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PARAMETRIC STUDY ON STEP BACK & STEP BACK-SET BACK BUILDING ON SLOPING GROUND

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Abstract: The economic development and rapid urbanization in hilly regions has accelerated the real estate development in India. Because of this, population density within the hilly region has increased enormously. Buildings situated in hilly region are configured differently consistent with the topographical condition. The bottom level for consecutive rows of column could also be different leading to buildings having step back and step back-setback configurations. The behaviour and response of such buildings is significantly different than buildings on plain ground because of combination of irregularity, mass irregularity and stiffness irregularity. Soft storey buildings have shown very poor performance in past earthquakes. G+5 Residential buildings with OGS on sloping ground under highly seismic areas are under study. The modelling of step back and step back-setback building with Infill brick masonry with and without Shear wall are to be provided at corners. The slope at which the structures are to be kept 15°, 25°, 35°and 45°. Different response parameters like the variation of Storey Displacement, Base shear, Storey drift, and Period of time with reference to variation in several sloping ground are studied with regard to fixed base. The analysis is performed by using equivalent static force method (ESFM), response spectrum method (RSM) and nonlinear time history method (NLTHM). For construction of the building on sloping ground the Step back-Set back building configuration is suitable, alongside shear wall placed the corner of the building. Corner shear wall provided good strengthening to the building on sloping ground.
Keywords: Step back building, Step back-Set back building, Shear wall, Short column effect

1. INTRODUCTION

Earthquake is that the most disastrous and unpredictable phenomenon of nature. When a structure is subjected to seismic forces it doesn't cause loss to human lives directly but because of the damage cause to the structures that results in the collapse of the building and hence to the occupants and therefore the property. The structures are generally constructed on level ground but because of scarcity of level grounds the development activities are started on sloping grounds. Multistoried R.C. framed buildings are decent popular in hilly areas as a result of increase in land cost and under shunless circumstances due to inadequacy of land in urban areas. Thus, many of them are constructed on hilly slopes. Set back & Step back-Set back buildings are quite common on hilly slopes.

North and north eastern parts of India have large scales of hilly terrain, which are categorized under seismic zone IV and V. During this region the development of multi-storey RC framed buildings on hill slopes features a popular and pressing demand, because of its economic development and rapid urbanization. This growth in construction activity is adding to tremendous increase in population density. While construction, it must be noted that hill buildings are different from those in plains i.e., they're very irregular and unsymmetrical in horizontal and vertical planes. Since there's scarcity of plane ground in hilly areas, it obligates the development of buildings on slopes. Dynamic characteristics of hill buildings are significantly different from the buildings resting on plain topography, as these are irregular and unsymmetrical in both horizontal and vertical directions. The irregular switch-over of stiffness and mass in vertical also as horizontal directions, leads to centre of mass and centre of stiffness of a storey not coinciding with one another and not being on a vertical line for various floors. Further, because of site conditions, buildings on hill slope are characterized by unequal column heights within a storey, which ends up in drastic variation in stiffness of columns of an equivalent storey. The short, stiff columns on uphill side attract much higher lateral forces and are susceptible to damage. If a brief column is not adequately designed for such a large force, it can suffer significant damage during an earthquake. This behavior is termed short column effect. OGS buildings have consistently shown poor performance in past earthquake across the planet.

In India, many are built with OGS and still this practice is goes on. It's observed from the past earthquakes, buildings in hilly regions have experienced high degree of demand resulting in collapse though they need been designed for safety of the occupants against natural hazards. Hence, while adopting practice of multistory R.C. buildings in these hilly and seismically active areas, utmost care should be taken, making these buildings earthquake resistant. It's been observed that a lot of buildings were collapsed because of major damage in sloping ground storey columns during past earthquake. Shear walls are one among the foremost efficient lateral force resisting elements in multistoried buildings. When shear walls are provided at a correct location during a building they will convince be very efficient. Additionally, advantage of reducing lateral sway within the building under seismic loading are often available using shear wall.

2. LITERATURE REVIEW

A significant amount of research work has been done involving hill buildings. Rahul Ghosh & Debbarma [1] studied on Structure on sloping ground are highly susceptible to earthquakes because of irregularities in plan and elevation. Structure considered Soil-Structure Interaction (SSI) and without SSI considering. G+4 storey plan-regular and bare frame model building models on sloping ground angles 0°,15°,30° and 45° with and without SSI were analyzed in ETABS software using, equivalent static force method (ESFM), response spectrum method (RSM), time history method(THM), non-linear static method (NLSM). Comparison was done between augment of slope angle with and without soil structure interaction. Structures on the sloping ground are found as more vulnerable than the structures on the flat ground, and therefore the degree of vulnerability augment with the increment of slope angle. Structure without SSI consideration overestimate the forces (base shear and bending moment) and underestimate the responses (time period, displacement, torsion). This improper estimation of forces and responses can affect the structure very badly. There are few limitation of the work plan irregularity is't considered here, and just one way slope is considered.

G.S.Kavya, Ramesh B.M. & P.S.Ramesh [2] studied on Structure step-back and step back- set back building resting on a hill slope angle 27° and different soil conditions (hard, medium and soft) using SAP 2000 software. 2,3,4 storey plan-regular and same bay consider Step back and Step back Set back building models were analyzed in SAP 2000 software using, response spectrum method (RSM), pushover analysis. Comparison was done between Step back and Step back Setback building different response parameters are studied with reference to fixed base and equivalent springs in hill slopes. In many cases it are often seen that Step back-Set back configuration is best.

Rahul Ghosh & Debbarma [7] studied on Structure with combination of irregularity, mass irregularity, stiffness irregularity which make structure so weak to survive during earthquake. G+4 storey plan-regular and setback building models were analyzed in ETABS software using, equivalent static force method (ESFM), response spectrum method (RSM), time history method (THM). Comparison was done between various mitigation measures like, provision of shear wall in OGS. OGS columns are designed for 2.5 times of storey shear and moments (cl.7.10.3-IS 1893:2002(Part 1). Replacing OGS columns with reinforced concrete filled steel tube columns (RCFSTC). RCFSTC in OGS has been found because the best solution for downfall prevention of setback building with soft storey configuration at ground level during earthquakes.

Choudhury & Kaushik [8] assessed the seismic vulnerability of low to medium-rise masonry infill RC frames with different infill configurations. Nonlinear static pushover analysis was administered in SAP2000 software for performance assessment of three sorts of building models like bare frame, OGS and fully infill model. Different parameters were studied in fragility analysis such as natural period of vibration, number of bays, storeys and openings. It's a general perception about OGS buildings that openings present within the infill walls reduce the stiffness of upper storeys, and thus, offsets the soft storey effect. It had been observed that opening in masonry infills don't influence on lateral load behaviour of OGS frames. OGS frames remain highly vulnerable during earthquake although the frame having large openings in infill walls or any bay and storey configuration. It absolutely was concluded that seismic fragility of OGS frames found above the fully infilled and bare frames because columns in ground storey had lack adequate ductility, stiffness, and strength required to resist high storey shear.

