height. The study is performed for applied lateral load to find base shear and the displacement. The buildings adopted consist of reinforced concrete. The frames are assumed to be firmly fixed at the bottom and the soil–structure interaction is neglected.

Inputs: Model Geometry for both Solid and Hollow sections:

Table 1: Input parameters

Number of stories	Type of frame	Bay width	Height of each storey
5	2D-Frame	6m	3m
10	2D-Frame	6m	3m
15	2D-Frame	6m	3m
20	2D-Frame	6m	3m
25	2D-Frame	6m	3m
30	2D-Frame	6m	3m
35	2D-Frame	6m	3m
40	2D-Frame	6m	3m

Material properties for both Solid and Hollow sections:

- Young’s modulus of material (E) = 2.05×10^8 kN/m²
- Poisson’s ratio (nu) = 0.3
- Density = 76.8195kN/m³
- Thermal expansion = 1.2×10^{-5}
- Critical damping = 0.03

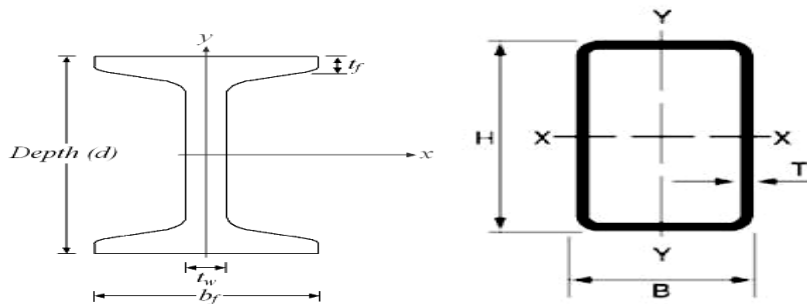


Fig. 2 Cross section of both Solid and Hollow sections

Pushover Analysis Methodology:

Figure 3 shows the pushover methodology for both solid and hollow section. In this chart describes the pushover steps and details over the pushover analysis.

