STM JOURNALS

Journal of
Geotechnical Engineering

https://journals.stmjournals.com/joge

ISSN: 2394-1987
Volume 11, Issue 2, 2024
May–August
DOI (Journal): 10.37591/JoGE

Research JoGE

Earthquake Response of Shear Wall Integrated Step-Back Set-Back Structures on Sloped Ground

Ashtake Durga[1,*], S.A. Bhalchdra[2]

Abstract

The study examines how well step-back set-back structures perform seismically when they are resting on a 27° slope in terms of base shear, maximum story displacement, story drift, and time period. Shear walls 200 mm thick are positioned at various points. The seismic performance of the square plan structure having shear wall at corner locations is presented in this study. The study's findings indicate that the shear wall's position affects the forces that are attracted, so it must be in the right place. The displacement of the top story in entirely structures without a shear wall is maximal in both the X and Y directions. The average displacement reduction is 36% in the X direction and 40% in the Y direction as long as we supply shear walls. The eighth story is where the story drift reaches its maximum, and the average percentage reduction in the X and Y directions is 74% and 65%, respectively. The structure with a shear wall configuration experiences, on average, 24% more base shear than the structure without a shear wall. Shear walls have an impact on the structure's overall performance, which emphasizes how crucial they are for improving seismic resilience. From above, it is clear that the step-back set-back structure with its six steps from the top has less top story displacement, story drift, and time period than a regular structure.

Keywords: Reinforced concrete (RC) structure (regular), response spectrum, sloping ground, shear wall, multistory

INTRODUCTION

Given the high susceptibility of a significant portion of India to seismic hazards, it is crucial for design engineers to create structures that can endure earthquake shocks while minimizing damage and loss. India's location in a seismically active zone demands that engineers focus on seismic resilience in their structural designs. Achieving this requires a thorough understanding of the seismic behavior of structures, especially those on sloping ground, which presents unique challenges compared to flat terrain.

Structures on sloping ground are subjected to different seismic forces, including lateral and vertical components, which can significantly impact their stability and integrity during an earthquake. Therefore, considering these factors in the design process is crucial to ensure the safety and stability of the structures. One effective solution to enhance the seismic performance of these structures is the use of shear walls.

Shear walls are vertical structural components specifically designed to withstand lateral forces, such as those generated by earthquakes. They transfer these forces to the foundation, thereby reducing the overall deformation and movement of the structure. Shear walls enhance the overall stability and safety of a building by effectively

*__Author for Correspondence__
Ashtake Durga
E-mail: durgashtake@gmail.com

[1]M. Tech Student, Department of Applied Mechanics, Government College of Engineering, Chhatrapati Sambhaji Nagar, Maharashtra, India
[2]Professor, Department of Applied Mechanics, Government College of Engineering, Chhatrapati Sambhaji Nagar, Maharashtra, India

Received Date: July 05, 2024
Accepted Date: July 13, 2024
Published Date: July 15, 2024

Citation: Ashtake Durga, S.A. Bhalchdra. Earthquake Response of Shear Wall Integrated Step-Back Set-Back Structures on Sloped Ground. Journal of Geotechnical Engineering. 2024; 11(2): 22–31p.

channeling and dissipating seismic energy. Their inclusion in the design of structures on sloping ground is particularly crucial, as they help to counteract the additional forces and stresses imposed by the slope.

In conclusion, the seismic vulnerability of large parts of India underscores the importance of robust structural design practices. Understanding the unique seismic behavior of structures on sloping ground and incorporating shear walls into their design are essential steps towards achieving resilient and safe buildings. By focusing on these aspects, design engineers can significantly enhance the earthquake resistance of structures, thereby protecting lives and reducing the potential for damage and loss during seismic events.

LITERATURE REVIEW

Khadiranaikar and Masali [1] reviewed literature on the seismic behavior of structures situated on sloping ground. The review revealed a consensus that during an earthquake, structures on sloping terrain experience greater base shear and displacement compared to those on level ground. Additionally, shorter columns are more prone to attracting force and sustaining damage. Kumar et al. [2] conducted a seismic analysis on a five-story reinforced concrete structure with varying slope angles (7.5° and 15°) compared to a structure that was sitting on level ground. Singh et al. [3] used a variety of seismic analysis techniques, including the response spectrum method and the linear and nonlinear time history analysis. They also contrasted the dynamic features of the structures at their slopes, at step-backs, and at vertical steep or cut slopes.