Zaid Mohammad, Abdul Baqi & Mohammed Arif [9] administered a parametric study in hill building are geometrically varied height and length (along slope & across slope direction). Response spectrum method was administered in Etabs software for performance assessment of Step back and Step back-Set back sorts of building models. Inclination of ground slope angle 26°. Storey height depends on parametric variation of building along & across slope direction. Inter-storey height is taken as 3m. Analysis is completed by, response spectrum method (RSM) dynamic parameter obtained (top storey displacements, period of time, drifts and storey shear) comparison was done between Step back and Step back-Set back building on hill slope.

Khan & Rawat [18] studied the G+6 RC framed building with eccentric bracing at soft storey level and masonry infill at other upper storeys. The seismic performance of eccentric bracings for a G+6 building located in Indian seismic zone – V as per IS 1893-2002 were investigated using nonlinear static pushover analysis. Results shows that buildings with eccentric bracings have lower drift in open ground storey and probability of collapse.

Mahmoud et al. [10] analysed 12 storey reinforced concrete moment resisting frame with and without fully infill walls as well as frame building with open soft storey at different levels in ETABS. Nonlinear time history analysis performed using dynamic time history of two ground motion records from near and far-fault regions such as El centro (1940) and Loma Prieta (1989). Analysis of various models of buildings with and without infill walls taking soft storey at different levels like at base level,3rd storey level, 6th storey level, 9th storey level, 12th storey level was administered. Masonry infill walls enhance the seismic performance of the building structure during earthquake fermentation in terms of displacement control, storey drifts & lateral stiffness. For near fault motion, storey shear, displacements and moments are significantly suffering from the switch-over of OGS levels and for far-fault motion it's unaffected. Existence of an OGS at a specified level highly magnifies storey drift at that level.

Prasad Ramesh Vaidya [26] dispensed behaviour building G+7 on sloping ground for various positions of shear walls and to review the effectiveness of shear wall on sloping ground using SAP 2000 software. Building are modeled on 5° slope. Model one is of frame type structural system and other three models are of dual type (shear wall- frame interaction) structural system with three different positions of shear walls. Comparison was wiped out terms of response spectrum analysis applied at various positions of shear walls. It had been concluded for the buildings on the sloping ground location of shear wall are vital for resisting earthquake forces.

3. DETAILS OF BUILDING AND MODELLING OF STRUCTURE

Six-Storey (G+5) residential building (Step Back and Step Back-Set Back) of 18m height and 12m x 12m square plan, with 4 Nos. of bay (each bay @ 3m) is considered for analysis. The 3D View and plan of the building are shown in Figs. 1 to 4.

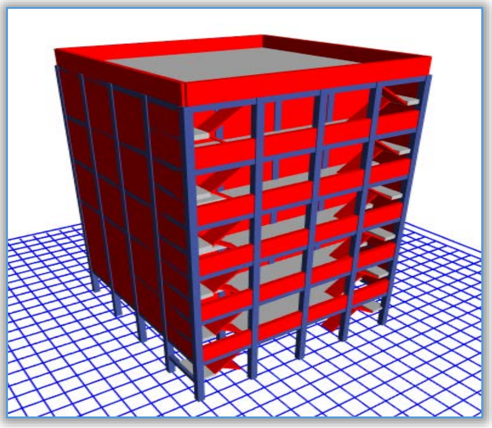


Figure 1. 3D view of Step Back Building

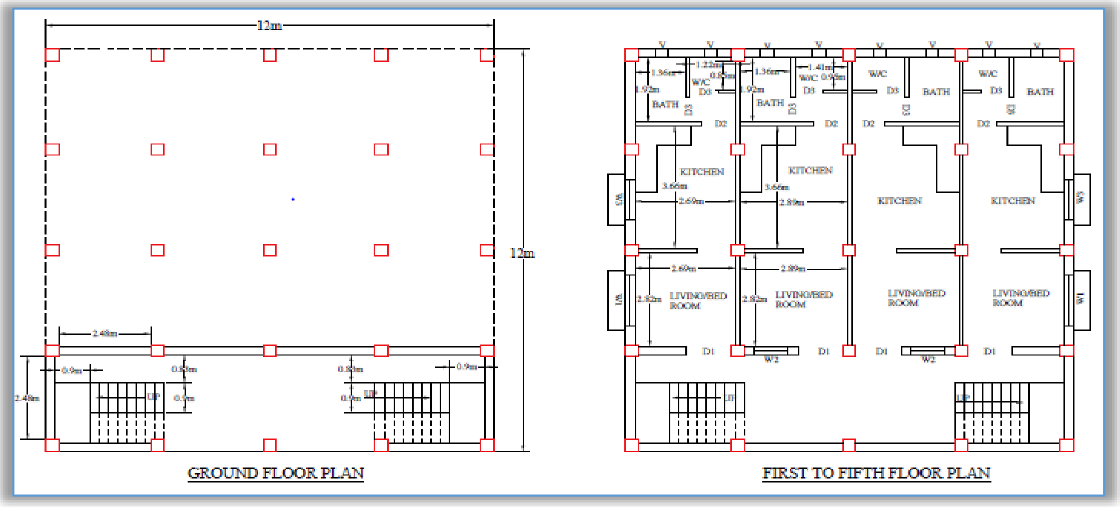


Figure 2. Plan of Step Back Building

Table 1. Details of structural elements

Beam:	250 mm X 300 mm
Column:	350 mm X 350 mm
Slab thickness:	150 mm
Wall thickness:	250 mm (External), 115mm (Internal)
Parapet height:	1000 mm
L-Shape shear wall thickness	250mm

Table 2. Details of various loads

Dead load	self-weight of all building element
	Floor finish 1 kN/m^2
Live load	3 kN/m^2 on typical floor
	1.5 kN/m^2 on Roof
Wall load	infill wall: 13.50 kN/m
	Parapet wall: 5.0 kN/m
Load combination	1.5 (DL ± EL)
Mass source	1.0DL + 1.0WL + 0.25LL

