

# **A Performance Based Evaluation of a Wall-Frame Structure Employing the Pushover Analysis Tool**

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**ABSTRACT:** In this study a performance based assessment of 2D concrete shear wall-steel framed structures subjected to 3 lateral load patterns has been made. The nonlinear behaviour has been carried out using default plastic hinges in accordance with ASCE41-13. The analysis has been carried out on structures with varying aspect ratio accompanied with a varying elastic lateral stiffness ratio of the shear wall with respect to the frame. Structures subjected to a uniform lateral load pattern exhibited a larger base shear and lower roof displacement at performance in comparison with its first mode shape and code specified lateral load pattern.

**KEYWORDS:** Stiffness Ratio, Load Pattern, Performance.

## **I. INTRODUCTION**

The Indian sub-continent is no stranger to earthquakes due to the rate at which the Indian plate is driving into Asia. This makes 54% of our land vulnerable to earthquakes and it is this statistic that makes earthquake engineering vital. Most building codes give us a linear method of analysis for earthquake loads although it is an established fact that structures move into a nonlinear behaviour during an earthquake activity and hence these linear methods fail to give us an estimate of the building demands during an earthquake. With the advent of performance based design of structures, nonlinear behaviour of structures is given more importance and this technique helps us better understand the seismic demands on a structure. The nonlinear static pushover procedure can be considered as a simplified non-linear analysis method in which the dynamic load is substituted by a gradually increasing (static) lateral load.

## **II. RELATED WORK**

The nonlinear static pushover analysis has multiple purposes besides a performance based evaluation of a structure. It is used to evaluate/verify the overstrength ratio values used to calculate the response reduction factor of a structure (A. Mondal et al. [1], D. M. Patil, K. K. Sangle [2] and M. Izadinia et al. [3]). It is used to estimate the plastic mechanisms and distribution of damage in a structure during seismic activity. It is used to assess the structural performance of existing or retrofitted buildings (Ismail [4]).

## **III. DESCRIPTION OF MODELS**

All models considered in this study are 2D wall-frame structures comprising of 3 bays (Fig.1). The bay width has been adjusted in the models in order to attain the required elastic lateral stiffness ratio of the concrete shear wall ( $K_{SH}$ ) with respect to the steel frame ( $K_{SF}$ ). For simplicity, the models have been assumed to be fixed at the base. The aspect ratio (height of the structure with respect to its base width) has been varied from 2.0 to 4.5 in steps of 0.5 by keeping the base width constant at 12 m and varying its height. The stiffness ratio is varied from 0.5 to 3.5. Grade of steel used is Fe250 whereas the concrete grade varies with the aspect ratio. Typical storey height is assumed to be 3m.

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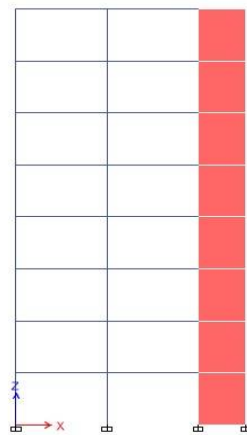


Figure 1: Typical models considered in the study.

## GRAVITY LOADING

Each structure has been designed using IS800:2007[5] for the various load combinations specified in the Indian standards. The slab is considered to be of concrete with thickness 120mm. A floor finish of 1kN/m<sup>2</sup> has been assumed along with a live load of 3 kN/m<sup>2</sup>. The structures were assumed to be located in Zone IV with all three soil types according to IS1893 (part-1):2002 [6] under consideration. ISMB250 has been used as beam sections for all aspect ratios while ISWB350, ISWB400, ISWB450, ISWB500, ISWB550 and ISWB600-1 have been used as column sections for aspect ratio 2.0, 2.5, 3.0, 3.5, 4.0 and 4.5 respectively. Unit weight of concrete is assumed to be 25 kN/m<sup>3</sup> and of masonry to be 20 kN/m<sup>3</sup>.