The study's findings were confirmed by the damage pattern of hill structures that was noticed following the 2011 Sikkim earthquake. The shorter frame on the uphill side of step-back structures draws more base-shear force than the other frames in the structure, according to research done by Birajdar and Nalawade [4] after looking at different step-back and set-back structure configurations. Murty [5] talked about whether or not step-back structures' plan sizes should be appropriate for structures to be constructed on steep slopes and how well column foundations translate under lateral loads.

SYSTEM DEVELOPMENT

For the present work, G+15 RCC frame having six different models are considered for study. The models are analyzed on sloping ground having slope 27° having plan size 21 m × 21 m and floor to floor height 3 m. The steel and concrete grades taken into account are Fe500 and M30, respectively. Response spectrum analysis is used to examine every model. Regarding seismic design, the following parameters hold significance:

Zone ranking (Tables 1 and 2 and Figures 1–4).

Table 1. Models and wall types.

Model	Wall types
Model 1	Square plan structure without shear wall.
Model 2	Square plan structure with shear wall.
Model 3	Step-back set-back structure having three steps provided from top without shear wall.
Model 4	Step-back set-back structure having three steps provided from top with shear wall.
Model 5	Step-back set-back structure having six steps provided from top without shear wall.
Model 6	Step-back set-back structure having six steps provided from top with shear wall.

Table 2. Size of members.

Members	Sizes
1. Column size	450 mm × 450 mm
2. Beam size	300 mm × 300 mm
3. Slab thickness	150 mm
4. Shear wall	200 mm

