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Parametric Modelling and Analysis of RC Shear Walls in Moment Resisting Framed Hill Buildings

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Abstract: In steep terrain, framed buildings present more complex structural behavior than conventional buildings. These buildings' asymmetrical structures have vertical irregularity, as the centers of mass and stiffness differ at different floor levels. When exposed to seismic loads, these structures are drawn to significant shear forces and torsional moments. The significant damage in buildings is restrained against lateral distortion by RC shear walls. Not only are the placement and design of shear walls crucial for their practical function, but they also have a big impact on how well the building will hold up structurally. This study investigates the influence of shear wall placement on the seismic performance of two hill building configurations: Stepback and Stepback-setback layouts. Shear walls were positioned at corners, mid-edges, and the center of the buildings, with all 36 models analyzed using Equivalent Static and Response Spectrum methods. The key dynamic parameters—including fundamental time period, storey drift, storey shear, and column shear forces at the foundation level—were evaluated and compared. To ensure consistency across geometric variations and slope orientations, the volume and number of shear walls were kept constant. The parametric study also explores the effect of building size on seismic response.

Keywords: Stepback and Stepback-setback; Hill building; RC Shear wall; Irregular buildings; Dynamic analysis.

1. Introduction

Buildings constructed on sloping terrain in hilly regions exhibit more intricate structural behavior compared to traditional buildings. Due to their asymmetrical design, these structures display vertical irregularities, with the center of mass and stiffness shifting across different levels. Consequently, these buildings endure heightened shear forces and torsional moments when subjected to seismic loads. Additionally, the columns on the uphill side, being shorter yet stiffer, encounter greater shear forces compared to their downhill counterparts. Historical seismic events have revealed that reinforced concrete buildings incorporating shear walls tend to experience lower to moderate damage in comparison to regular framed buildings facing similar earthquake forces. Shear walls play a vital role in absorbing a significant portion of lateral forces stemming from both wind and seismic activity. These walls can be integrated into stairwells or take the form of concrete elevator shafts. The placement and design of shear walls are critical not only for their functional purpose but also for the overall structural response of the building.

Over the past few decades, there has been a flurry of research studies presenting diverse mathematical models for earthquake analysis of buildings situated on hilly terrain. Noteworthy among these are the works of Cheung and Tso [1] and Shahrooz and Moehle [2], which delve into both analytical and experimental investigations concerning seismic design strategies for setback buildings. Paul [3] put forth a straightforward one-dimensional approach for dynamically analyzing buildings with asymmetry. A distinct method of analysis was introduced by Kumar and Paul [4, 5], where each floor of the building was represented with three degrees of freedom (D.O.F.) per story, assuming rigid floor diaphragms. The results were juxtaposed with prescribed code provisions. Extending this, Kumar [6], alongside Kumar and Paul, introduced a three-dimensional modeling technique for dynamically analyzing uneven hill structures, incorporating three D.O.F. per floor. This was contrasted with the more rigorous method employing six D.O.F. per floor [7, 8]. Birajdar and Nalawade [9] conducted an analysis and parametric comparison of dynamic attributes among hill buildings, offering suggestions on their suitability. Singh et al. [10] harnessed Time History analysis to assess linear and non-linear seismic traits along and across the slopes of stepback buildings situated on steep vertical cut slopes. The parameters derived from this study were aligned with the damage patterns observed in a real-life case of a hill building damaged during the Sikkim earthquake of 2011. In parallel, Mohammad et al. [11, 12, 13] delved into the behavior of hill buildings when subjected to earthquakes, ultimately concluding that configurations involving stepback-setback designs exhibited superior resistance compared to simple stepback building layouts under seismic loads. Additionally, the impact of base isolation on the seismic performance of hill buildings was subjected to examination [18, 19].

Shear walls provide a cost-effective solution for countering seismic lateral forces in tall buildings. In terms of their structural behavior, these lateral forces are predominantly resisted through flexural resistance rather than shear actions. A well-devised shear wall system within a building significantly enhances its seismic performance. Previous research has streamlined the modeling and analysis of structural systems featuring shear walls, thereby assessing the buildings' seismic reactions. Medhekar and Jain [14] extensively examined the seismic behavior, failure modes, and factors impacting structural responses due to shear walls. Wallace [15] introduced an analytical method to ascertain the necessity for transverse reinforcement in reinforced concrete structural walls of varying cross-sectional designs. The study determined that the strain distribution within shear walls is notably influenced by their aspect ratios, configurations, and reinforcement levels. Patel et al. [16] and Mohammad et al. [17] scrutinized and deliberated upon the effects of diverse column arrangements on the seismic response of reinforced concrete frame structures situated on sloping terrain. These structures incorporated shear walls in different positions. The study demonstrated that the presence of shear walls substantially alters the overall structural behavior and significantly diminishes seismic parameters compared to models lacking shear walls.

Prior investigations have extensively delved into the behavior of hill buildings, yet only a limited number of inquiries have delved into the effects of shear walls on the seismic resilience of such structures. The placement of shear walls within a structure significantly influences its overall response when confronted with seismic forces. Generally, shear walls are symmetrically incorporated, which mitigates the generation of torsional forces and moments stemming from structural asymmetry. Consequently, it becomes crucial to analyze buildings with vertical irregularities, such as hill constructions. Due to varying center of mass at each level, these buildings exhibit considerable torsional eccentricity under lateral loads. Therefore, investigating the seismic response of hill buildings with shear walls positioned at various locations within the structure is imperative in determining the most optimal arrangement for constructions on sloping terrain. Both stepback and stepback-setback configurations have been geometrically simulated with shear walls situated at three distinct points: corners, mid-edges, and the building's center. These models have also been varied in terms of height and length to discern any alterations in seismic outcomes. Furthermore, for a more meaningful assessment of position suitability, the volume and quantity of shear walls were maintained equivalent across different geometric variations and various hill slope orientations.

2. Materials and Methods

This study explores how the inclusion of reinforced concrete shear walls influences the seismic response of two hill building configurations: stepback and stepback-setback designs. The buildings were systematically varied to analyze seismic responses as the building's length increased along the hill slope. All configurations were represented in three dimensions, both without shear walls (bare frame) and with their incorporation. Seismic analyses were conducted using the Equivalent Static and Response Spectrum methods, employing the SRSS combination in finite element software. Essential dynamic metrics, such as the fundamental time period (FTP), storey displacement, story drift, story shear, and base shear at the foundation level, were assessed along with the hill slope and across directions. These findings were then juxtaposed with their respective configurations lacking shear walls. The seismic parameters were assessed following the guidelines of IS 1893 (Part 1) [17].

2.1. Modelling of bare frame configurations

Two distinct bare frame models, namely step-back and step-back setback configurations, were subjected to analysis. All models shared a common ground inclination of 26 degrees and were characterized by identical geometric and material properties (refer to Fig. 1 and Table 1). The concrete material was assumed to possess homogeneity, isotropy, and elasticity, featuring a concrete modulus of elasticity measuring 25000 MPa, accompanied by a Poisson's ratio of 0.2. In the analysis, the yield stress of the reinforcing steel was set at 415 MPa. Beam and column members were uniformly represented as beam elements, while the floor system in all configurations was simulated as a rigid frame diaphragm. To account for torsional effects and accidental eccentricity, the analysis adhered to the guidelines outlined in IS 1893 (Part 1): 2002. Both hill building configurations were subjected to geometric alterations in length along the hill slope, while maintaining a consistent width of four bays. The slab thickness remained uniform at 125 mm across all floors in every model. Moreover, variations in the length of both configurations along the slope ranged from four bays (each measuring 6 meters) to eight bays, incrementing by one bay at each stage (as illustrated in Figs. 5 and 6).

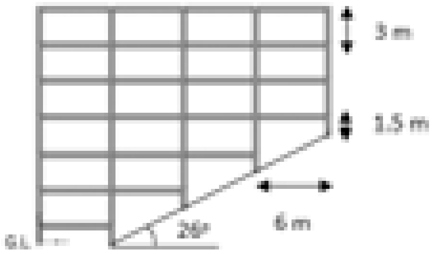


Fig. 1 Typical finite element model of a hill building

2.2. Modelling of configurations with Shear Walls

Shear walls play a significant role in withstanding a substantial portion of lateral forces generated by wind or earthquakes. The placement of shear walls within a structure holds sway over its overall response. In the case of hill building designs, such as step-back and step-back setback configurations, these have been simulated with shear walls positioned at three distinct locations. Within the analytical framework, the shear wall is represented as a reinforced concrete bar-bell shaped element (refer to Fig. 2) crafted from M 25 grade concrete, utilizing four-node shell elements. This shear wall is 150 mm thick and incorporates a minimum reinforcement percentage of 0.25 percent. The positioning of the shear walls follows three approaches: at corners, along the middle of edges, and at the center of the building (depicted in Fig. 3). In order to ensure equitable comparison and maintain an economically feasible perspective, the surface area and volume of shear wall within each category remain consistent.