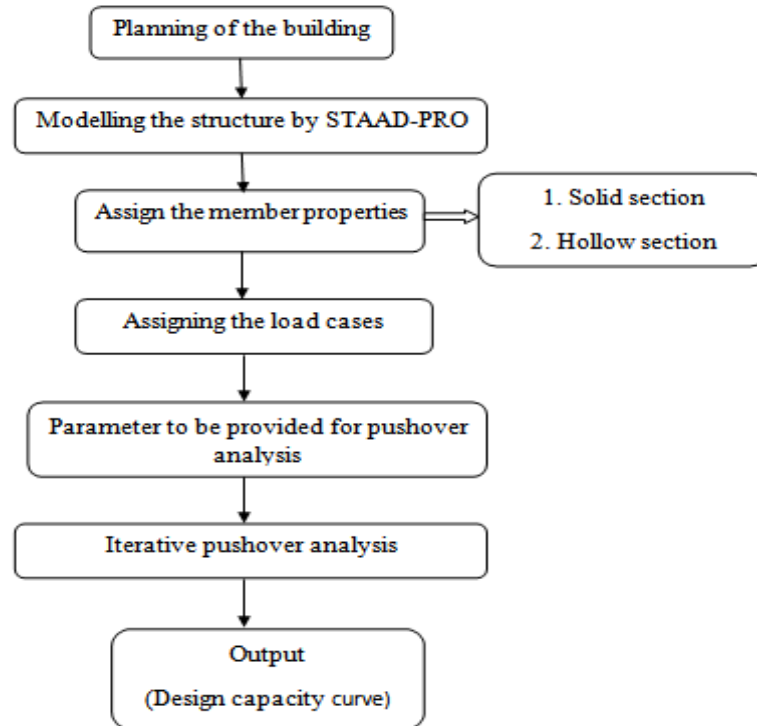


Figure 3: Pushover analysis methodology

III. RESULTS AND DISCUSSION

The capacity curve obtained through the pushover analysis is shown in Figure 4, 5,6,7,8,9,10. The difference in results may be due to difference in the applied lateral force and its estimation. In the present study the lateral forces has been estimated by using seismic coefficient method as per IS: 1893-2002. The zone is considered as zone V with medium soil. The analysis carried out by representing the proposed inelastic member behaviour with semi-rigid connection will resemble the most practical case. The sequence of hinge formation observed during the analysis is shown in Figure 11. At the end of interaction severe hinges are observed in first floor beams and ground floor columns and which gives an insight in structural behaviour and understanding. It may be concluded that under a severe earthquake the first floor beams and ground floor columns retrofit may not meet all the structural requirements of the life safety level. Table 2 shows the inelastic response displacements of the frame. It is observed that inelastic displacement of the structure is within collapse prevention.