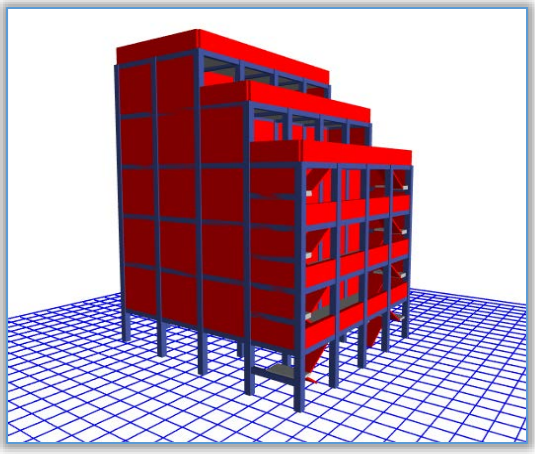


Figure 3. 3D view of Step Back-Set Back Building

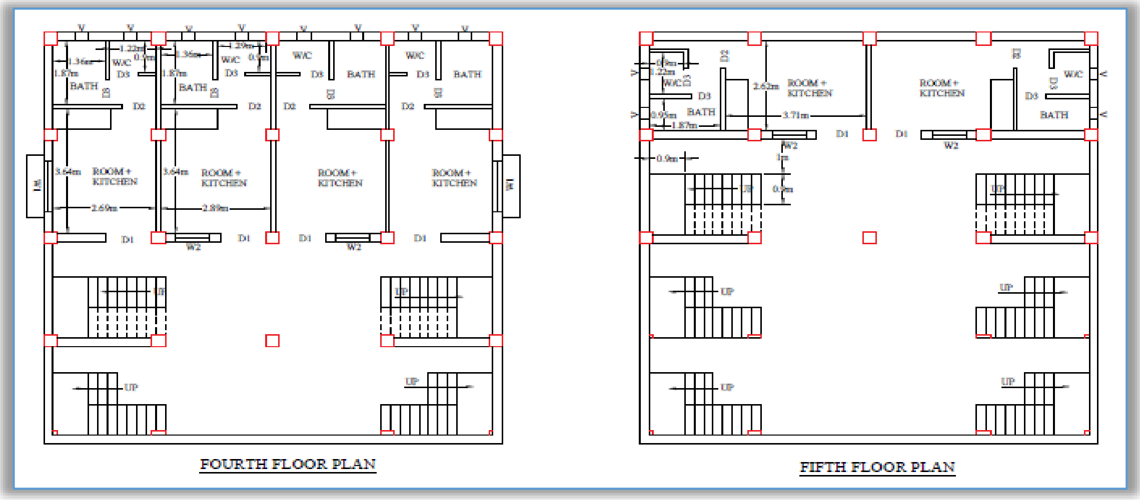


Figure 4. Plan of Step Back-Set Back Building

Seismic design data are as follows:

Seismic zone: V, zone factor (Z): 0.36, soil type: medium soil. Damping ratio: 5%, response reduction factor (R): 5, Importance factor (I): 1.

Material Properties are taken as, unit weight of concrete: 25kN/m^3, characteristic strength of concrete: 30 Mpa, characteristic strength of steel: 415 Mpa.

4. DESCRIPTION OF ANALYSIS MODELS

G+5 Residential buildings with OGS on sloping ground under highly seismic areas are under study. Step back & Step back Set back building with OGS, Infill brick masonry with and without Shear wall are to be provided at corners on sloping ground in ETABS 2017 software. Seismic zone V and medium type of soil only & without soil structure interaction considered here.

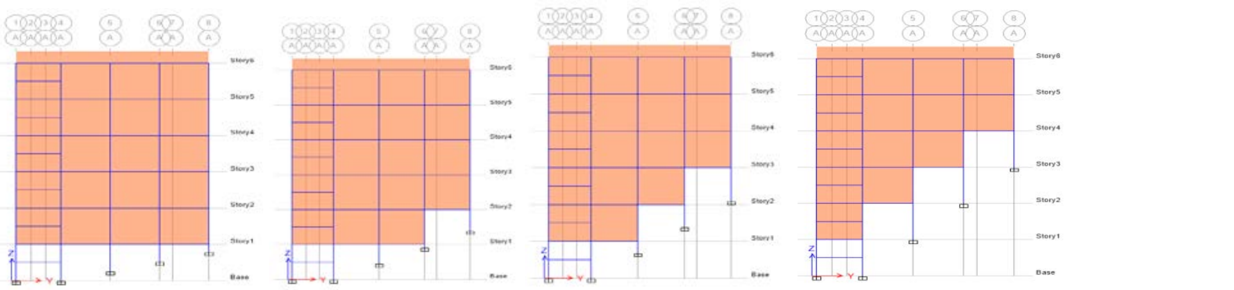
The slope at which the structures are to be kept: 15°,25°,35°and 45°. Setback is provided on fourth and fifth storey. To study the variation of Storey Displacement, Base shear, Storey drift, Time period with respect to variation in different sloping ground. Methods are to be used: Response Spectrum Method (Linear Dynamic Method) and Pushover analysis (Non-Linear Static Method), Non Linear Time History Method. El Centro earthquake data are used from non-linear time history method. Total 20 numbers of models are prepared. Notations of all these models are described in the following Table 3 & 4.

Table 3. Notations of Step Back Building

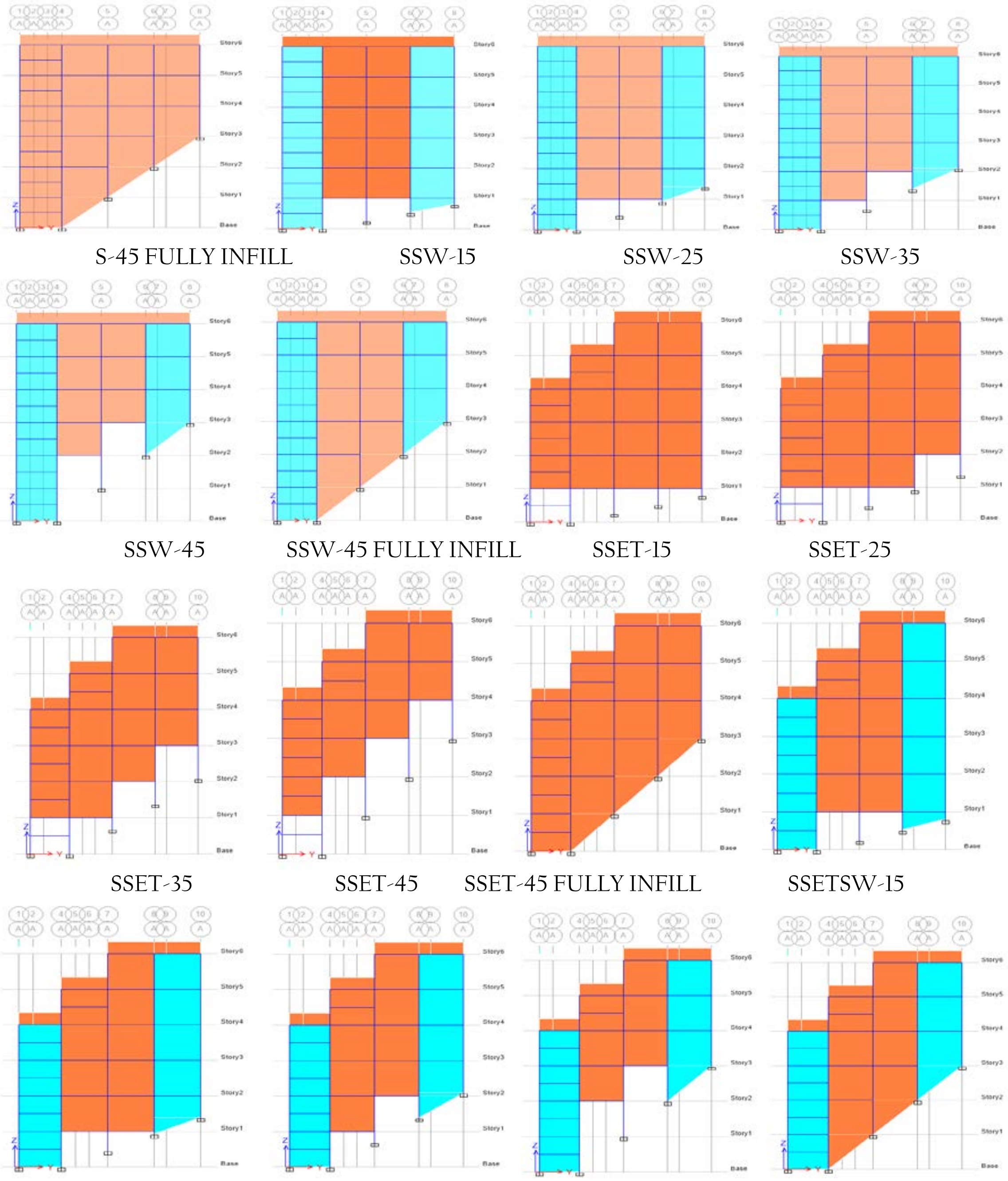
Sr. No.	Slope angles	Step back building with Infill and without Shear wall	Step back building with Infill and Shear wall
1.	15°	S-15	SSW-15
2.	25°	S-25	SSW-25
3.	35°	S-35	SSW-35
4.	45°	S-45	SSW-45
5.	FULLY INFILL45°	S-45 FULLY INFILL	SSW-45 FULLY INFILL