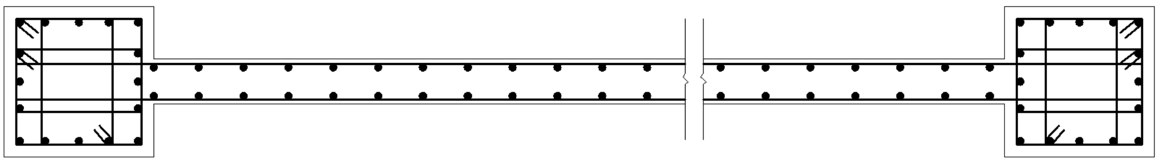
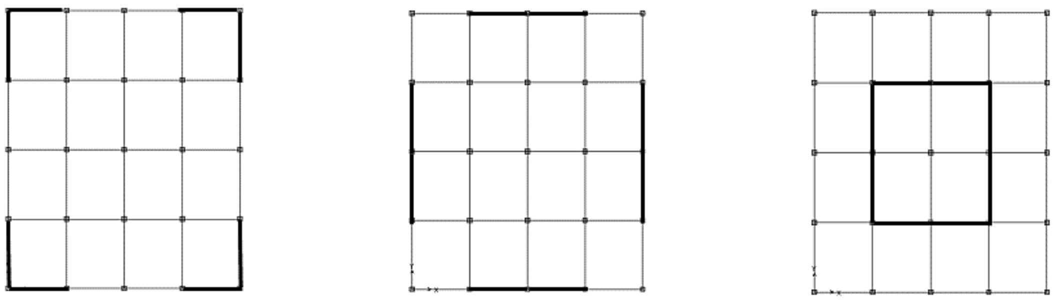


Fig. 2 Typical section of a bar-bell shaped shear wall



(a) At corners (b) At mid-edge (c) At centre

Fig. 3 Different positions of shear walls

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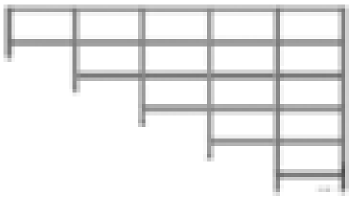
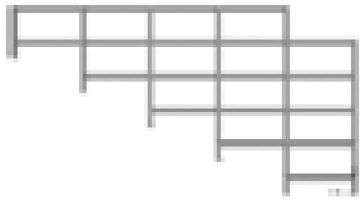
Table 1: Geometrical properties of hill building configurations

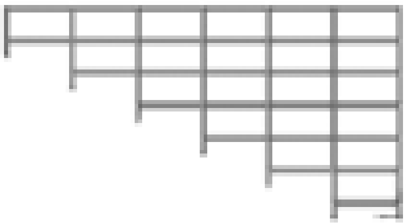
Building configuration	Parametric variation	Model designation				Column size	Beam size
		Bare frame	Frame with shear wall				
			In corners	In middle	In centre	(*mm*)	(*mm*)
Step-back	4 to 8 bays	BSTEPALS	WCRSTEPALS	WMDSTEPALS	WCESTEPALS	up to 5: 400×400 from 6 to 8: 450×450	along slope: 300×500 across slope: 300×450
Step-back setback	4 to 8 bays	BSETALS	WCRSETALS	WMDSETALS	WCESETALS	all: 400×400	



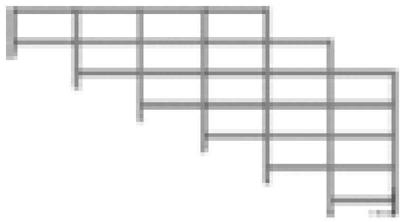
BSTEPALS 5



BSETALS 5



BSTEPALS 6



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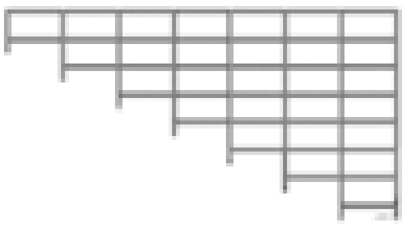
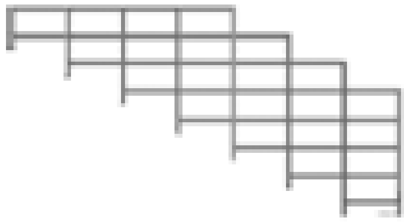


BSTEPALS 7



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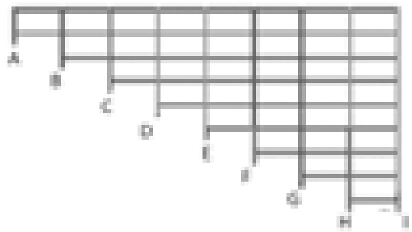
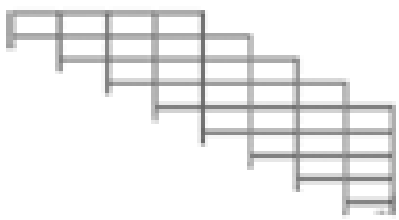


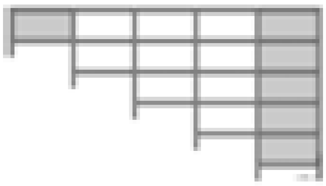
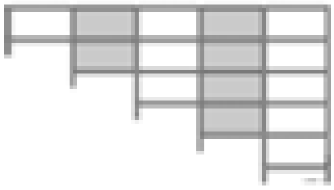
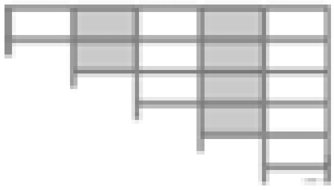
BSTEPALS 8



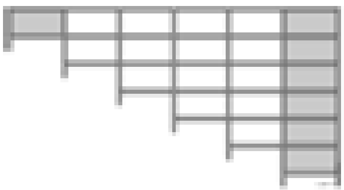
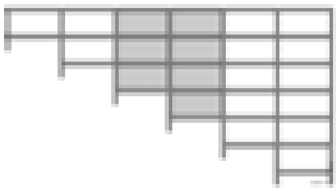
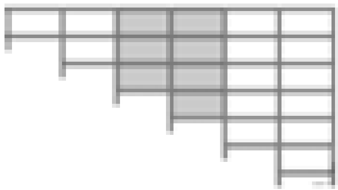
BSETALS 8

(b) (c)

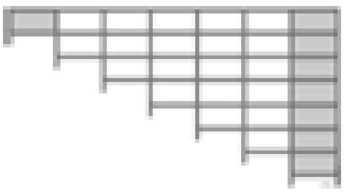
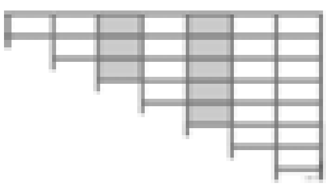
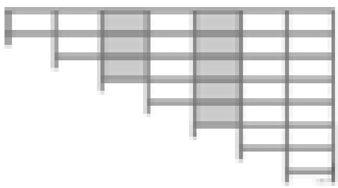
Fig. 4 Bare frame models; (a) step-back configuration varied in length and (b) step-back setback configuration varied in length

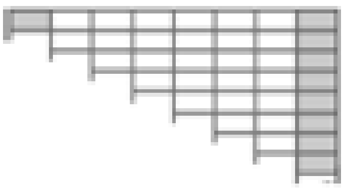
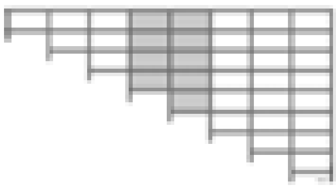
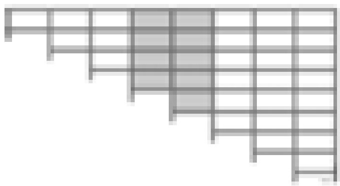
WCRSTEPALS 5 WMDSTEPALS 5 WCESTEPALS 5

WCRSTEPALS 6 WMDSTEPALS 6 WCESTEPALS 6

WCRSTEPALS 7 WMDSTEPALS 7 WCESTEPALS 7

WCRSTEPALS 8 WMDSTEPALS 8 WCESTEPALS 8

(a) At corners (outer frame) (b) At mid-edge (outer frame) (c) At centre (inner frame)

Fig. 5 Step-back buildings with varying length (bays) along slope

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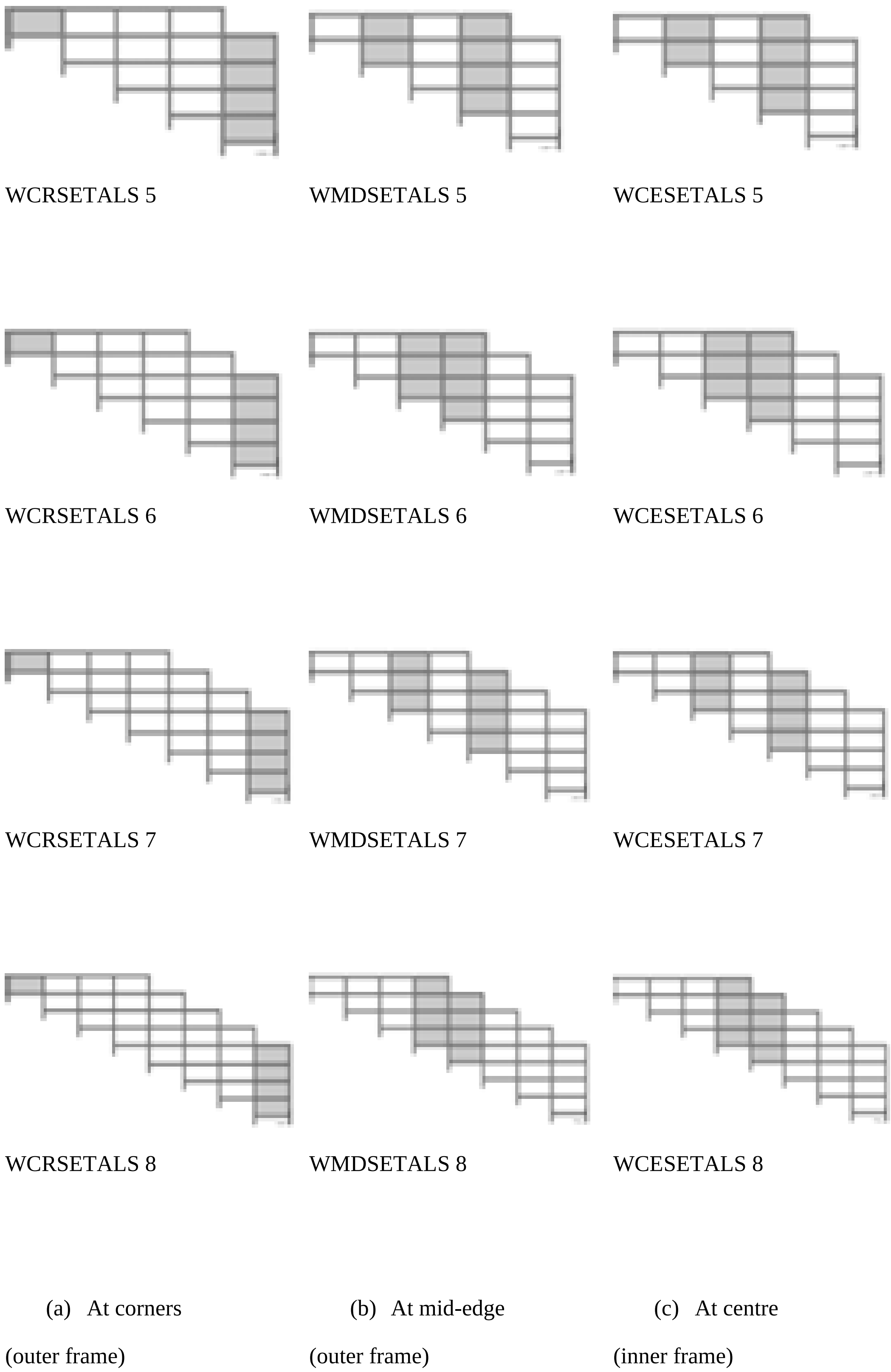


Fig. 6 Step-back setback buildings with varying length (bays) along slope

3. Discussion of results

This study examines the influence of shear wall placement on the seismic performance of two distinct hill building configurations. A total of 36 structural models were developed, incorporating shear walls positioned at three strategic locations: building corners, mid-edges, and central cores. To evaluate the impact of geometric variation, these models were systematically altered in terms of height and length. For consistency and comparative analysis, the volume and number of shear walls were maintained uniformly across all configurations and slope orientations. The investigation aims to identify the most effective shear wall placement strategy for enhancing seismic resilience in hill structures subjected to varying topographic and geometric conditions.