## NONLINEAR SIMULATION

Default hinges in accordance with ASCE41-13 [7] have been assigned to the structural elements in order to carry out the nonlinear behaviour. For beam elements, plastic hinges governed by the major axis bending have been assigned at its two ends whereas for columns, plastic hinges governed by the interaction of the axial force and biaxial bending moments is assigned at both of its ends. Shear walls have been modelled to yield based on the interaction of its axial force and major axis bending moment.

## LATERAL LOAD PATTERNS

Three different load patterns have been employed in this study. A load pattern consistent with the structures first mode shape (load case 1), a load pattern consistent with IS1893 (part-1):2002 (eq.2) (load case 2) and a uniform lateral load pattern (eq.3) (load case 3). The base shear is calculated with the help of IS1893 (part-1):2002. The equations used to calculate the distribution of the base shear for these load patterns are as follows:

$$V_B = A_h W \quad (1)$$

$$Q_i = \frac{V_B W_i h_i^2}{\sum_{j=1}^n W_j h_j^2} \quad (2)$$

$$Q_i = \frac{V_B W_i h_i}{\sum_{j=1}^n W_j h_j} \quad (3)$$

Where,

$V_B$  - Design seismic base shear as per IS1893 (part-1):2002

$A_h$  - Design horizontal acceleration spectrum value

$W_i$  - Seismic weight at floor i

$h$  - Height of the floor

$Q_i$  - Design lateral force at floor i

IV. SEISMIC PERFORMANCE

**CAPACITY CURVES**

In this study seismic demands such as base shear and roof displacement at performance are evaluated by utilizing the guidelines set by FEMA440 [8]. The target displacement is fixed at 4% of the height of the structure (ATC-40[9]). A  $P-\delta$  effect has been incorporated in the study considering the geometric nonlinearity parameter. The pushover analysis is carried out after the application of gravity loads with the help of commercially available ETABS [10] software. Pushover curves as well as the distribution of the base shear and roof displacement at performance with respect to the stiffness ratio ( $K_{SH}/K_{SF}$ ) has been plotted.

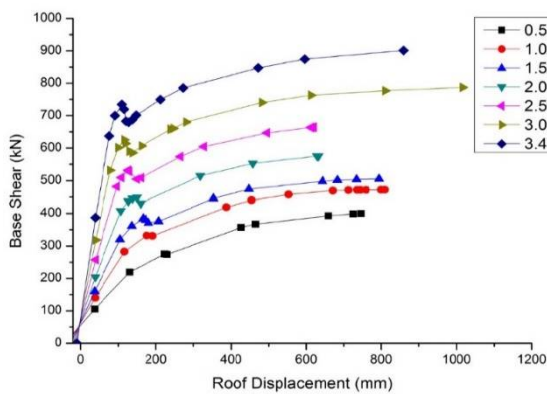


Figure 2: Capacity curves in aspect ratio 4.0 for load case 1.

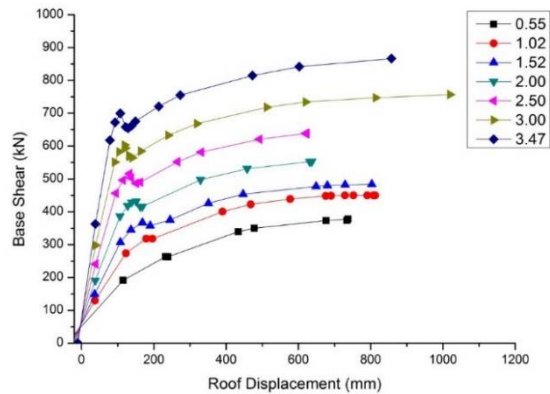


Figure 3: Capacity curves in aspect ratio 4.0 for load case 2.

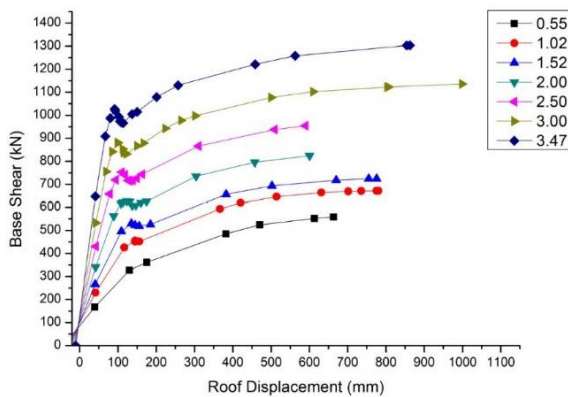


Figure 4: Capacity curves in aspect ratio 4.0 for load case 3.