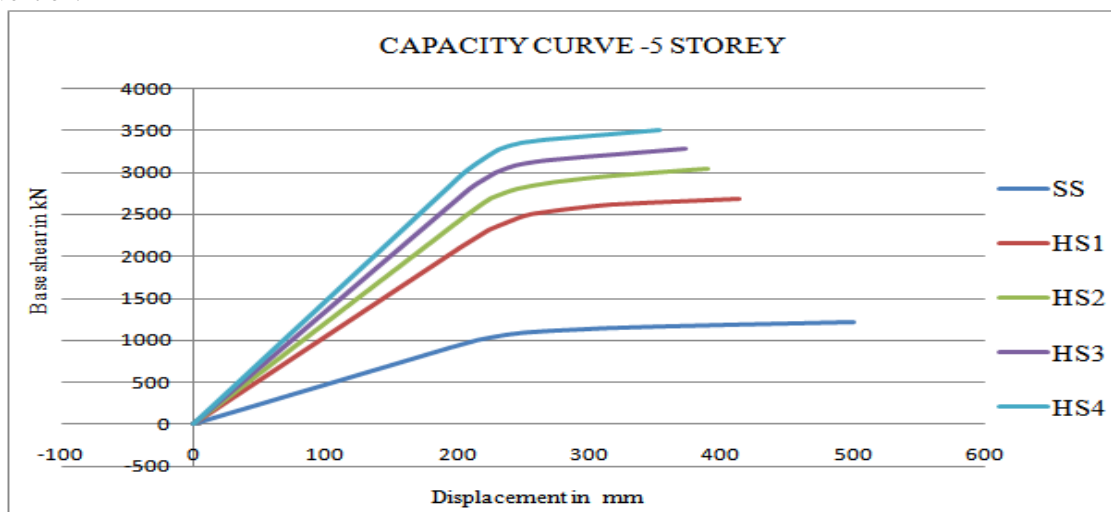


Figure 4: Capacity curve for 5-storey 2-D frame

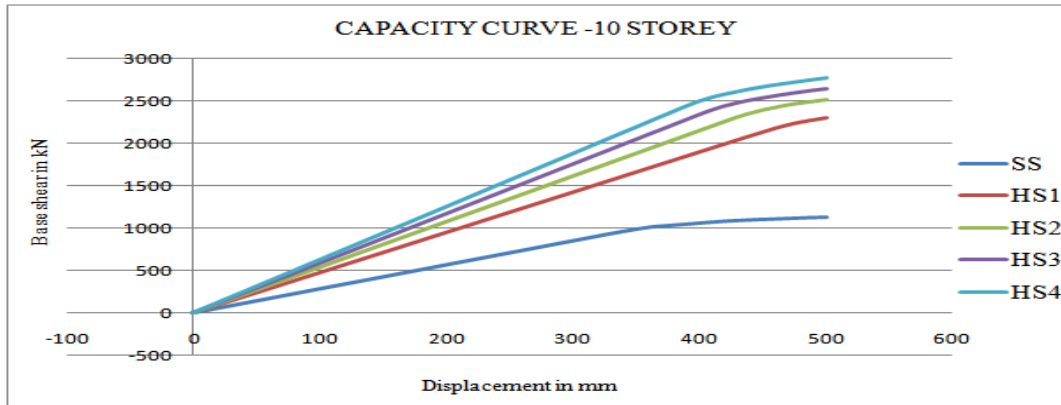


Figure 5: Capacity curve for 10-storey 2-D frame

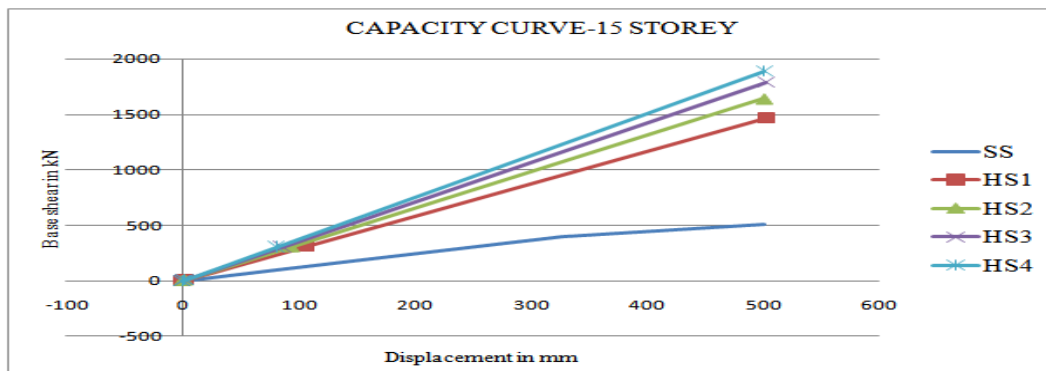


Figure 6: Capacity curve for 15-storey 2-D frame

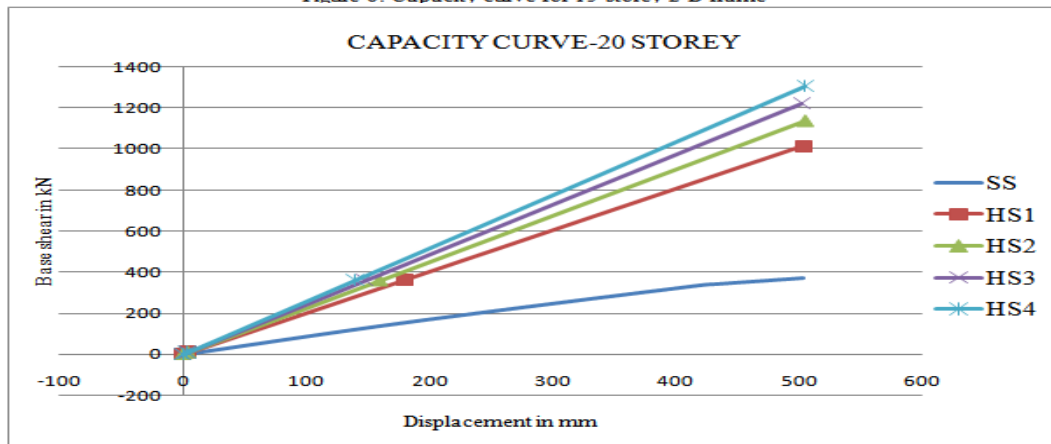


Figure 7: Capacity curve for 20-storey 2-D frame

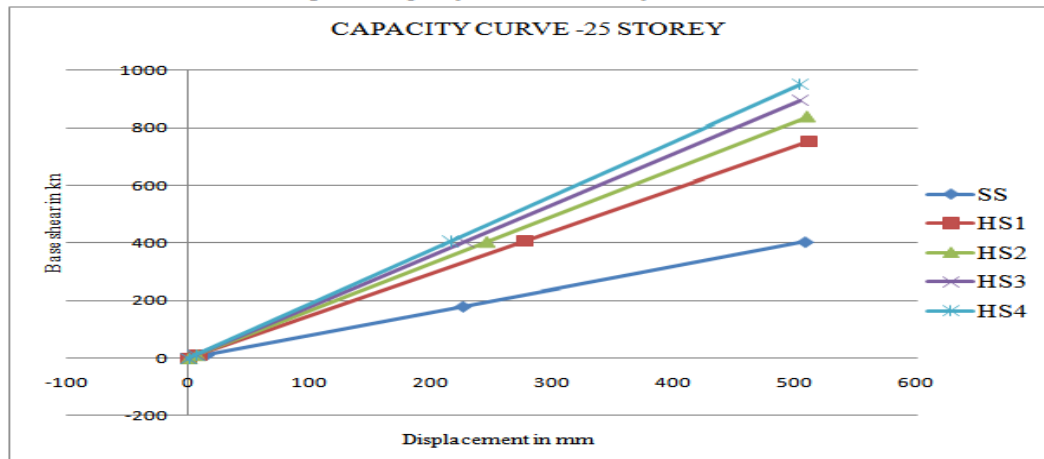


Figure 8: Capacity curve for 25-storey 2-D frame

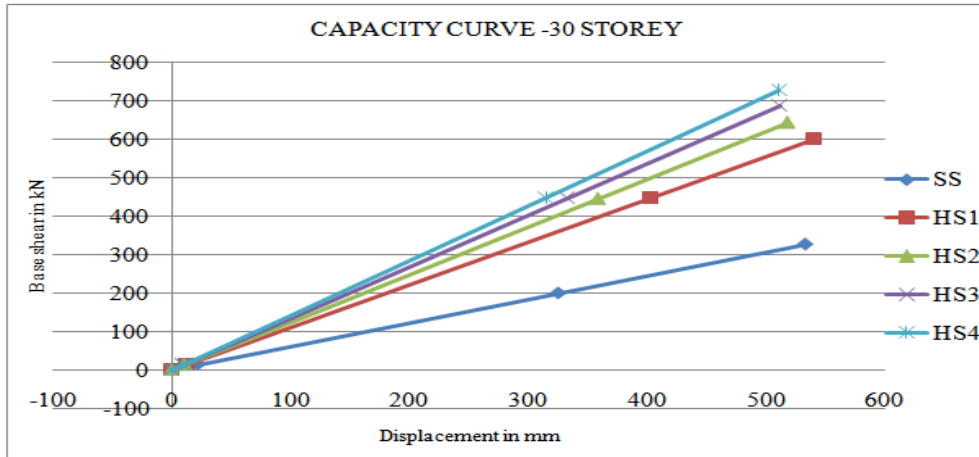


Figure 9: Capacity curve for 30-storey 2-D frame

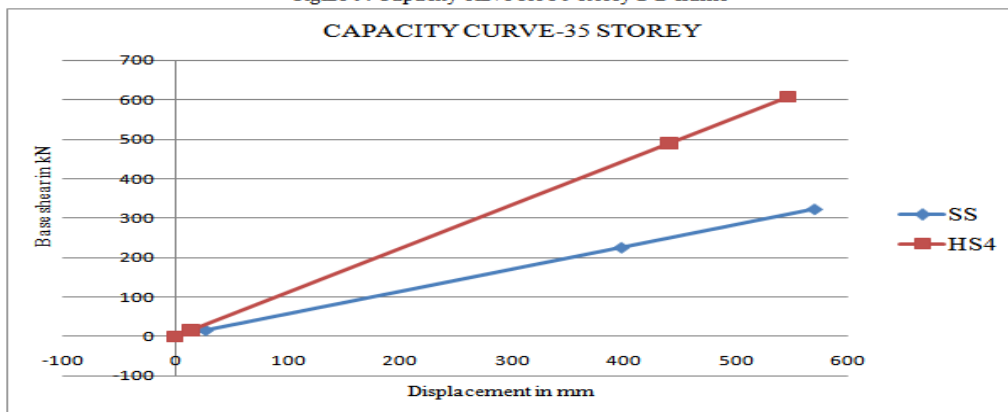


Figure 10: Capacity curve for 35-storey 2-D frame

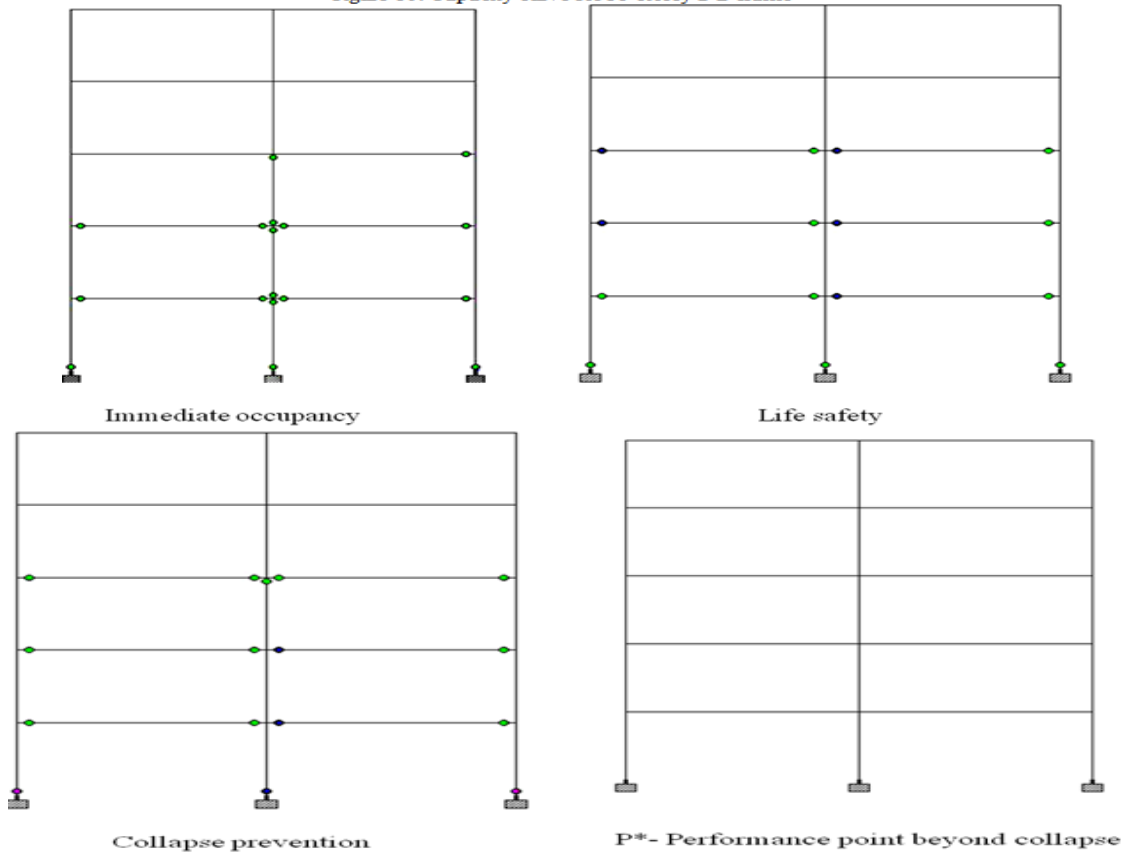