Table 4. Notations of Step Back-Set Back Building

Sr. No.	Slope angles	Step back Set back building with Infill and without Shear wall	Step back Set back building with Infill and Shear wall
1.	15°	SSET-15	SSETSW-15
2.	25°	SSET-25	SSETSW-25
3.	35°	SSET-35	SSETSW-35
4.	45°	SSET-45	SSETSW-45
5.	FULLY INFILL45°	SSET-45 FULLY INFILL	SSETSW-45 FULLY INFILL



S-15 S-25 S-35 S-45



S-45 FULLY INFILL SSW-15 SSW-25 SSW-35

SSW-45 SSW-45 FULLY INFILL SSET-15 SSET-25

SSET-35 SSET-45 SSET-45 FULLY INFILL SSETSW-15

SSETSW-25 SSETSW-35 SSETSW-45 SSETSW-45 FULLY INFILL

Figure 5. Images of models

5. METHODS OF ANALYSIS

In this study, all the models are analyses in linear static method which is known as ESFM (Equivalent Static Force Method), linear dynamic method, which is known as RSM (Response Spectrum Method), NLTHM (Non-Linear Time History). Linear analysis is performed using the software ETABS 2017. Study the variation of Storey Displacement, Base shear, Storey drift, Time period with respect to variation in different sloping ground. ESFM analysis and RSM analysis are carried out and results are compared to study the seismic behaviour of the structures. In modal analyses, mode shapes are generally obtained in normalised form, for that the results of response spectrum method need to be properly scaled. In the present study, the scaling has been done by equating the base shears obtained from ESFM and RSM as per IS 1893 (2016). Real earthquake data of El Centro earthquake are used for non-linear time history analysis.

6. RESULTS AND OBSERVATIONS

Comparison between Step back & Step back Set back building with OGS, Infill brick masonry with and without using L-shape Shear wall is provided at corners on different sloping ground. Analyse these models by using linear static and dynamic analysis such as Equivalent static analysis and Response Spectrum analysis respectively. Analyse same models by using non-linear time history method respectively. Study the variation of Storey Displacement, Base shear, Storey drift, Time period with respect to variation in different sloping ground.

— **Base Shear**

Estimated of maximum expected lateral force on the base of the structure due to seismic activity, which depends on mass and stiffness of the structure, these are presented in Figure 6 & 7. According to results both type of building base shear increased with shear wall compared to without shear wall. Base shear decreased lower angle to higher angle.

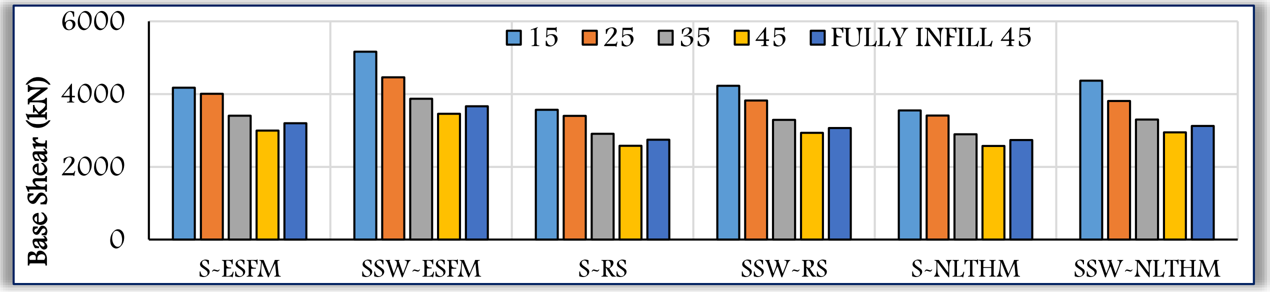


Figure 6. Base shear of Step back building with and without Shear wall

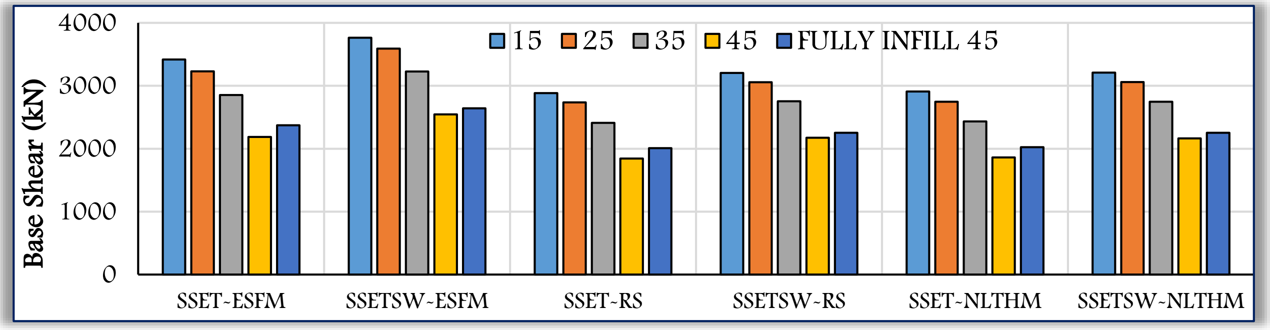


Figure 7. Base shear of Step back-Set back building with and without Shear wall

— **Time Period**

It is property of system, when it is allows vibrating freely without any external force and it depends on mass & stiffness of the structure; these are presented in Figure 8 & 9. According to the both type of building fundamental time period less with shear wall compared to without shear wall.