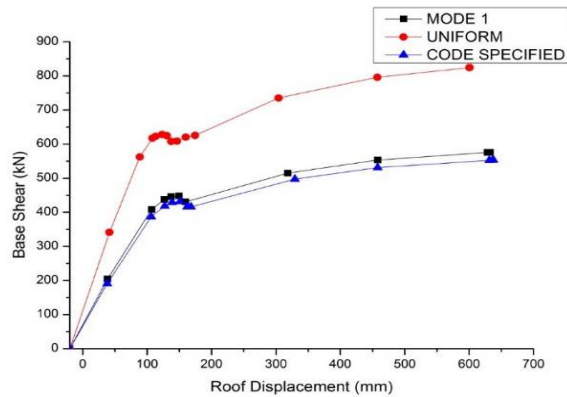


Figure 5: Comparison between the capacity curves within aspect ratio 4.0 for a stiffness ratio of 2.00.

Figures 2, 3 and 4 show the capacity curves for aspect ratio 4.0 with the varying stiffness ratios. In general, as the stiffness ratio ( $K_{SH}/K_{SF}$ ) increases the initial slope of the capacity curve begins to increase. This behaviour is observed in all the three types of load cases under consideration and is due to the fact that as the stiffness ratio increases the overall stiffness of the structure also increases. The degree of rotation as well as the location of formation of plastic hinges is similar in all three load cases under consideration. Fig. 5 shows us a comparison between the pushover curves for an aspect ratio of 4.0 and a stiffness ratio of 2.00. It can be observed that for the uniform load pattern, the structure exhibits a higher initial stiffness in comparison to the other two load cases. This is observed in all the stiffness ratios in the study. A pushover carried out using the code specified lateral load pattern and the structure's first mode of vibration show a similar behaviour.

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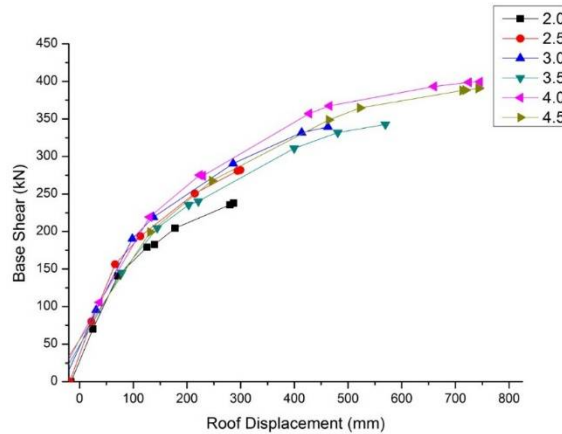


Figure 6: Comparison between capacity curves for a stiffness ratio of 0.5.

Fig. 6 shows the capacity curves for a stiffness ratio of 0.5 subjected to load case 1 for all aspect ratios under consideration. The structures exhibit a similar initial stiffness. However, its post yield ductility varies with the aspect ratios under consideration. In general it increases with the aspect ratio.

## BASE SHEAR AND ROOF DISPLACEMENT AT PERFORMANCE

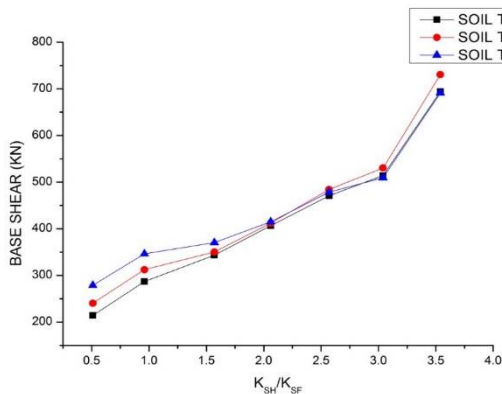


Figure 7: Base shear vs stiffness ratio in aspect ratio 3.5 for load case 1.