Figure 11: Formation of plastic hinges-5 storey

Level : <=IO , Colour : Green
 Level : <=IO-LS , Colour : Blue
 Level : <=LS-CP , Colour : Magenta
 Level : <=CP , Colour : Red.

Table 2: Results of Displacement, Base shear and Performance Level

Models	Storey level	Displacement in mm	Base shear in kN	Performance level
Solid section	5-storey	496.869	1211.879	IO - LS
	10-storey	501.037	1127.953	IO - LS
	15-storey	500.328	511.839	IO - CP
	20-storey	502.833	369.625	P*
	25-storey	508.349	404.824	P*
	30-storey	533.106	328.047	P*
	35-storey	570.086	323.151	P*
Hollow section-1	5-storey	413.315	2690	IO
	10-storey	500.140	2304.661	IO
	15-storey	502.681	1469.171	P*
	20-storey	503.392	1014.527	P*
	25-storey	511.116	753.338	P*
	30-storey	540.131	601.590	P*
Hollow section-2	5-storey	388.734	3037.833	LS - CP
	10-storey	500.134	2513.278	IO - LS
	15-storey	500.459	1642.466	P*
	20-storey	504.837	1138.995	P*
	25-storey	510.418	840.159	P*
	30-storey	518.374	644.675	P*
Hollow section-3	5-storey	370.616	3279.376	LS - CP
	10-storey	500.549	2648.393	IO - LS
	15-storey	501.966	1784.332	P*
	20-storey	501.785	1123.604	P*
	25-storey	503.858	896.065	P*
	30-storey	511.216	687.266	P*
Hollow section-4	5-storey	352.962	3507.017	IO - LS
	10-storey	500.507	2770.105	IO - LS
	15-storey	500.742	1888.673	P*
	20-storey	505.462	1305.431	P*
	25-storey	504.152	949.701	P*
	30-storey	511.017	728.511	P*
	35-storey	545.327	605.834	P*

