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# Seismic Behaviour and Pushover Analysis of Steel Frames

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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 proposed analysis technique is illustrated for two steel frameworks of solid and hollow member properties.This investigation studies aim to analyse the comparison between hollow and solid frames. The technique is based on the conventional displacement method of elastic analysis. The analytical procedure developed is 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.

**Key words:** Seismic Performance · Pushover · Non-linear · Performance levels · Steel frame · Capacity Curves

## 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 [1]. 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 [2].

**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 [3].

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 trainer 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

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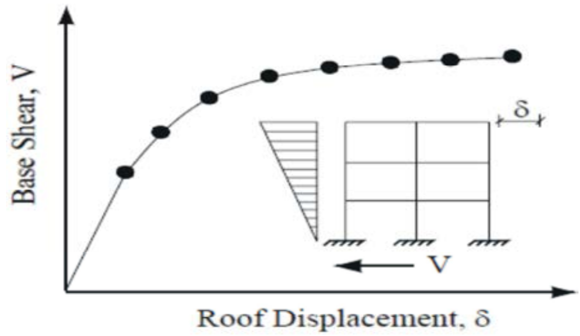


Fig. 1: Design capacity curve

Table 1: Input parameters for both sections

| 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 |

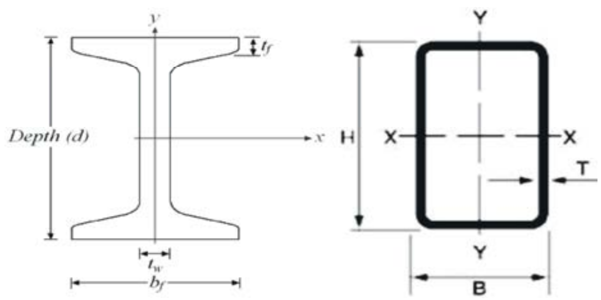


Fig. 2: Cross section of both Solid and Hollow sections

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 [4].

**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 [5]. The frames are assumed to be firmly fixed at the bottom and the soil–structure interaction is neglected. The input parameters for the model geometry for both solid and hollow sections are given in Table 1.

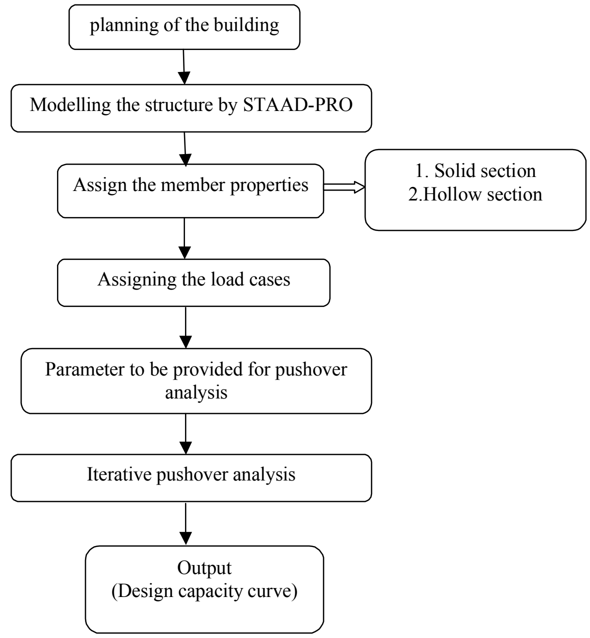


Fig. 3: Pushover analysis methodology

**Material Properties for Both Solid and Hollow Sections:** Figure 2 shows the cross section of the solid and hollow sections

| | | |
|---|---|---|
| Young's modulus of material (E) | = | $2.05 \times 10^8$ kN/m$^2$ |
| Poisson ratio (nu) | = | 0.3 |
| Density | = | 76.8195kN/m$^3$ |
| Thermal expansion | = | $1.2 \times 10^{-5}$ |
| Critical damping | = | 0.03 |

**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 [6].

## 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 is due to difference in the applied lateral force and its estimation. In this paper, the lateral forces have 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.