3.1. Seismic behaviour of Step-back configuration

Both bare frame models and models with shear walls are varied in length from 4 bays to 8 bays in along hill slope direction and keeping the width of the building fixed in across hill slope to 4 bays. The dynamic parameters obtained in the analysis are discussed below:

Under seismic loading along the slope direction, the introduction of shear walls significantly improved dynamic performance. Models with corner shear walls (WCRSTEPALS 8) showed a 21.9% reduction in time period and a 52.56% decrease in top storey displacement compared to the bare frame (BSTEPALS 8). Mid-edge shear wall models (WMDSTEPALS 8) achieved 74.18% of the bare frame's time period and 43.12% of its displacement. The most effective configuration was with centrally placed shear walls (WCESTEPALS 8), yielding the lowest time period of 0.247 seconds and top storey displacement of 11.71 mm (Table 2 to 5).

The dynamic response of models under seismic loading across the slope direction (Tables 6 to 9) shows increased time periods and top storey displacements compared to along-slope excitation. For corner shear wall models (WCRSTEPALS 8), the time period and displacement are 66.03% and 44.57% of the bare frame (BSTEPALS 8), respectively. Mid-edge shear wall models (WMDSTEPALS 8) exhibit further improvement, with values of 0.455 seconds and 18.48 mm. Central shear wall models (WCESTEPALS 8) achieve the greatest reduction, with time period and displacement at 58.55% and 24.21% of the bare frame values.

Figure 7 illustrates the storey drift variation in step-back models with varying lengths along the hill slope. Shear walls significantly reduce drift values compared to bare frame models (BSTEPALS 8). For corner shear wall models (WCRSTEPALS 8), reductions of 77.7% (along slope) and 67.81% (across slope) are observed. Mid-edge shear wall models (WMDSTEPALS 8) show further reductions of 79.16% and 73.21%, respectively. The greatest drift reduction occurs in centrally placed shear walls (WCESTEPALS 8), with 86.76% (along slope) and 87.94% (across slope). Peaks in drift profiles indicate soft storey formation due to the absence of shear walls at the foundation level.

Figure 8 presents storey shear distribution. Maximum shear occurs at the second-last storey near the highest foundation level in the along-slope direction. Across the slope, peak shear shifts to mid-storeys, especially in models with central shear walls. At lower foundation levels, corner shear wall models show the highest shear along the slope, while mid-edge shear wall models dominate across the slope.

Figure 9 compares foundation-level shear forces in models with and without shear walls (along slope). Frame 'A' shows the highest reduction in column shear force in mid-edge shear wall models (WMDSTEPALS). However, mid-building frames exhibit increased shear in models with mid-edge and central shear walls. Figure 10 (across slope) reveals a substantial decrease in column shear at middle frames due to shear wall incorporation. An abrupt increase at frame 'F' in WCESTEPALS is attributed to elevated axial forces in the shear wall, leading to higher column shear demand. Larger frames ('G', 'H', 'I') show notable shear increases in models with corner and mid-edge shear walls.

Table 2 Seismic response of step-back building along hill slope (BSTEPALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
BSTEPALS 4	4	13.5	0.285	0.248	5.15	1.351
BSTEPALS 5	5	16.5	0.299	0.271	5.69	1.326
BSTEPALS 6	6	19.5	0.313	0.293	6.37	1.345
BSTEPALS 7	7	22.5	0.325	0.312	6.97	1.342
BSTEPALS 8	8	25.5	0.337	0.331	7.63	1.355

Table 3 Seismic response of step-back building along hill slope (WCRSTEPALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WCRSTEPALS 4	4	13.5	0.178	0.248	1.49	1.101
WCRSTEPALS 5	5	16.5	0.204	0.271	2.08	1.135
WCRSTEPALS 6	6	19.5	0.225	0.293	2.60	1.154
WCRSTEPALS 7	7	22.5	0.245	0.312	3.13	1.151
WCRSTEPALS 8	8	25.5	0.263	0.331	3.62	1.148

Table 4 Seismic response of step-back building along hill slope (WMDSTEPALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WMDSTEPALS 4	4	13.5	0.183	0.248	1.40	1.075
WMDSTEPALS 5	5	16.5	0.209	0.271	2.09	1.105
WMDSTEPALS 6	6	19.5	0.22	0.293	2.25	1.111
WMDSTEPALS 7	7	22.5	0.246	0.312	3.39	1.198
WMDSTEPALS 8	8	25.5	0.25	0.331	3.29	1.167

Table 5 Seismic response of step-back building along hill slope (WCESTEPALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WCESTEPALS 4	4	13.5	0.188	0.248	1.40	1.055
WCESTEPALS 5	5	16.5	0.211	0.271	2.07	1.095
WCESTEPALS 6	6	19.5	0.222	0.293	2.10	1.080
WCESTEPALS 7	7	22.5	0.245	0.312	3.24	1.172
WCESTEPALS 8	8	25.5	0.247	0.331	2.91	1.123

Table 6 Seismic response of step-back building across hill slope (BSTEPALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
BSTEPALS 4	4	13.5	0.418	0.272	16.53	1.681
BSTEPALS 5	5	16.5	0.495	0.332	23.56	1.646
BSTEPALS 6	6	19.5	0.574	0.392	31.61	1.654
BSTEPALS 7	7	22.5	0.655	0.453	39.89	1.782
BSTEPALS 8	8	25.5	0.736	0.513	48.37	1.929

Table 7 Seismic response of step-back building across hill slope (WCRSTEPALS)

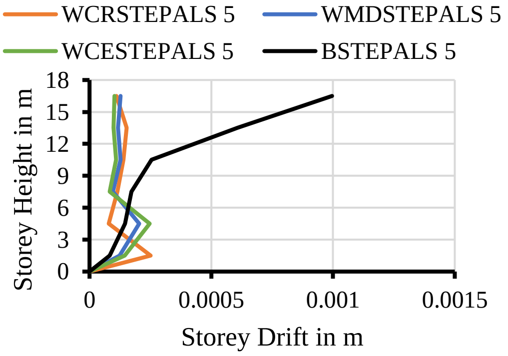
Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WCRSTEPALS 4	4	13.5	0.214	0.272	3.06	1.269
WCRSTEPALS 5	5	16.5	0.275	0.332	5.60	1.321
WCRSTEPALS 6	6	19.5	0.329	0.392	8.78	1.368
WCRSTEPALS 7	7	22.5	0.405	0.453	14.31	1.418
WCRSTEPALS 8	8	25.5	0.486	0.513	21.56	1.450

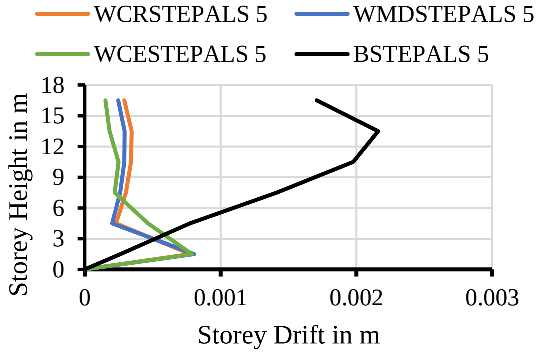
Table 8 Seismic response of step-back building across hill slope (WMDSTEPALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WMDSTEPALS 4	4	13.5	0.205	0.272	2.70	1.240
WMDSTEPALS 5	5	16.5	0.262	0.332	5.02	1.304
WMDSTEPALS 6	6	19.5	0.311	0.392	7.65	1.351
WMDSTEPALS 7	7	22.5	0.381	0.453	12.53	1.400
WMDSTEPALS 8	8	25.5	0.455	0.513	18.48	1.429

Table 9 Seismic response of step-back building across hill slope (WCESTEPALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WCESTEPALS 4	4	13.5	0.221	0.272	2.63	1.168
WCESTEPALS 5	5	16.5	0.269	0.332	4.47	1.207
WCESTEPALS 6	6	19.5	0.326	0.392	6.41	1.148
WCESTEPALS 7	7	22.5	0.372	0.453	9.33	1.185
WCESTEPALS 8	8	25.5	0.431	0.513	11.71	1.109