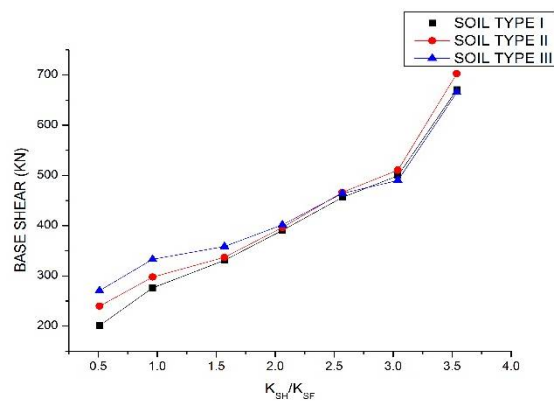


Figure 8: Base shear vs stiffness ratio in aspect ratio 3.5 for load case 2.

Fig. 7, 8 and 9 shows the distribution of base shear at performance with respect to the stiffness ratio under consideration. The plots are similar for load case 1 and 2. However a pushover based on the uniform load pattern gives a higher base shear at performance (Fig.10). This is due to the higher lateral stiffness obtained from the capacity curves (Fig.5).

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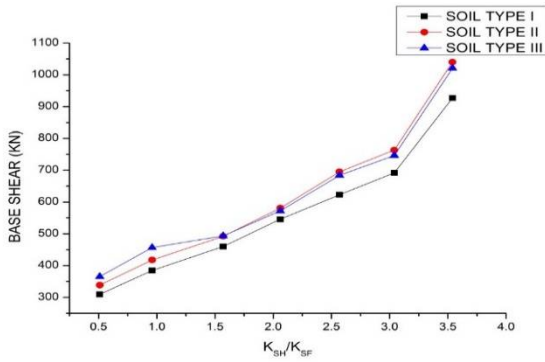


Figure 9: Base shear vs stiffness ratio in aspect ratio 3.5 for load case 3.

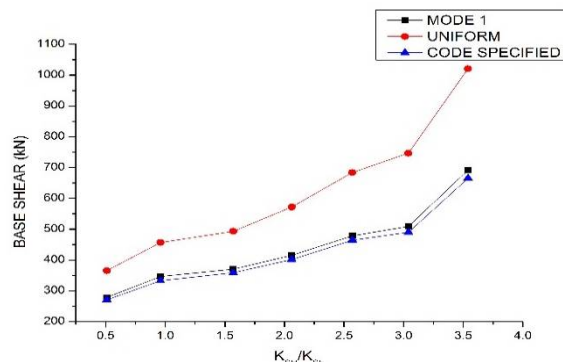


Figure 10: Comparison of base shear vs stiffness ratio in aspect ratio 3.5 for all three load patterns.

Upto a stiffness ratio of 2.01, the base shear is higher in soil type III followed by soil type II and soil type I in load case 1 and 2. However in load case 3, beyond a stiffness ratio of 1.57 the structures begin to exhibit a higher base shear in soil type II followed by soil type III and soil type I. This behaviour is attributed to the spectral acceleration vs spectral displacement graph wherein the single demand obtained using the guidelines set by FEMA 440 meets the capacity spectrum in the regions with negative slope. Load case 3 shows a 38.85% increase in base shear at performance in comparison to load case 1; whereas load case 2 shows a 3.55% reduction in base shear at performance in comparison to load case 1. This kind of behaviour is observed in all the aspect ratios under consideration.

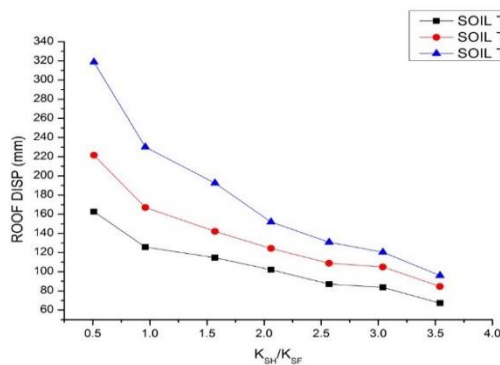


Figure 11: Roof displacement vs stiffness ratio in aspect ratio 3.5 for load case 1.