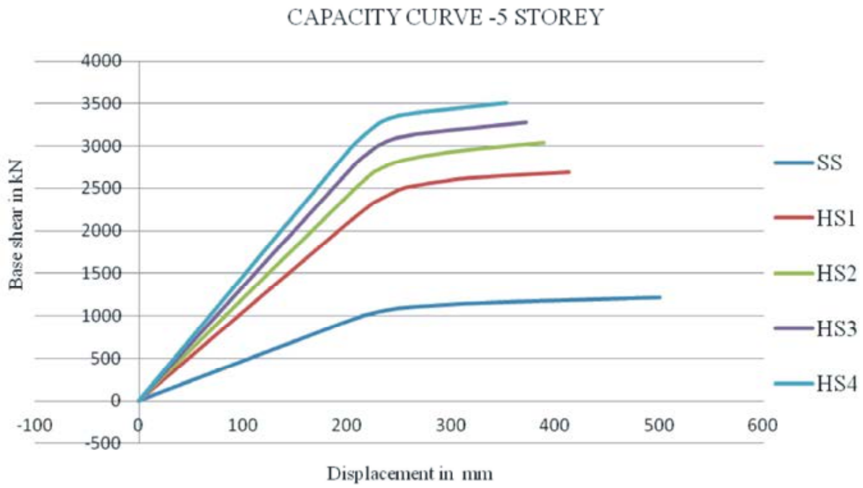


Fig. 4: Capacity curve for 5-storey 2-D frame

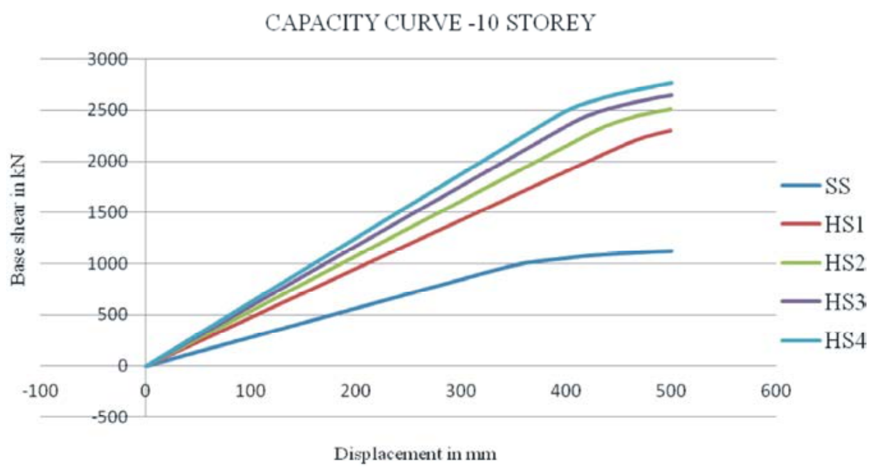


Fig. 5: Capacity curve for 10-storey 2-D frame

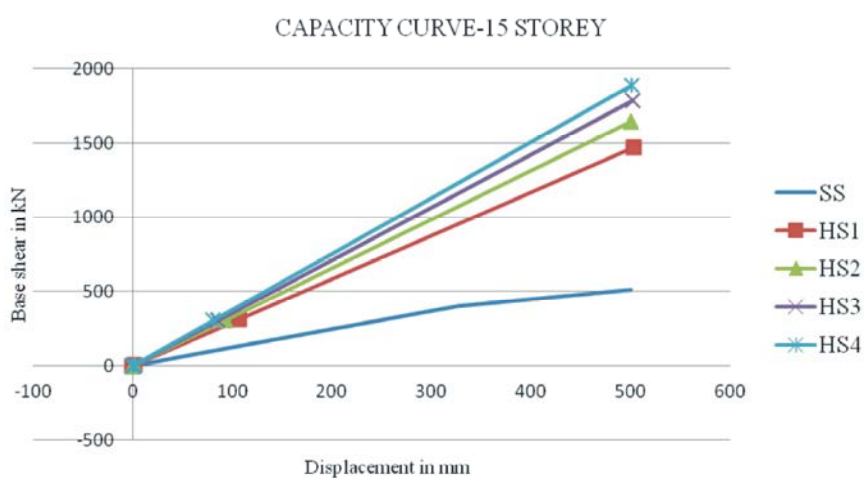


Fig. 6: Capacity curve for 15-storey 2-D frame

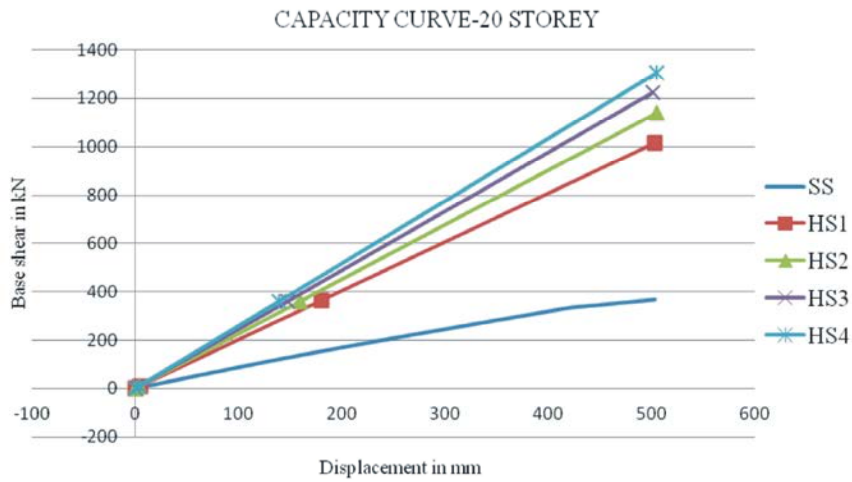


Fig. 7: Capacity curve for 20-storey 2-D frame

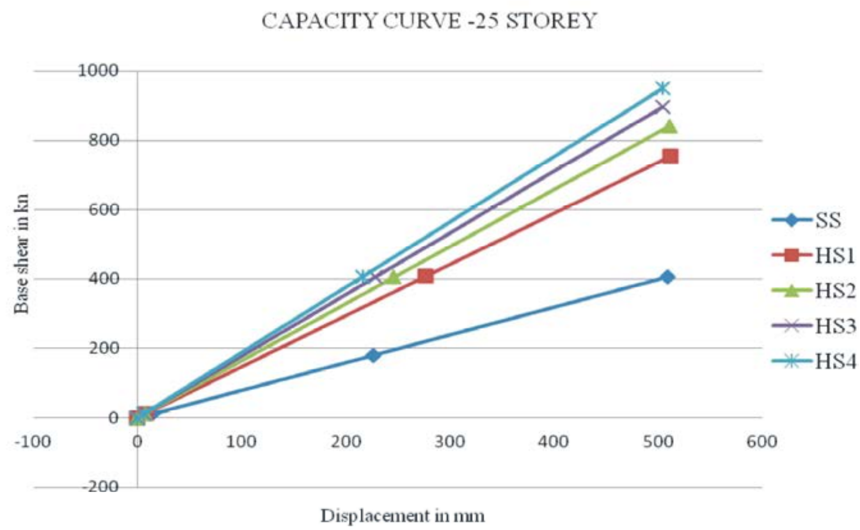


Fig. 8: Capacity curve for 25-storey 2-D frame

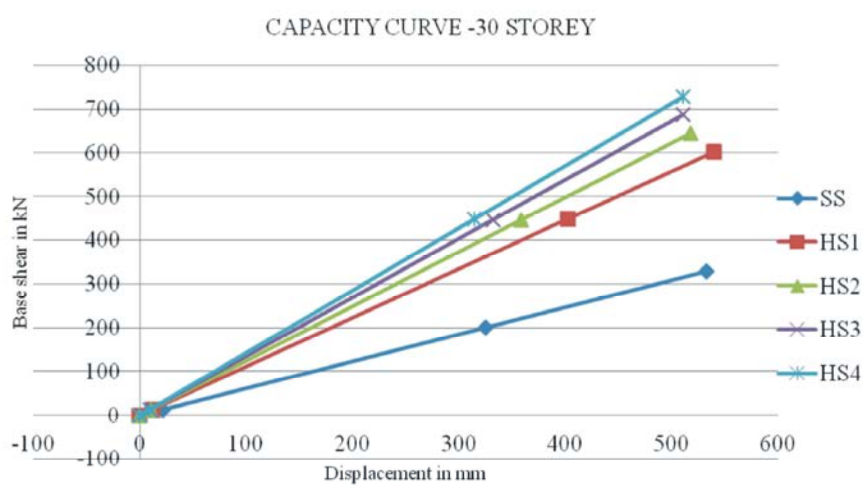