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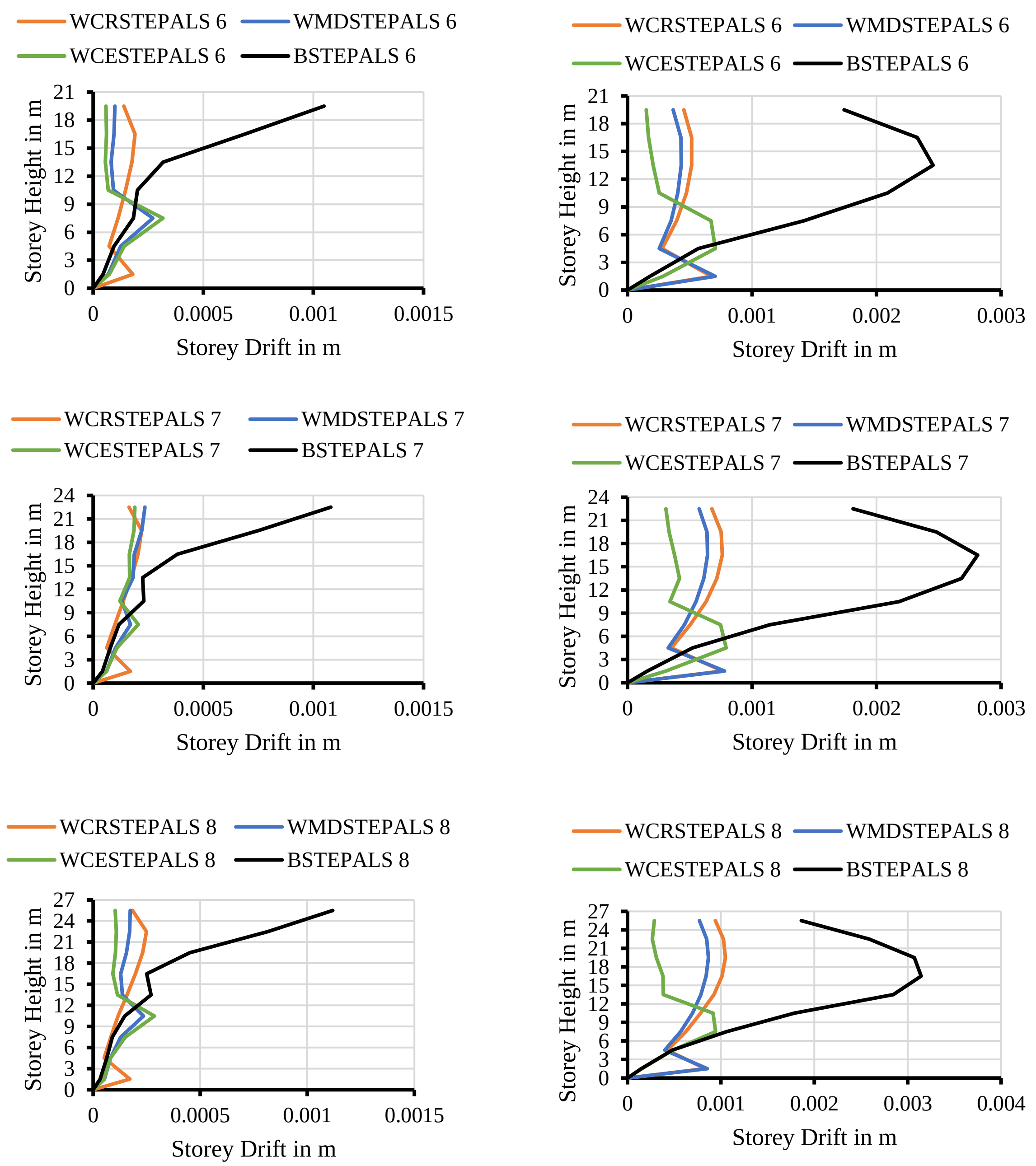
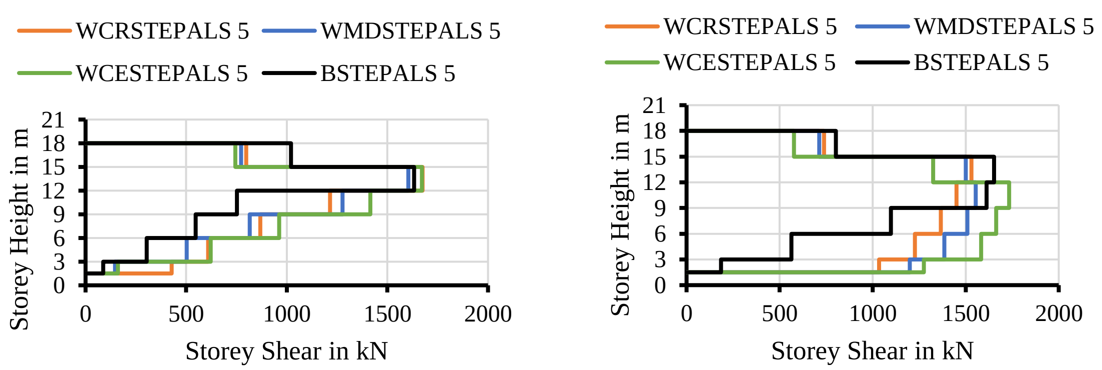


(a) Along Slope (b) Across slope

Fig. 7 Comparison of storey drift variation in step-back configuration



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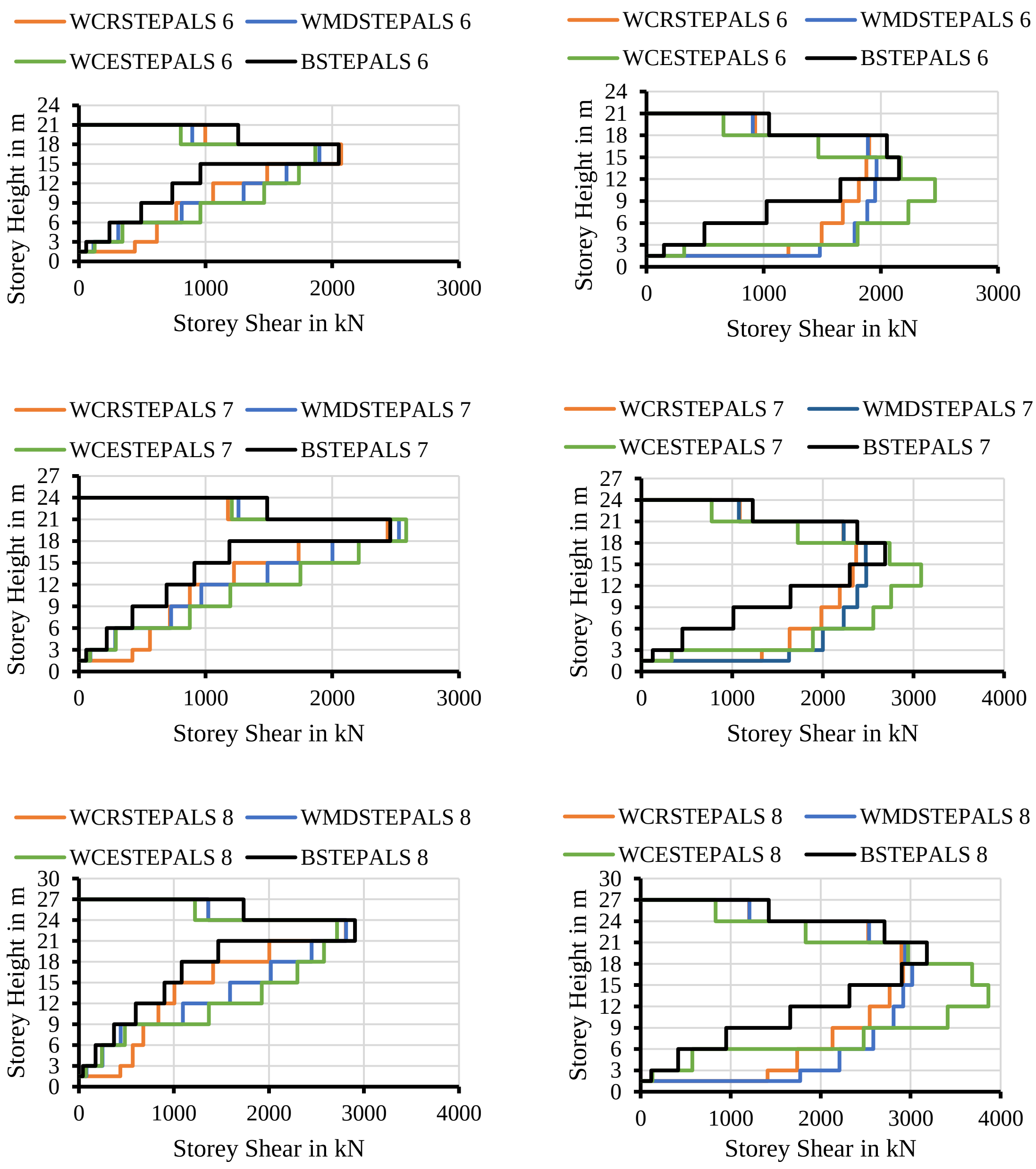
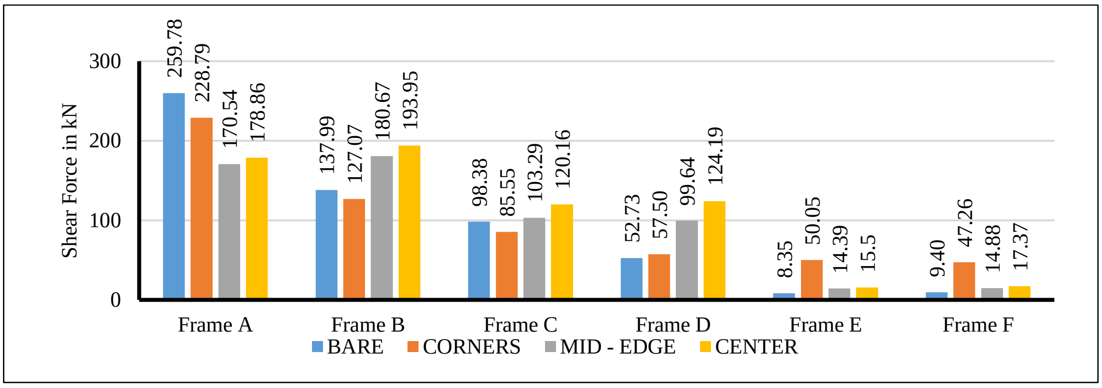


(a) Along Slope (b) Across slope

Fig. 8 Comparison of storey shear distribution in step-back configuration



(a)