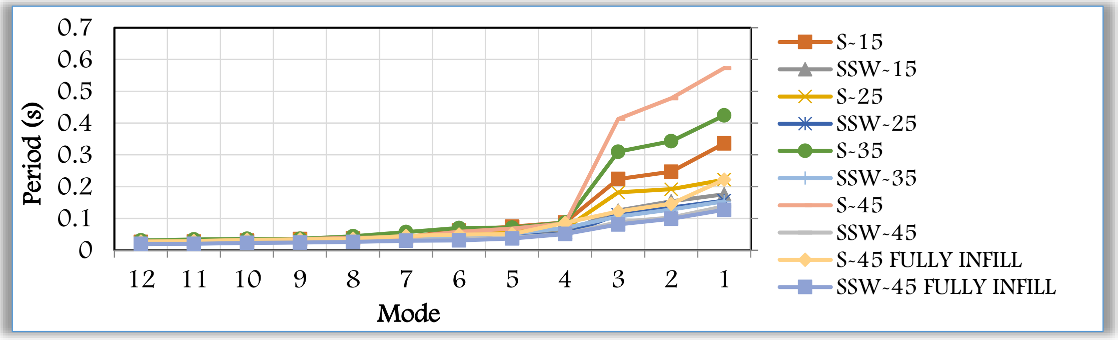


Figure 8. Variation of fundamental time period of Step back building

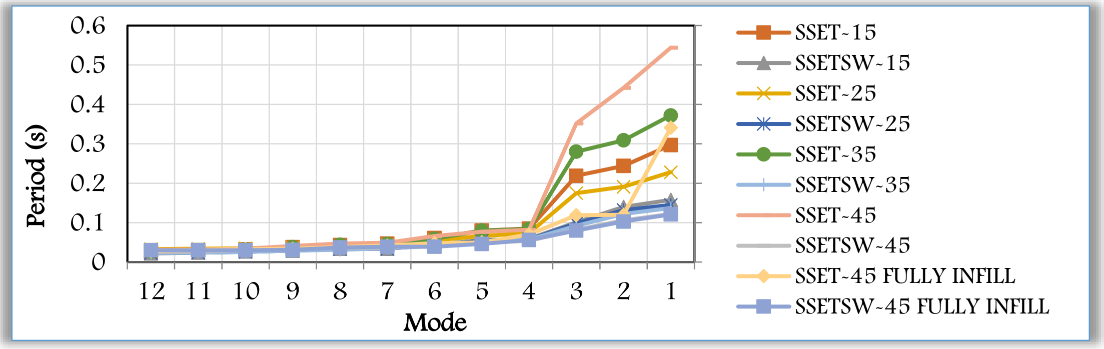


Figure 9. Variation of fundamental time period of Step back-Set back building

— Torsional Response

Maximum torsional response from nonlinear time history method carried out. The nonlinear time history analysis is the best technique to evaluate structural response under earthquake excitations described by ground acceleration records. Here, El Centro earthquake data used from non-linear time history method. Step back and Step back Set back building torsional response shown in Figure 10 & 11.

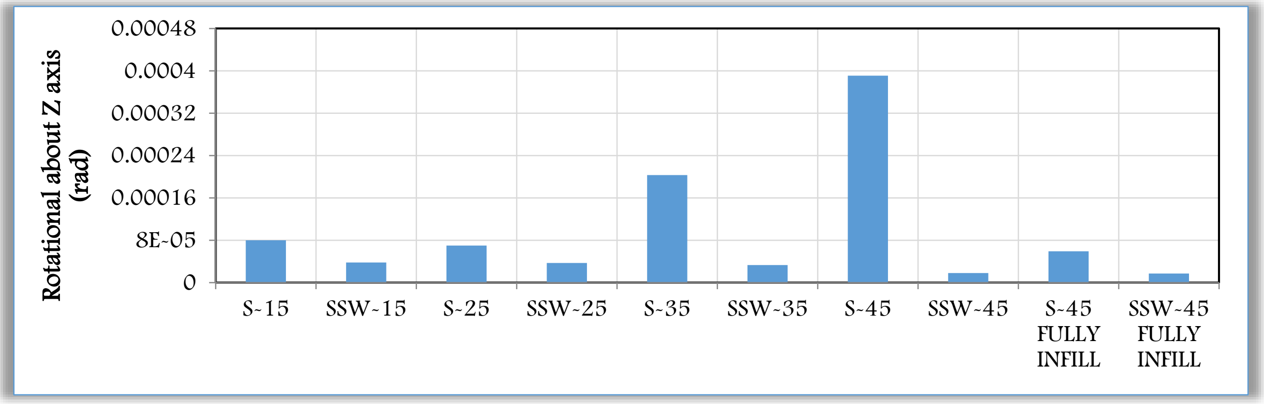


Figure 10. Torsional response for step back building

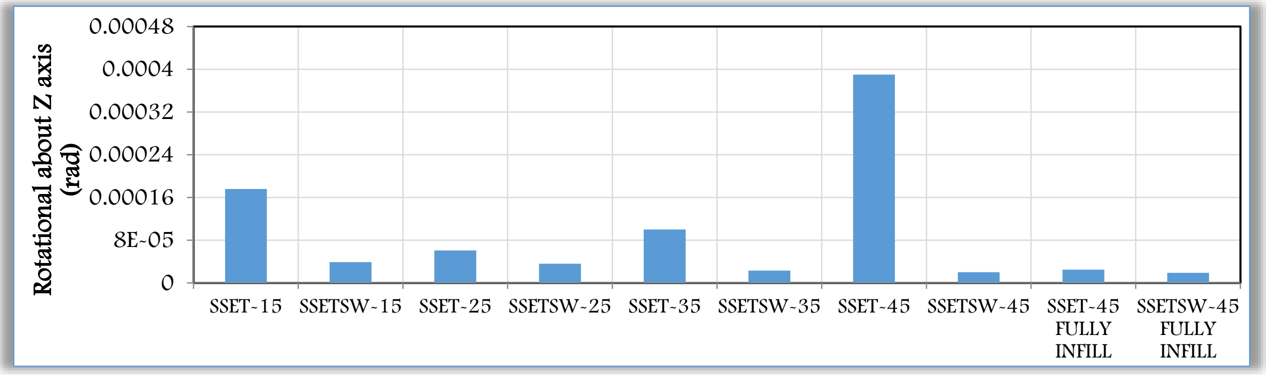
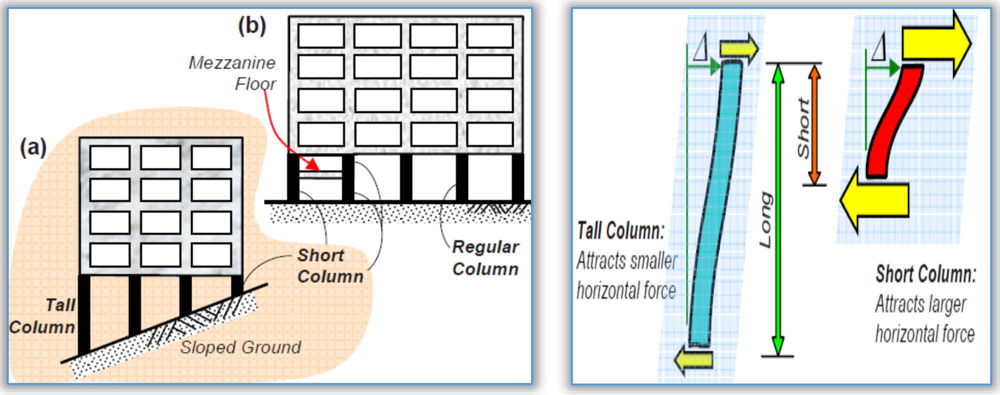