Note: Performance levels are as follows,
 IO-Immediate Occupancy,
 LS- Life Safety,
 CP- Collapse Prevention,
 C-Collapse,
 P*- Performance point beyond collapse.

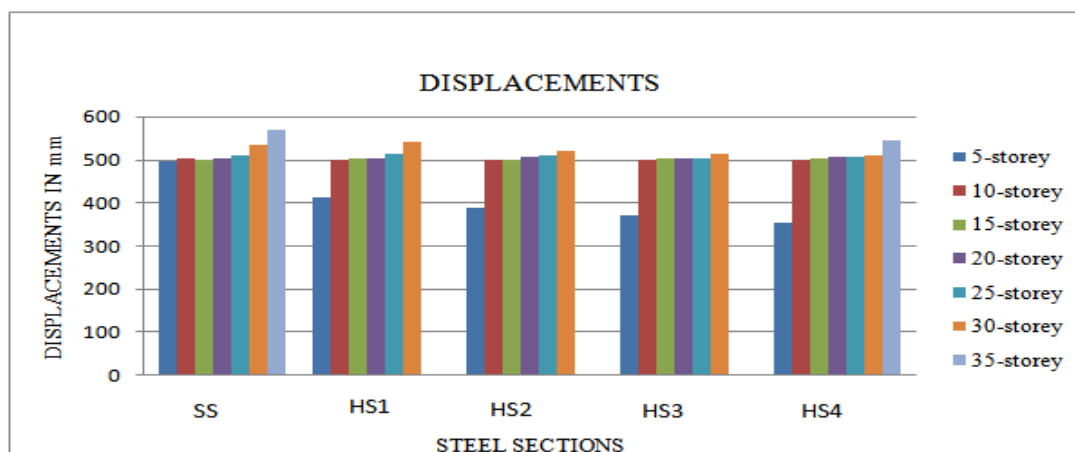


Figure 12: Displacement for various stories

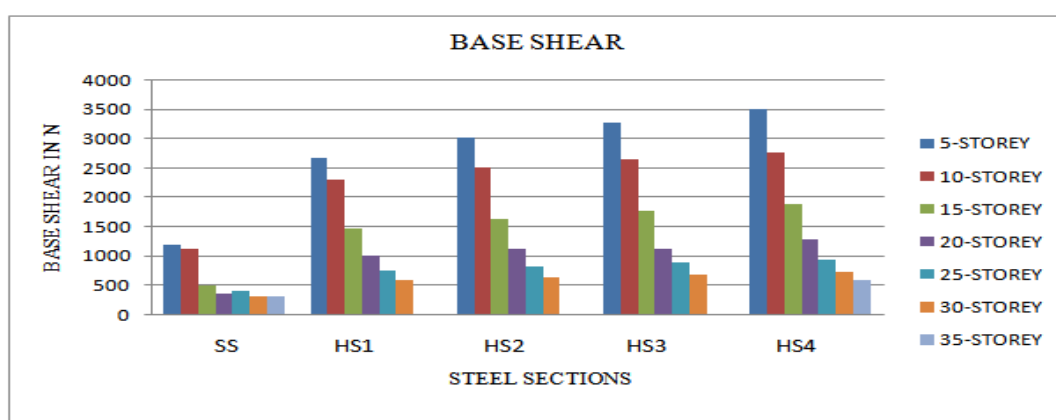


Figure 12: Base shear for various stories

IV. CONCLUSIONS

In this study, 2-D frames are modelled for both solid and hollow sections for various stories with constant bay width and storey height which was analysed by pushover analysis using STAAD.Pro.