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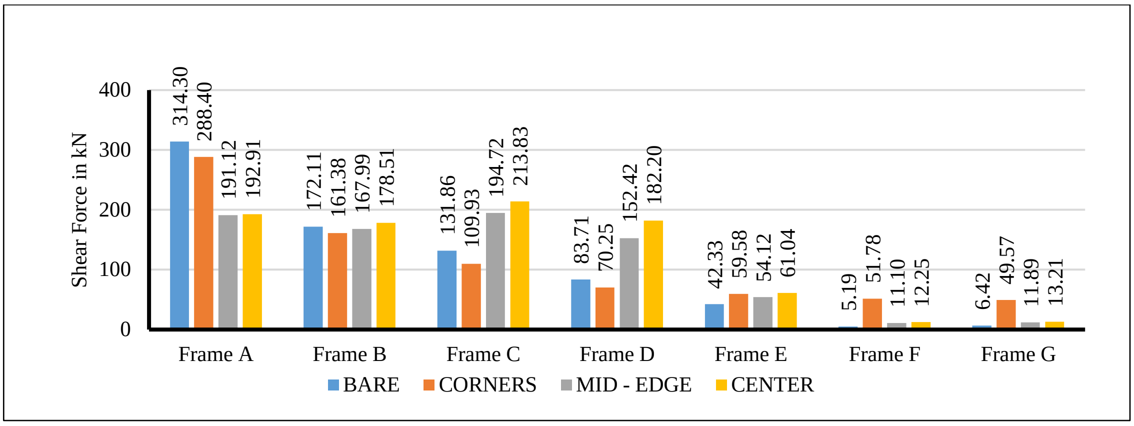

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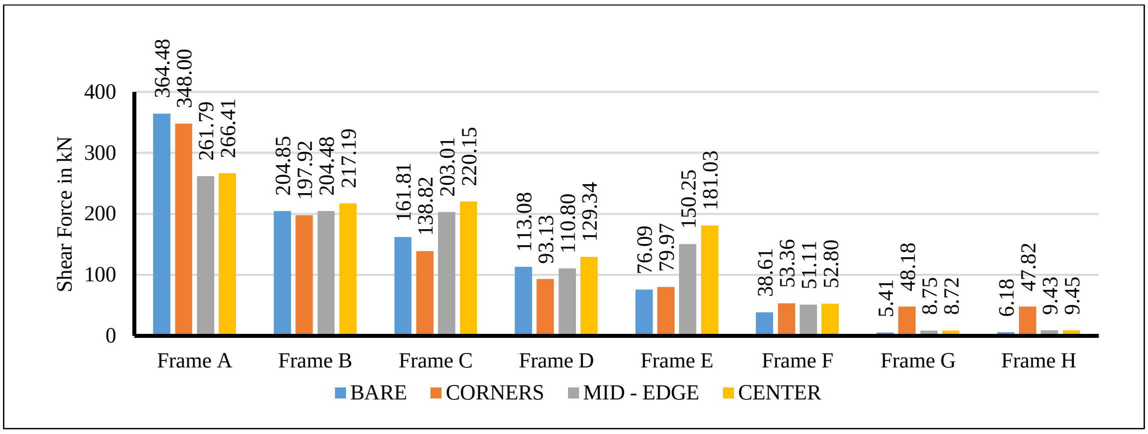

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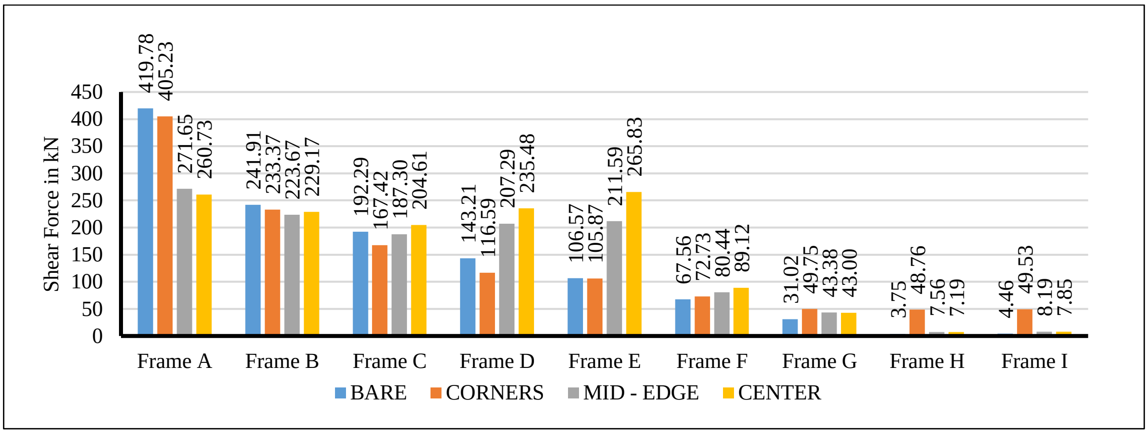
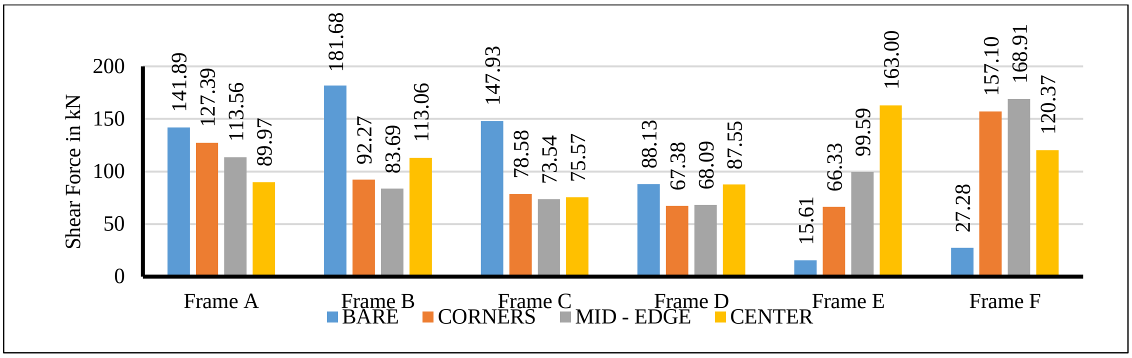


(d)

Fig. 9 Base shear distribution at foundation level in step-back configuration in along hill slope direction (a) 5 bays (b) 6 bays (c) 7 bays and (d) 8 bays



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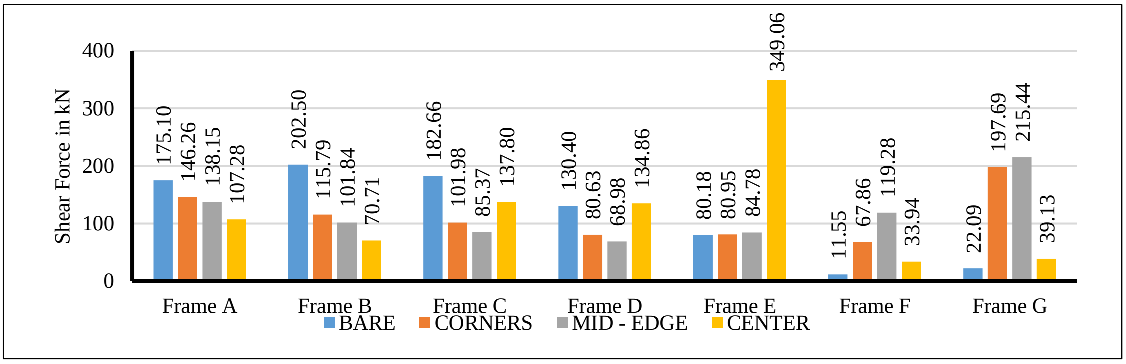

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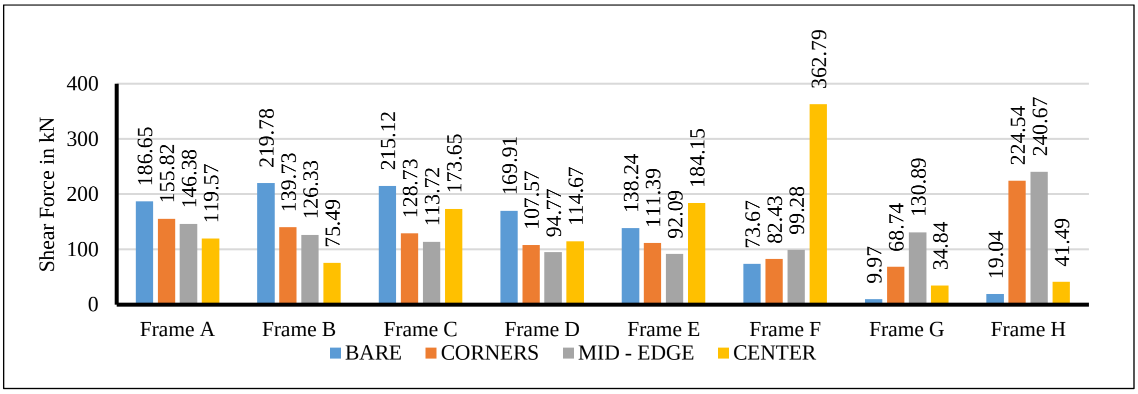

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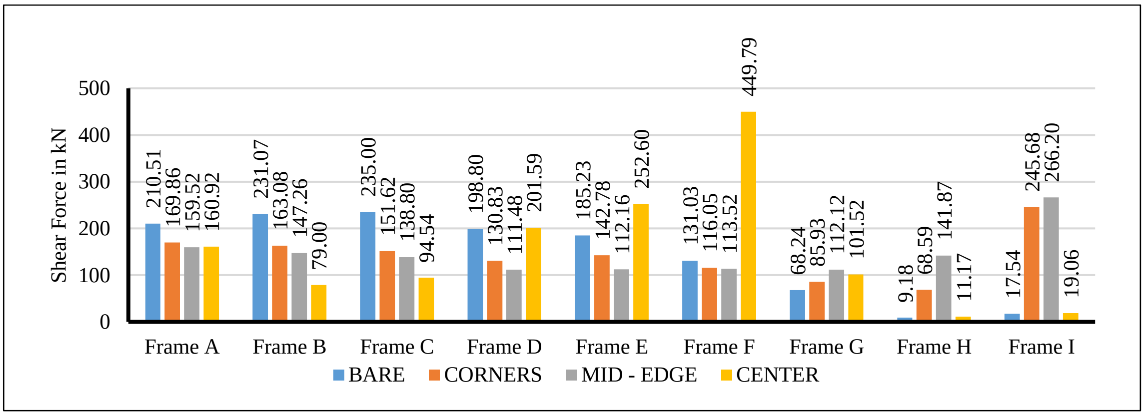

(d)

Fig. 10 Base shear distribution at foundation level in step-back configuration in across hill slope direction (a) 5 bays (b) 6 bays (c) 7 bays and (d) 8 bays

3.2. Seismic behaviour of Step-back setback configuration

The step-back setback configurations modelled without and with shear walls, viz. at corners (WCRSETALS), at mid-edge (WMDSETALS) and at centre of the structure (WCESETALS), are geometrically varied in length from 4 bays to 8 bays in along hill slope direction and keeping the length of the models fixed at 4 bays (20 m) in across slope direction.