Figure 11. Torsional response for step back-Set back building

— Short Column Effect

During past earthquakes, reinforced concrete (RC) frame buildings that have columns of different heights within one storey, suffered more damage in the shorter columns as compared to taller columns in the same storey. Two examples of buildings with short columns are shown in Figure 12. – buildings on a sloping ground and buildings with a mezzanine floor.[32]



Source: IITK-BMTPC Earthquakes Tips

Figure 12. Buildings with short columns – two explicit examples of common occurrences

Poor behaviour of short columns is due to the fact that in an earthquake, a tall column and a short column of same cross-section move horizontally by same amount (Δ). However, the short column is stiffer as compared to the tall column, and it attracts larger earthquake force. Stiffness of a column means resistance to deformation – the larger is the stiffness, larger is the force required to deform it. If a short column is not adequately designed for such a large force, it can suffer significant damage during an earthquake. This behaviour is called Short Column Effect.

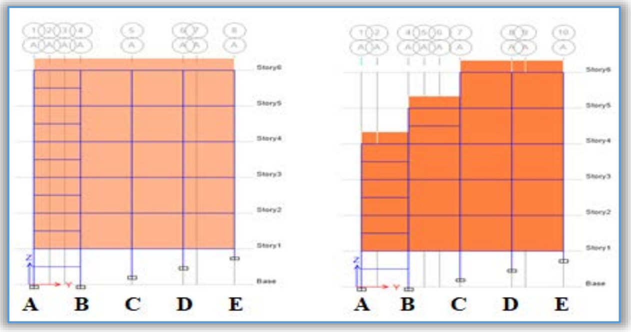


Figure 13. Short column effect due to consecutive levels on sloping ground

Short Column effect considered in Step back & Step back Set back building with and without corner shear wall on different sloping ground. Consecutive levels on sloping ground considered shown in Figure 13. Short column effect find out consecutive level due to maximum axial force, shear force & bending moment shown in Table 5 & 6. According to results maximum axial force, shear force and bending moment occurs in short column. Due to various sloping ground column height varied. Construction on sloping ground in both type of building using corner shear wall less axial force, shear force and bending moment compare to without shear wall.

Table 5. Short column effect of Step back building

		Axial Force (KN)		Shear Force (KN)		Bending Moment (KN-M)	
Consecutive Level & Angle	Column Height	S	SSW	S	SSW	S	SSW
E & 15°	0.59	684.43	117.75	264.68	32.87	80.28	10.94
D & 25°	0.2	480.43	228.75	376.80	96.07	43.73	12.52
C & 35°	0.9	266.94	90.35	191.91	7.48	113.40	4.93
A & 45°	1.5	224.99	30.54	71.25	0.74	65.44	2.56
A & Fully Infill 45°	1.5	57.91	22.08	2.409	0.65	8.53	2.27

Table 6. Short column effect of Step back-Set back building

		Axial Force (KN)		Shear Force (KN)		Bending Moment (KN-M)	
Consecutive Level & Angle	Column Height	SSET	SSETSW	SSET	SSETSW	SSET	SSETSW
E & 15°	0.59	516.59	82.24	234.82	24.53	72.23	8.28
D & 25°	0.2	433.58	206.37	305.30	91.48	34.19	10.93
C & 35°	0.9	299.30	91.75	179.51	12.79	84.18	6.24
A & 45°	1.5	172.22	20.12	43.48	4.74	38.75	2.80
A & Fully Infill 45°	1.5	62.29	18.42	56.21	4.95	41.84	2.90

Step back & Step back- Set back building infill with corner shear wall provided maximum axial force, shear force & bending moment has been decreased by;

Table 7. Percentage difference for building short column effect

Building Name	Axial Force	Shear Force	Bending Moment
Step back	70%	86%	85%
Step back- Set back	73%	86%	87%

According to result, Step back building infill without OGS (fully infill 45) provided axial force, shear force & bending moment has been decreased by 84%, 75% & 78% compared to with OGS. Step back-Set back building infill without OGS (fully infill 45) provided axial force, shear force & bending moment has been decreased by 62%, 50% & 52% compared to with OGS.

— **Displacement**

Storey displacement profiles in major direction (X direction) and minor (Y direction) of force, with the storey height for different models in ESFM, RSM and NLTHM are shown in Figure 14- 19. According to results both type of building less displacement with shear wall provided at corner compare to the without shear wall.