Fig. 9: Capacity curve for 30-storey 2-D frame

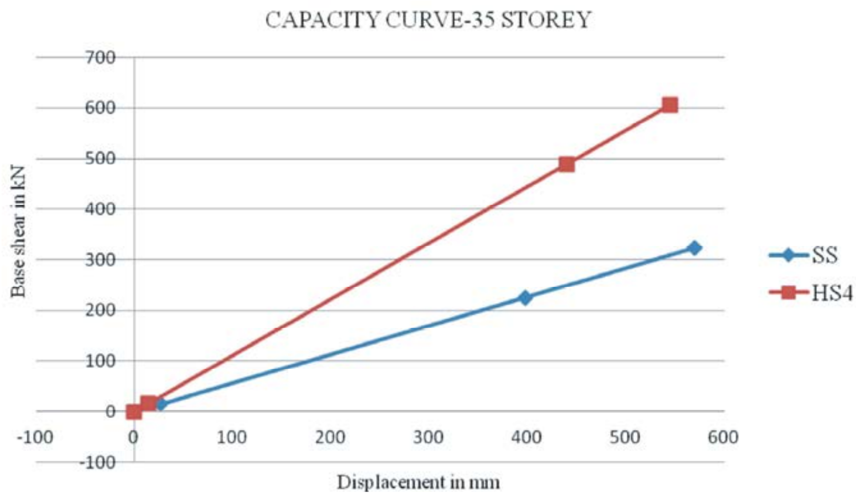


Fig. 10: Capacity curve for 35-storey 2-D frame

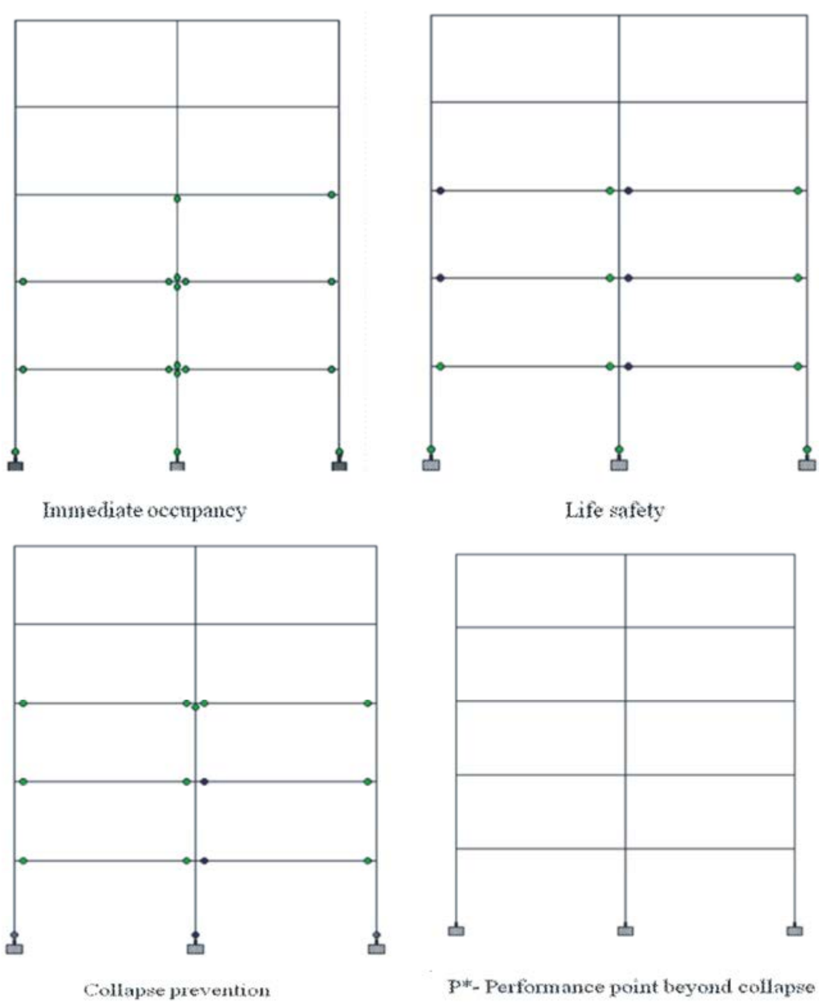


Fig. 11: Formation of plastic hinges-5 storey
Level: <=IO, Colour: Green  Level: <=IO-LS, Colour: Blue
Level: <=LS-CP, Colour: Magenta  Level: <=CP, Colour: Red.

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.

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 [7].