The seismic analysis of step-back setback models reveals improved performance compared to step-back configurations with identical geometric variations. Dynamic properties for models BSETALS, WCRSETALS, WMDSETALS, and WCESETALS under slope-aligned seismic forces are detailed in Tables 10 to 13. Corner shear wall models (WCRSETALS 8) show modest reductions—21.05% in time period and 47.84% in top storey displacement relative to the bare frame (BSETALS 8). Mid-edge shear wall models (WMDSETALS 8) exhibit the greatest improvement, with reductions of 25.96% and 57.19%, respectively. Central shear wall models (WCESETALS 8) also perform well, achieving 24.91% reduction in time period and 61.51% in displacement.

Consistent with the trend observed in step-back models, seismic parameters in step-back setback configurations subjected to across-slope excitation are notably higher than those under along-slope loading. Dynamic properties for bare frame and shear wall models (WCRSETALS, WMDSETALS, WCESETALS) are detailed in Tables 14 to 17. Corner shear wall models (WCRSETALS 8) show reductions of 15.84% in time period and 30.13% in top storey displacement compared to the bare frame (BSETALS 8). Mid-edge shear wall models (WMDSETALS 8) perform better, with time period reduced to 74.73% and displacement to 9.65 mm (a 51.0% reduction). The most significant improvement is seen in central shear wall models (WCESETALS 8), with time period reduced by 29.12% and displacement by 79.01% relative to the bare frame.

Figure 11 highlights a distinct storey drift pattern in step-back setback configurations, differing significantly from previous geometric variations due to their asymmetric layout. While earlier configurations showed minimal drift, setback models exhibit increased drift at upper storeys—particularly in corner shear wall models—as building length increases. This rise is attributed to the absence of shear walls at upper levels. In contrast, mid-edge shear wall models (WCRSETALS 8) show drift reductions of 90.92% (along slope) and 57.69% (across slope). Central shear wall models demonstrate the most effective performance, reducing drift to 8.0% and 15.6%, respectively.

Figure 12 presents storey shear distribution, which also deviates from prior configurations. In the along-slope direction, maximum shear occurs at upper and lowest foundation levels in corner shear wall models. Mid-storey peaks are observed in central shear wall models. Across the slope, WCESETALS shows maximum mid-storey shear, while lower foundation shear peaks in mid-edge wall models.

Figure 13 shows base shear distribution in setback models. Along the slope, shear patterns resemble previous cases, with increased demand at frame ‘A’ in corner wall models as length increases. Mid-frame shear rises in mid-edge and central wall models. Across the slope, base shear behavior shifts: WMDSETALS shows abrupt increases at frame ‘A’, while mid-frame shear significantly decreases in shear wall models. Consistent with earlier trends, frame ‘F’ in WCESETALS 8 experiences peak shear due to elevated axial forces. Figure 14 confirms that setback configurations generally experience lower base shear than standard step-back models.

Table 10 Seismic response of step-back setback building along hill slope (BSETALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
BSETALS 4	4	13.5	0.285	0.248	5.15	1.351
BSETALS 5	5	16.5	0.285	0.271	5.52	1.344
BSETALS 6	6	19.5	0.285	0.293	5.69	1.328
BSETALS 7	7	22.5	0.285	0.312	5.67	1.297
BSETALS 8	8	25.5	0.285	0.331	5.56	1.259

Table 11 Seismic response of step-back setback building along hill slope (WCRSETALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WCRSETALS 4	4	13.5	0.178	0.248	1.49	1.101
WCRSETALS 5	5	16.5	0.196	0.271	1.90	1.129
WCRSETALS 6	6	19.5	0.214	0.293	2.71	1.238
WCRSETALS 7	7	22.5	0.222	0.312	2.85	1.209
WCRSETALS 8	8	25.5	0.225	0.331	2.90	1.197

Table 12 Seismic response of step-back setback building along hill slope (WMDSETALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WMDSETALS 4	4	13.5	0.183	0.248	1.40	1.075
WMDSETALS 5	5	16.5	0.200	0.271	1.97	1.116
WMDSETALS 6	6	19.5	0.203	0.293	1.88	1.084
WMDSETALS 7	7	22.5	0.214	0.312	2.66	1.167
WMDSETALS 8	8	25.5	0.211	0.331	2.38	1.121

Table 13 Seismic response of step-back setback building along hill slope (WCESETALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WCESETALS 4	4	13.5	0.188	0.248	1.40	1.055
WCESETALS 5	5	16.5	0.202	0.271	1.91	1.090
WCESETALS 6	6	19.5	0.207	0.293	1.79	1.066
WCESETALS 7	7	22.5	0.215	0.312	2.50	1.127
WCESETALS 8	8	25.5	0.214	0.331	2.14	1.085

Table 14 Seismic response of step-back setback building across hill slope (BSETALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
BSETALS 4	4	13.5	0.418	0.272	16.53	1.681
BSETALS 5	5	16.5	0.443	0.332	17.07	1.618
BSETALS 6	6	19.5	0.455	0.392	17.40	1.573
BSETALS 7	7	22.5	0.462	0.453	17.67	1.538
BSETALS 8	8	25.5	0.467	0.513	18.92	1.615

Table 15 Seismic response of step-back setback building across hill slope (WCRSETALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WCRSETALS 4	4	13.5	0.214	0.272	3.06	1.269
WCRSETALS 5	5	16.5	0.255	0.332	4.54	1.318
WCRSETALS 6	6	19.5	0.311	0.392	8.30	1.458
WCRSETALS 7	7	22.5	0.36	0.453	11.58	1.563
WCRSETALS 8	8	25.5	0.393	0.513	13.22	1.573

Table 16 Seismic response of step-back setback building across hill slope (WMDSETALS)

Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WMDSETALS 4	4	13.5	0.205	0.272	2.70	1.240
WMDSETALS 5	5	16.5	0.241	0.332	3.73	1.287
WMDSETALS 6	6	19.5	0.28	0.392	5.52	1.306
WMDSETALS 7	7	22.5	0.325	0.453	8.83	1.395
WMDSETALS 8	8	25.5	0.349	0.513	9.65	1.368

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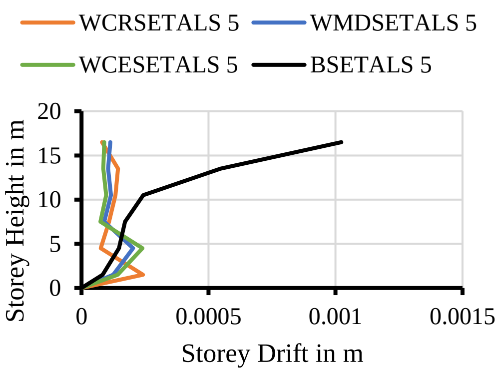
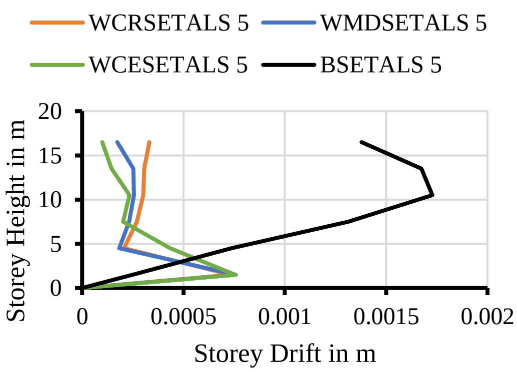
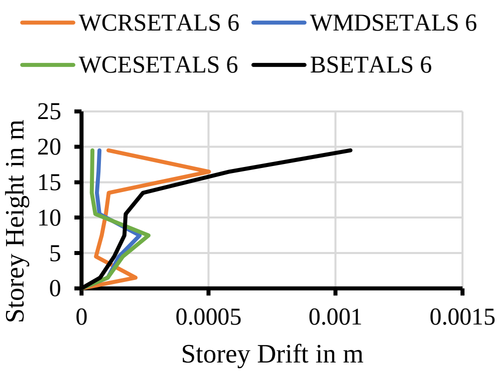
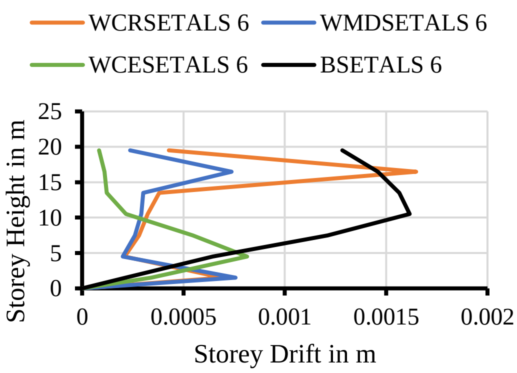
Table 17 Seismic response of step-back setback building across hill slope (WCESETALS)