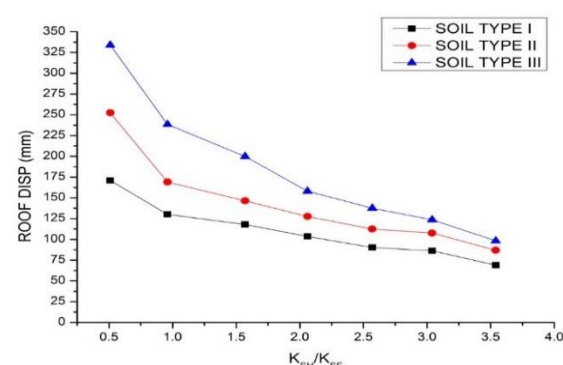


Figure 12: Roof displacement vs stiffness ratio in aspect ratio 3.5 for load case 2.

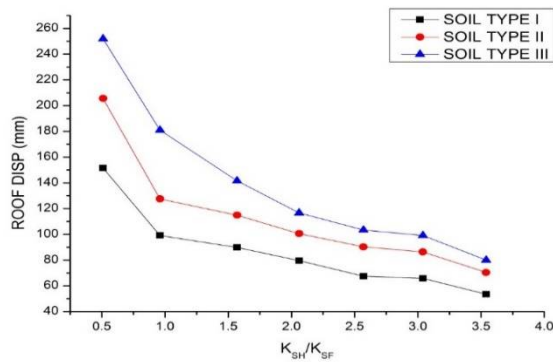


Figure 13: Roof displacement vs stiffness ratio in aspect ratio 3.5 for load case 3.

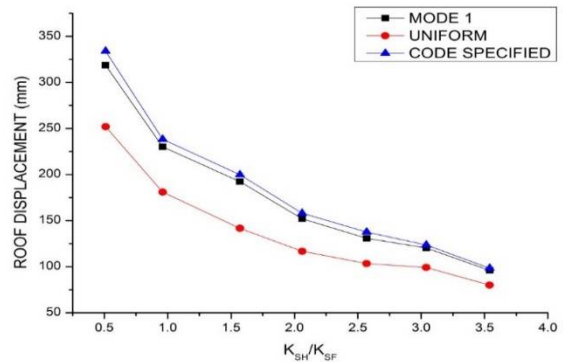


Figure 14: Comparison of roof displacement vs stiffness ratio in aspect ratio 3.5 for all three load cases.

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As the stiffness ratio increases, the roof displacement at performance decreases in all the three load cases under consideration (Fig. 11, 12 and 13). This is due to the increase in the overall stiffness of the structure. Load case 3 shows a reduction in roof displacement of about 19% in comparison to load case 1. This is attributed to the higher initial slope of the capacity curves for load case 3 in comparison to load case 1 and 2. Load case 2 shows an average increase in roof displacement of 4.18% in comparison to load case 1 due to the lower initial slope of exhibited in its capacity curves (Fig. 14).

## V. CONCLUSIONS

The following conclusions have been drawn by carrying out the nonlinear static analysis of the structures in this study:

1. Variation in soil type and zones do not affect the capacity curves of a structure when the code specified lateral load pattern is employed.
2. The structures exhibit a similar initial stiffness in the capacity curves for a specific stiffness ratio. However, their post yield behaviours vary with the aspect ratio.
3. The locations and states of the plastic hinges formed in a structure are similar when pushed in a load pattern consistent with its first mode shape, code specified lateral load pattern and the uniform lateral load pattern.
4. Structures subjected to a uniform lateral load pattern exhibit a higher initial stiffness in its capacity curves when compared to the lateral load consistent with the first mode shape and the code specified lateral load pattern yet, the post yield behaviour remains the same.

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