The displacement and the base shear are shown in Figure12 and 13. Effect of lateral displacement for 5-storey 2-D frame with hollow section provides 16.73% reduction when compared with the solid sections [8]. Base shear values for 5-storey 2-D frame with hollow section when compared with solid section which is increased up to 54 %.

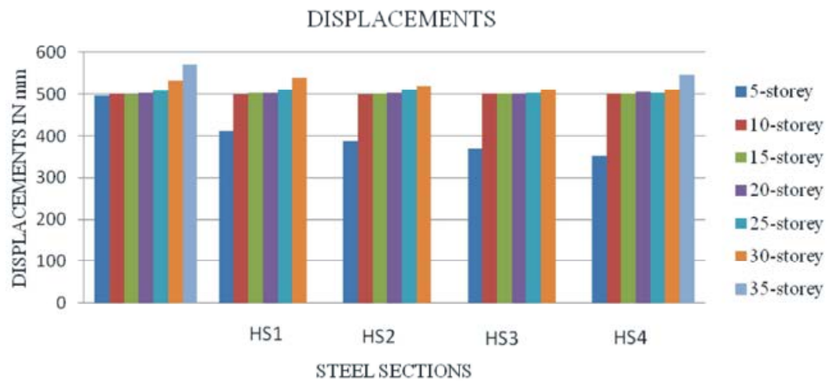


Fig. 12: Displacement for various stories

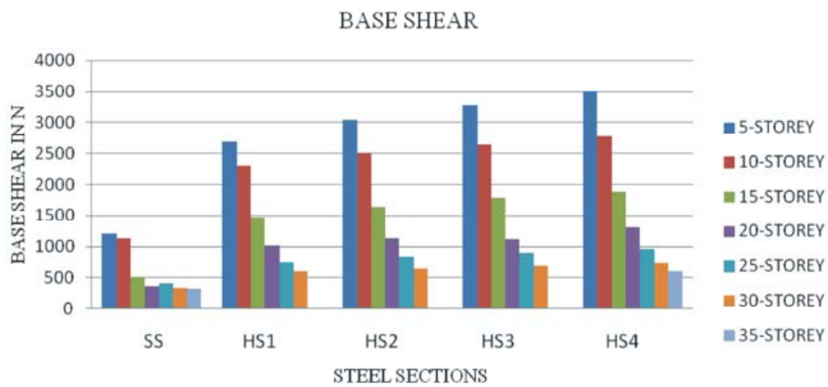


Fig. 13: Base shear for various stories

## CONCLUSION

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.

- When the number of storey decreases corresponding base shear increases and also number of storeys increases corresponding displacement increases [9].
- 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 lie in between life safety and collapse prevention. Formation of plastic hinges was 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 [10].
- 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.

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