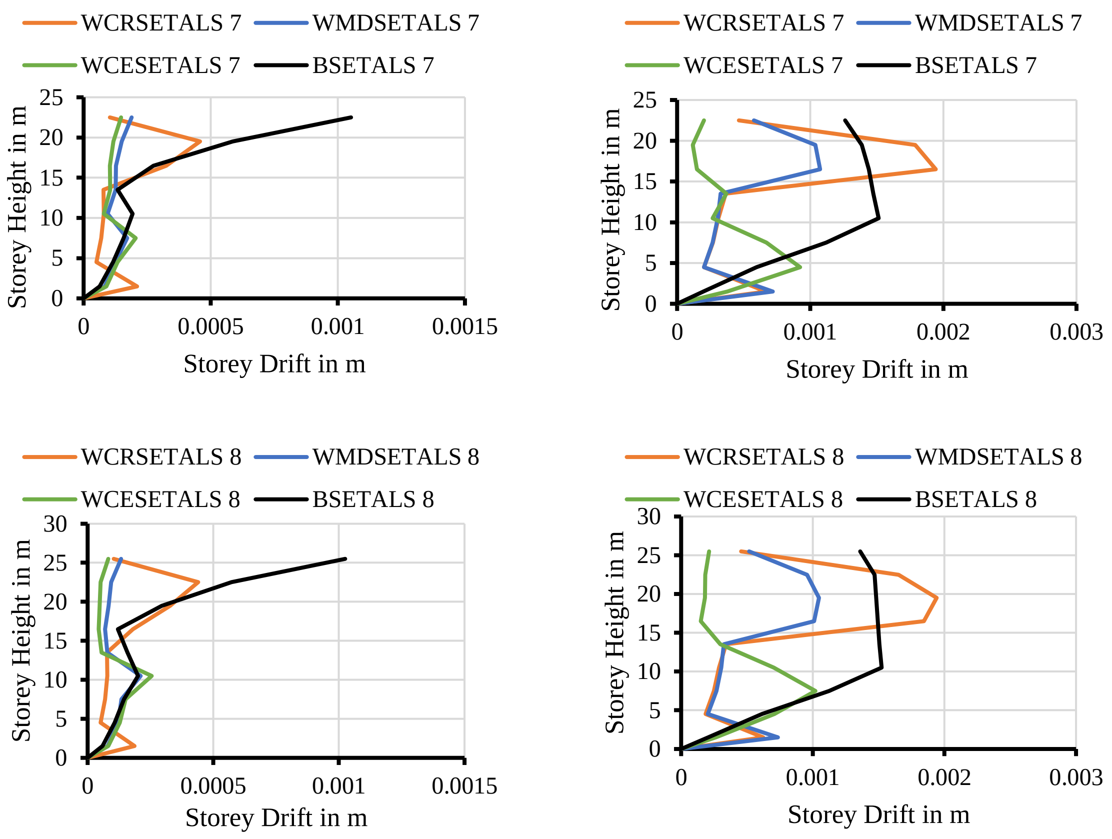
Designation	No. of Bays	Height (*m*)	FTP by RSA (*sec*)	FTP as per IS 1893 (*sec*)	Max. Top storey displacement (*mm*)	Base Shear ratio (λ)
WCESETALS 4	4	13.5	0.221	0.272	2.63	1.168
WCESETALS 5	5	16.5	0.248	0.332	3.21	1.207
WCESETALS 6	6	19.5	0.297	0.392	3.65	1.170
WCESETALS 7	7	22.5	0.310	0.453	4.09	1.216
WCESETALS 8	8	25.5	0.331	0.513	3.97	1.229





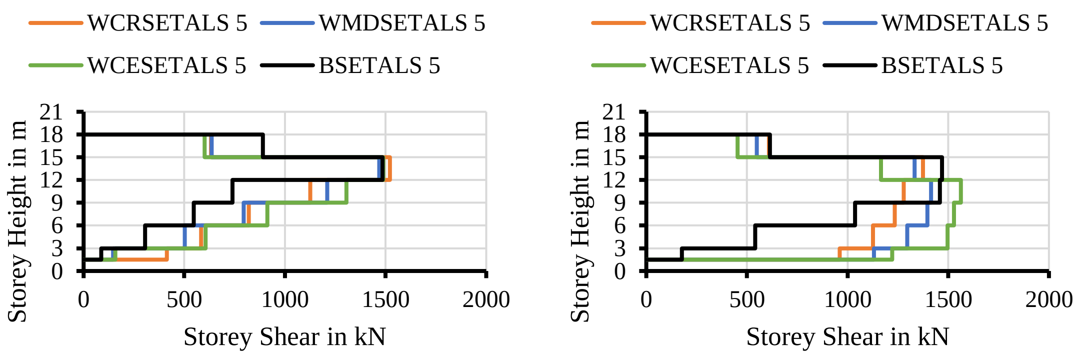






(a) Along Slope (b) Across slope

Fig. 11 Comparison of storey drift variation in step-back setback configuration



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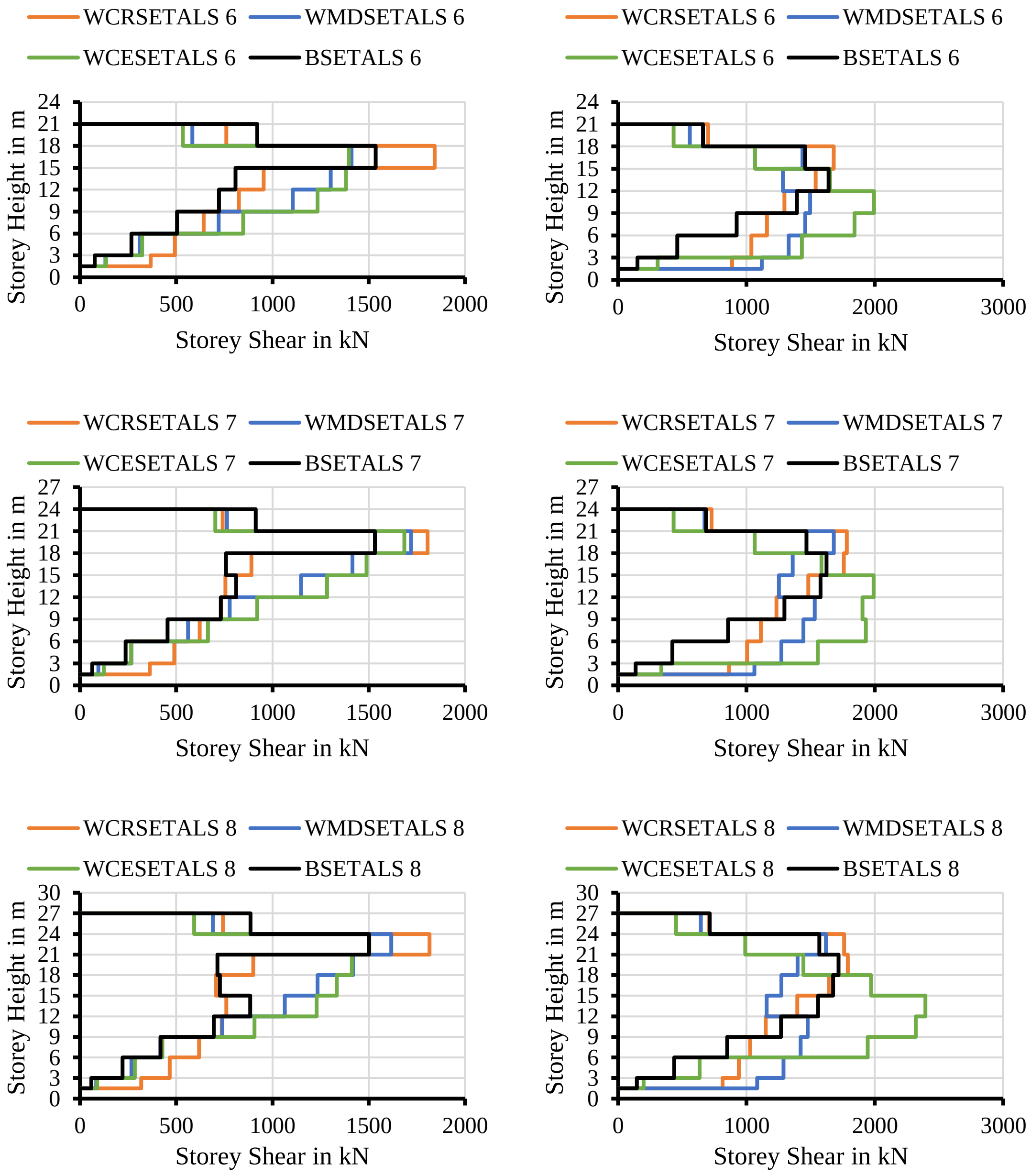
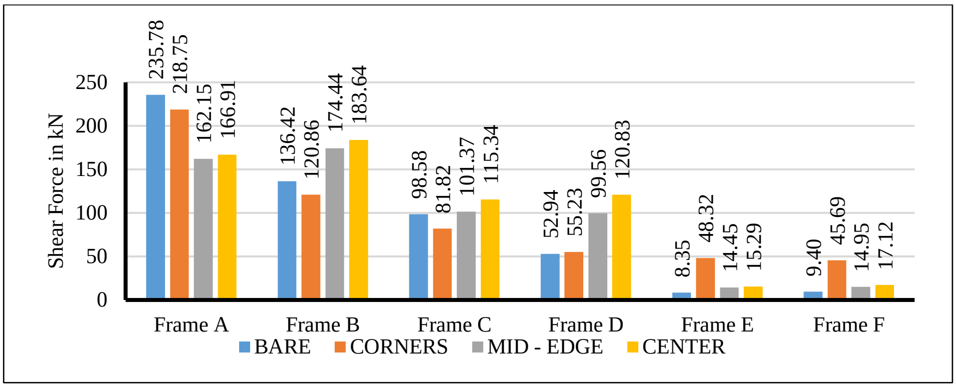


(a) Along Slope (b) Across slope

Fig. 12 Comparison of storey shear distribution in step-back setback configuration