- From this study, when the number of storey decrease corresponding base shear increases and also number of storeys increases corresponding displacement increases.
- It is found that the drift to height ratio is limited to 35 stories despite of increased base width.
- The performances of all the solid and hollow section 2-D models are lies in between life safety and collapse prevention. Formations of plastic hinges were maximum when the storey levels are minimum.
- Comparing the results of solid and hollow sections base shear vs. displacement curve indicates that the hollow section is far better than solid sections.
- Effect of lateral displacement for 5-storey 2-D frame with hollow section provides 16.73% reduction when compared with the solid sections.
- Base shear values for 5-storey 2-D frame with hollow section when compared with solid section which is increased up to 54 %.
- When storey level get increased pushover load steps get decreased, so the capacity curve become linear for some models corresponding to its storey level.
- Self weight of both solid and hollow section clearly reveals that the hollow section is having maximum dead weight than solid sections. Comparatively 60% of self weight values get increased in hollow section than the solid section.
- The seismic performance evaluation of a steel building frame is carried out by using pushover analysis accounted for user defined inelastic material behaviour and assigning inelastic effects to plastic hinges at member ends.
- The analytical procedure developed to estimate the inelastic deformations of beams, columns and connections are validated by incorporating the same in pushover analysis. Based on the analysis results it is observed that inelastic displacement of the structure is within the collapse prevention level.

Symbols

E	=	Young's modulus of materials
α	=	Co-efficient of thermal expansion
μ	=	Poisson's ratio
λ	=	Mode shape
u	=	Displacements
I	=	Moment of inertia of section
kN	=	Kilo Newton
mm	=	Millimetres
V	=	Base shear
A	=	Area of building
SRSS	=	Square roots of sum of squares
CSM	=	Capacity spectrum method
PO	=	Pushover
FEMA	=	Federal emergency and management agency
C	=	Critical damping
T	=	Time period
SS	=	Short period
B	=	Base dimensions
SS	=	Solid Section
HS1	=	Hollow Section-1
HS2	=	Hollow Section-2
HS3	=	Hollow Section-3
HS4	=	Hollow Section-4

REFERENCES

- [1]. R. Hasan, L. Xu, D.E. Grierson, (July 2002) "Push-over analysis for performance-based seismic design" *Computers and Structures* 80, P. 2483–2493.
- [2]. D.K. Baros , S.A. Anagnostopoulos, (Oct 2008) "An overview of pushover procedure for the analysis of building susceptible to torsional behaviour". The 14th World Conference on Earthquake Engineering October 12-17, Beijing, China.
- [3]. Cinitha A, Umesha P.K, Nagesh R . Iyer "Evaluation of seismic performance of an existing steel building- pushover analysis approach"
- [4]. T. Hasegawa ,and H. Kamura, (Oct 2008) "Seismic response prediction of steel frames utilizing plastic strain energy obtained from pushover analysis". The 14th World Conference on Earthquake Engineering October 12-17, Beijing, China
- [5]. Anil K. Chopra, and Rakesh K. Goel,(2004) "A modal pushover analysis procedure to estimate seismic demands for unsymmetric-plan buildings" *Earthquake engineering and structural dynamics*, Vol 33, pp. 903–927
- [6]. Bülent AKBAŞ, Jay SHEN, F. İlknur KARA, Ülgen Mert Tuğsal,(may 2003) "Seismic behavior and pushover analyses in steel frames çelik çerçevelerin deprem performansları ve öteleme analizleri" Fifth National Conference on Earthquake Engineering, 26-30 May 2003, Istanbul, Turkey Paper No: AT-053
- [7]. Helmut Krawinkler, and G.D.P.K.Seneviratna,(1988) "Pros and cons of a pushover analysis of seismic performance evaluation" *Engineering Structures*, Vol. 20, pp. 452-464
- [8]. L. Xu, and Y. Liu, (2005) "Nonlinear Analysis of Inelastic Steel Frames" . *Advances in Steel Structures*, Vol. I, pp. 217-224