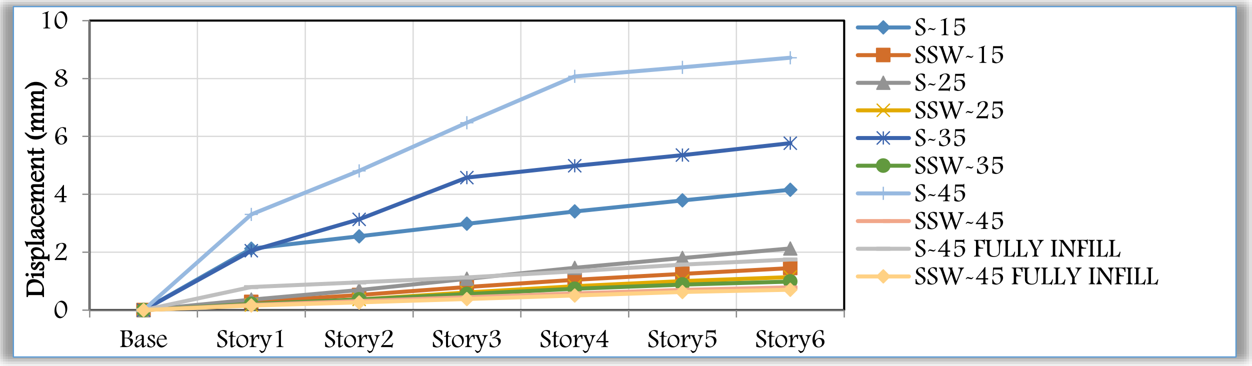


Figure 14. Variation of storey displacement ESFM for Step back building

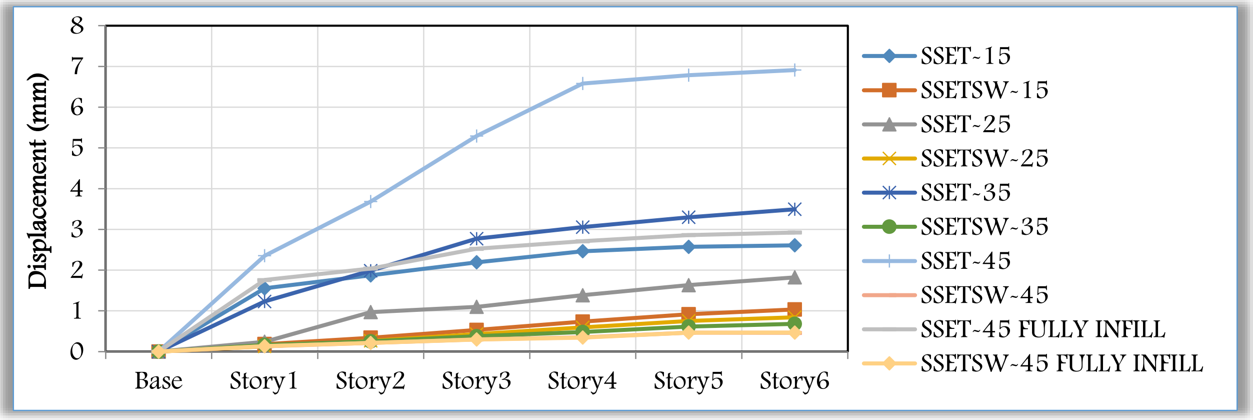


Figure 15. Variation of storey displacement ESFM for Step back-Set back building

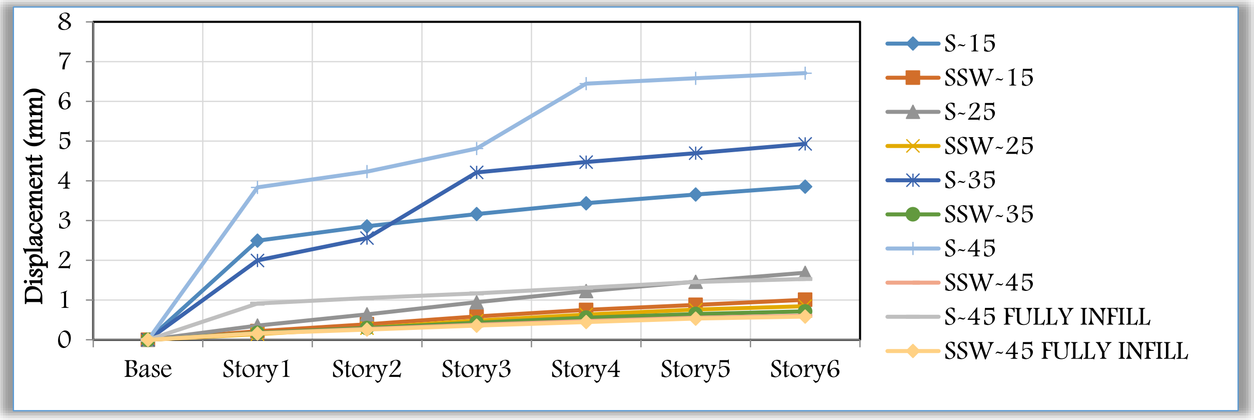


Figure 16. Variation of storey displacement RS for Step back building

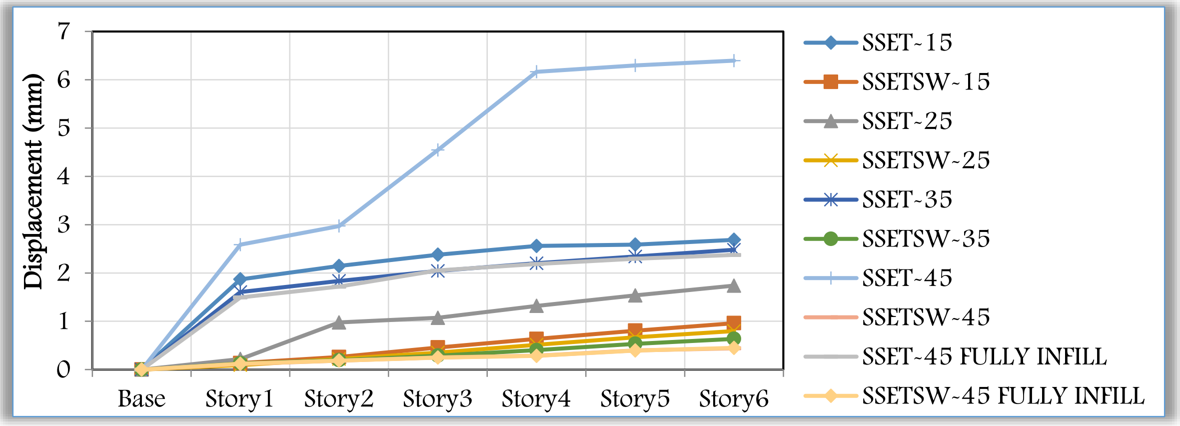


Figure 17. Variation of storey displacement RS for Step back-Set back building

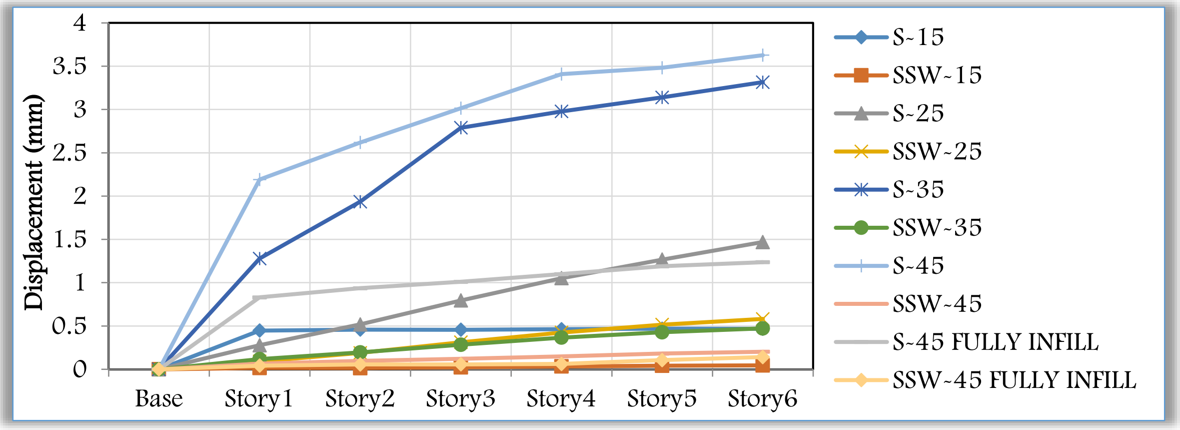


Figure 18. Variation of storey displacement NLTHM for Step back building

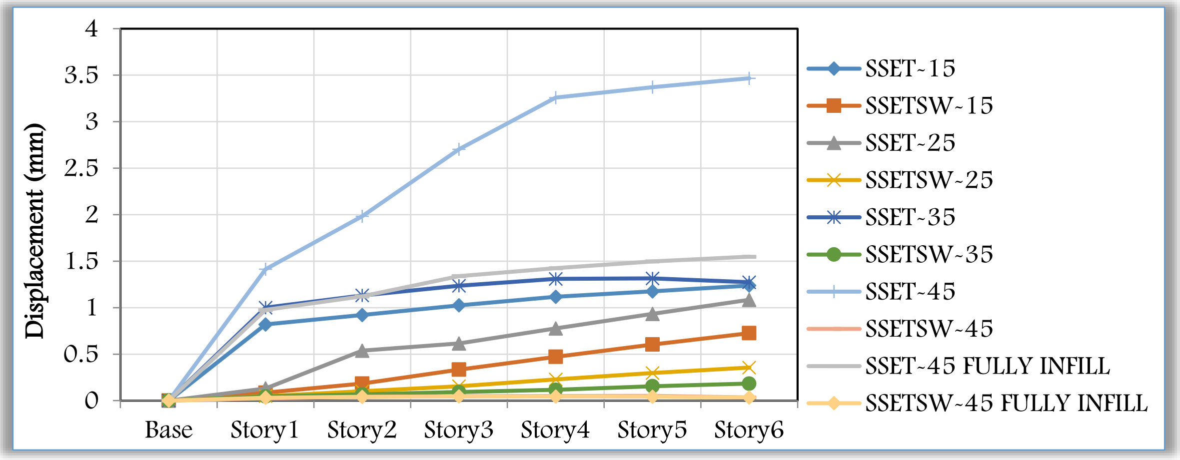


Figure 19. Variation of storey displacement NLTHM for Step back-Set back building

— **Drift**

Storey drift profiles in major direction (X direction) and minor (Y direction) of force, with the storey height for different models in NLTHM are shown in Figure 20 & 21.

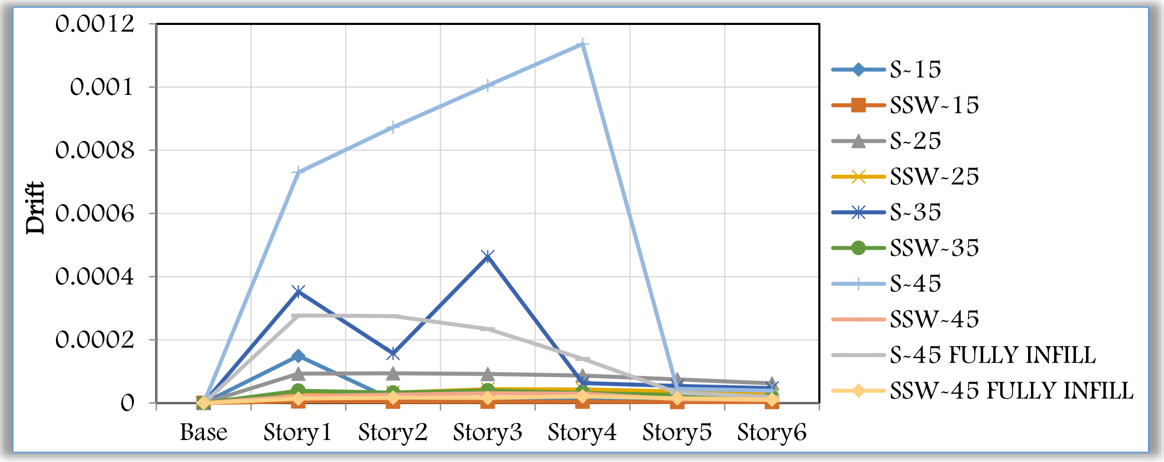


Figure 20. Variation of storey drift NLTHM for Step back building

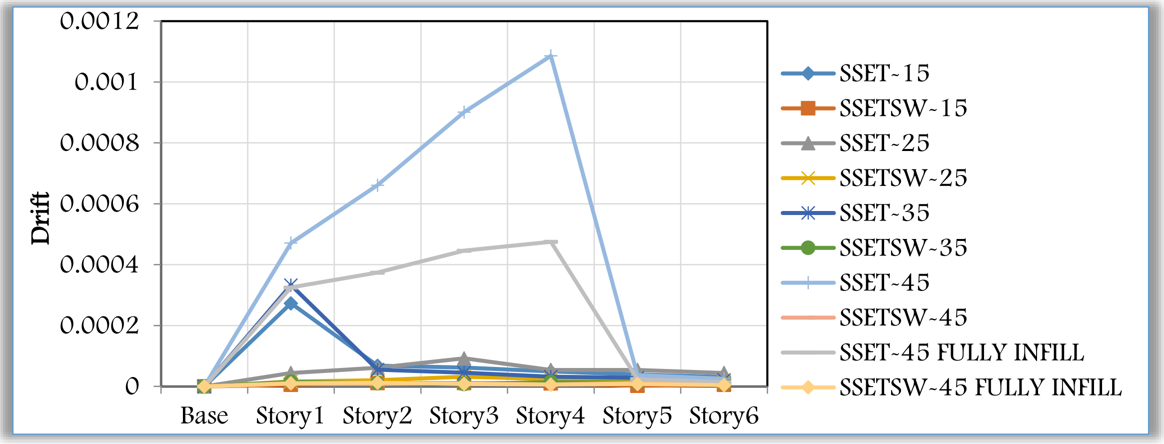


Figure 21. Variation of storey drift NLTHM for Step back-Set back building

7. CONCLUSIONS

In this paper, the seismic analysis of the structures resting on different slope angle with and without corner shear wall consideration is performed in static and dynamic methods. Structures on the sloping ground are found as more vulnerable than the structures on the plain ground, and the degree of vulnerability increases with increment of slope angle. Step back–Set back building configuration having 19% less base shear compared to the Step back building on different sloping ground. According to results and observed that base shear decreases from lower angle to higher angle. The Step back-Set back building configuration having 25% less displacements, 36% less storey drifts compared to the Step back building. In presence of the shear wall at corner of the building having 91% to 95% less displacements, 56% less storey drift, 48% to 50% less time period, 66% to 70% less torsional response respectively compared to without shear wall. Considering masonry fully infill action 45° modal reduces the induced storey 32% displacements as compared to the open ground storey case. However, Step back & Step back-Set back building infill without OGS (fully infill) provided axial force, shear force & bending moment has been decreased by 73%, 63% & 65% respectively. The building which are resting on sloping ground are subjected to short column effect attract more axial force, bending moments and shear forces worst affected during seismic excitation. So, special attention is required while detailing and designing there short columns. According to nonlinear time history results for both type of building without shear wall most suitable angle is 25°. Step back building without shear found that most critical angle is 45° & 35°. Step back-Set back building without shear wall highly venerable on 45° & 15°. For construction of the building on sloping ground the Step back-Set back building configuration is suitable, along with shear wall placed the corner of the building. Corner shear wall provided good strengthening to the building on sloping ground. There are few limitation of the work such as plan irregularity is not consider here, Soil structure interaction (SSI) is not consider here, Only one-way slope considered. This work is done considering seismic zone V and medium type of soil only. So, the same work can be continued considering other zones and other type of soils.

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