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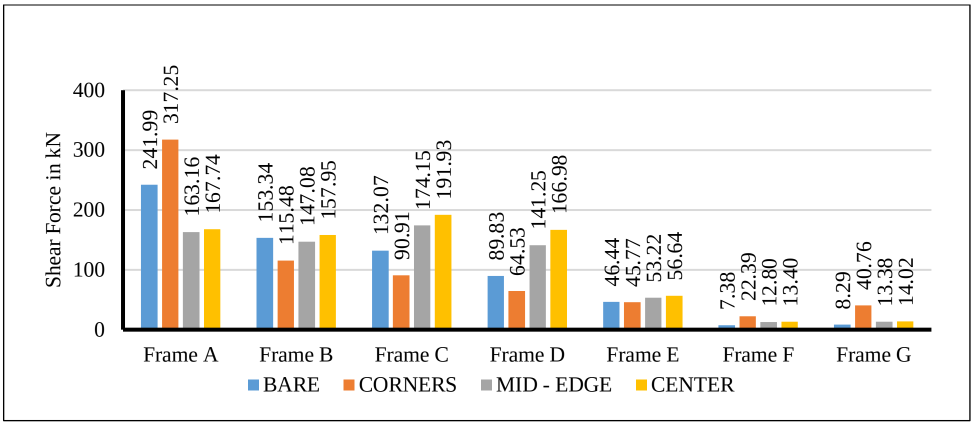

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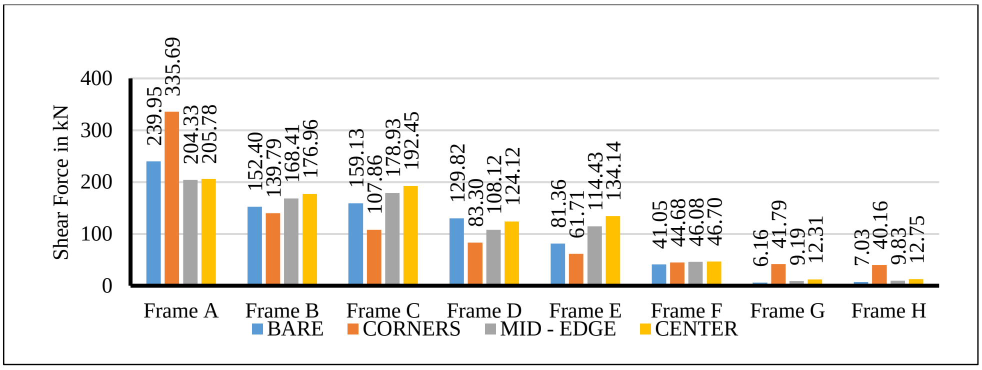

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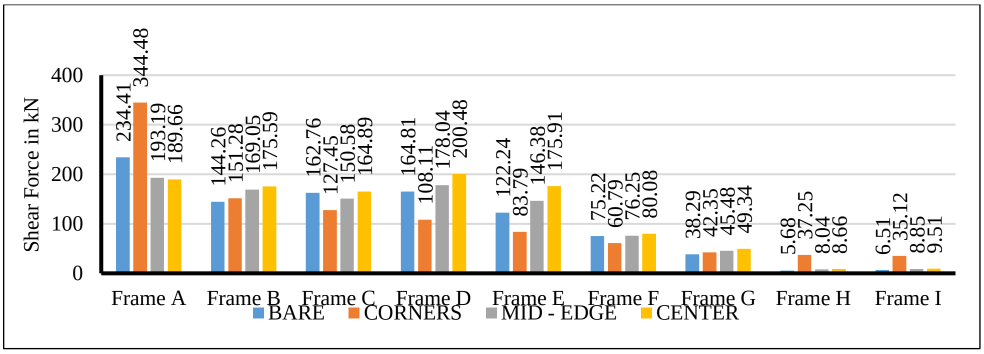
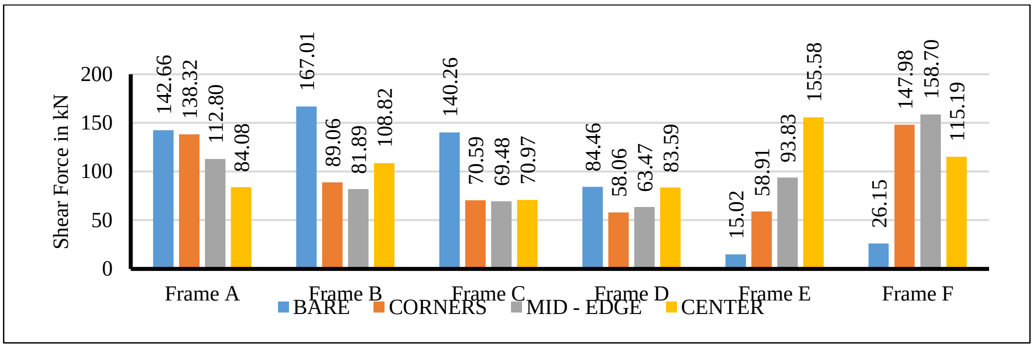


(d)

Fig. 13 Base shear distribution at foundation level in step-back setback configuration in along hill slope direction (a) 5 bays (b) 6 bays (c) 7 bays and (d) 8 bays



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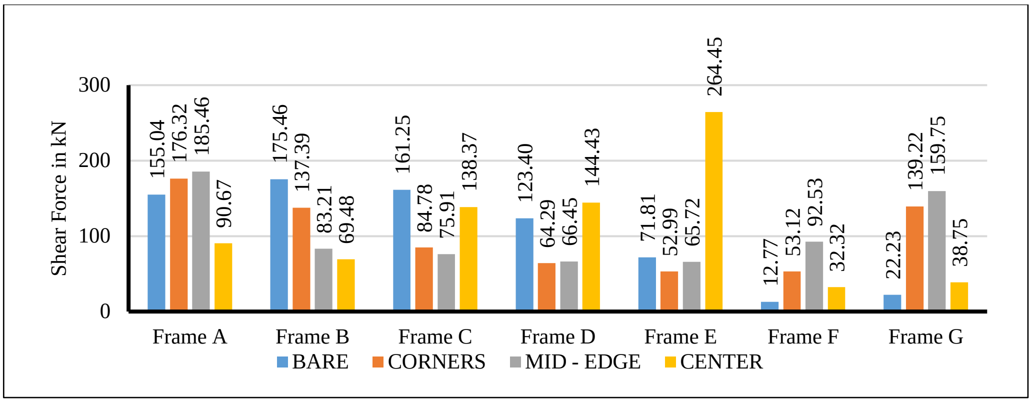

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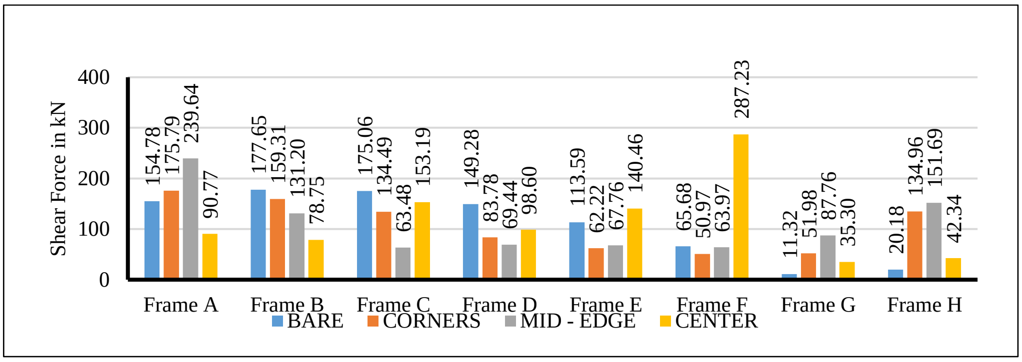

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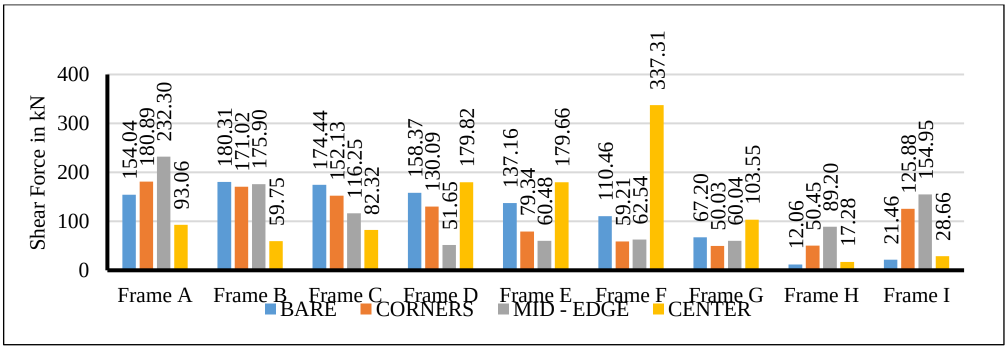

(d)

Fig. 14 Base shear distribution at foundation level in step-back setback configuration in across hill slope direction (a) 5 bays (b) 6 bays (c) 7 bays and (d) 8 bays

4. Conclusion

This study evaluated the impact of shear wall placement on two hill building configurations, focusing on their seismic performance. A total of 36 models were analyzed with shear walls positioned at corners, mid-edges, and the center, maintaining equal volume and quantity across geometric variations and slope directions. Shear walls play a critical role in resisting lateral forces from wind and earthquakes, and their placement significantly influences structural response.

Across all configurations, centrally placed shear walls consistently yielded the greatest reductions in fundamental time period, top storey displacement, and storey drift—up to 85% in WCESTEPALS and WCESETALS compared to bare frame models. Storey shear values were highest at foundation levels, with peak base shear observed in step-back models at the uppermost foundation level along the slope. In the transverse direction, mid-storey shear peaked when shear walls were placed at mid-edges.Base shear at frame ‘A’ (shortest frame) was generally reduced in the along-slope direction, while other frames showed marginal increases. Across the slope, shear force responses varied, with notable increases in middle frames for WCESTEPALS and WCESETALS due to elevated axial demands.

Overall, central shear wall placement proved most effective in enhancing seismic performance. However, the increased base shear in transverse loading conditions must be addressed in design. Corner and mid-edge shear walls contribute to reduced foundation-level shear and improved stiffness, helping mitigate torsional effects. A hybrid approach—combining shear walls at multiple strategic locations—offers a balanced solution for improving dynamic response and addressing geometric asymmetry in hill buildings.

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Conflicts of interest/Competing interests:

The author declares that there are no competing interests for this research work. This work is original and neither published elsewhere nor in communication with any other journal.

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