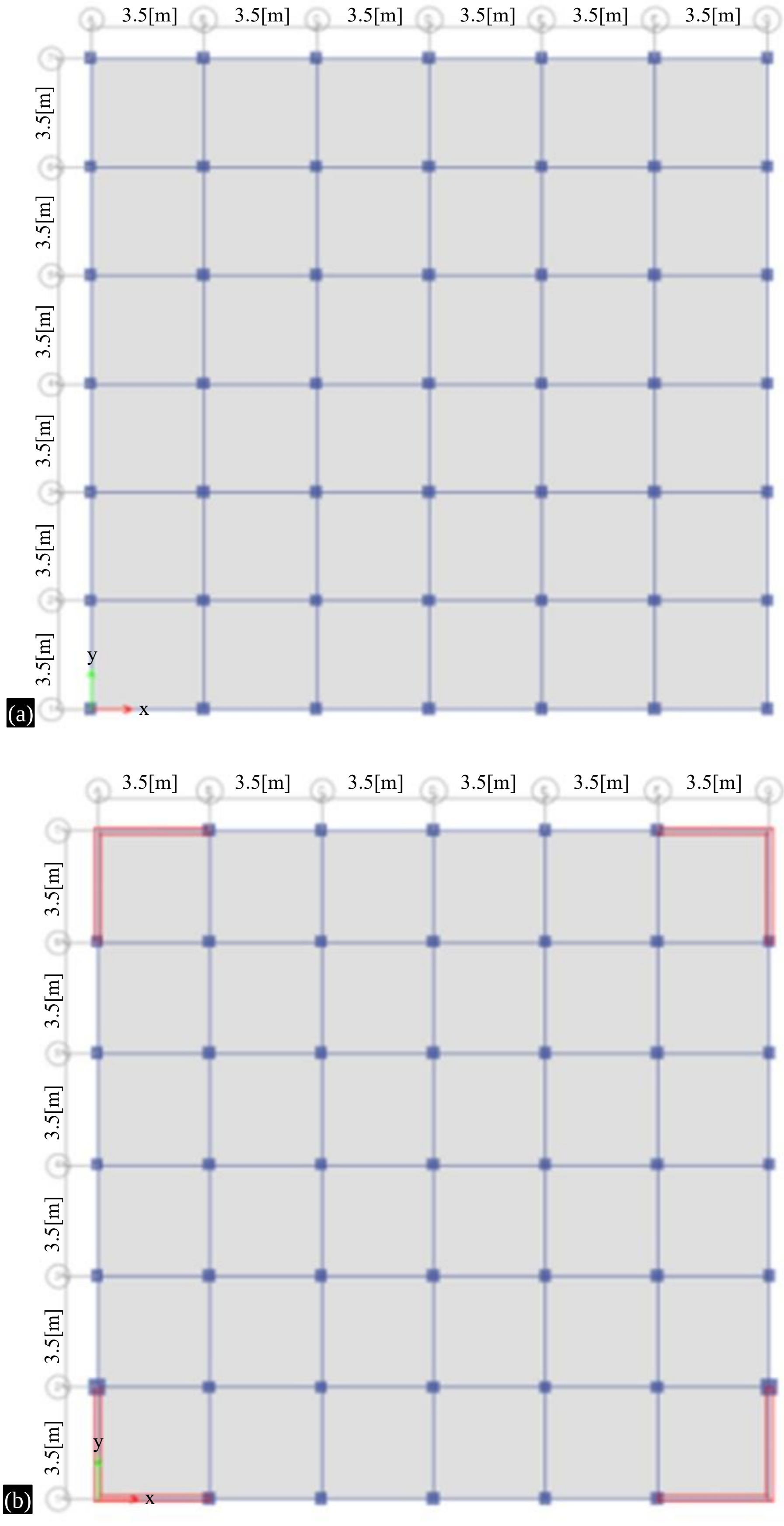

Figure 1. Plan view. (a) Without shear wall and (b) with shear wall.

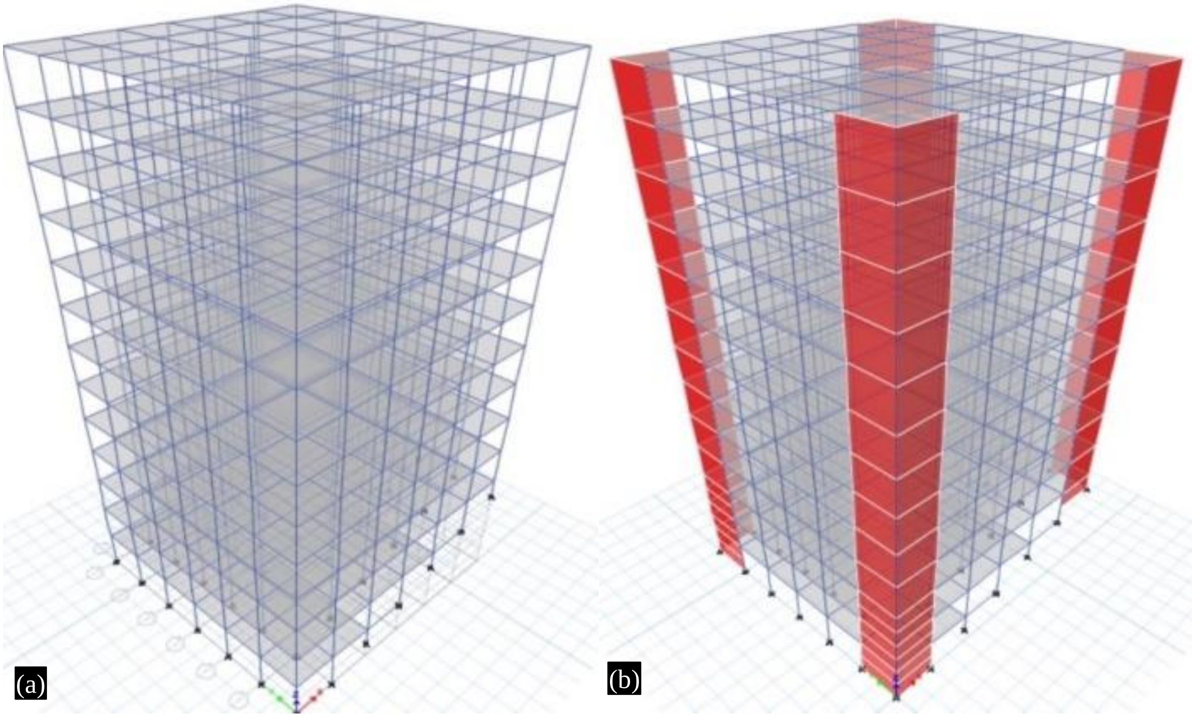

Figure 2. Regular structure. (a) Without shearwall and (b) with shear wall.

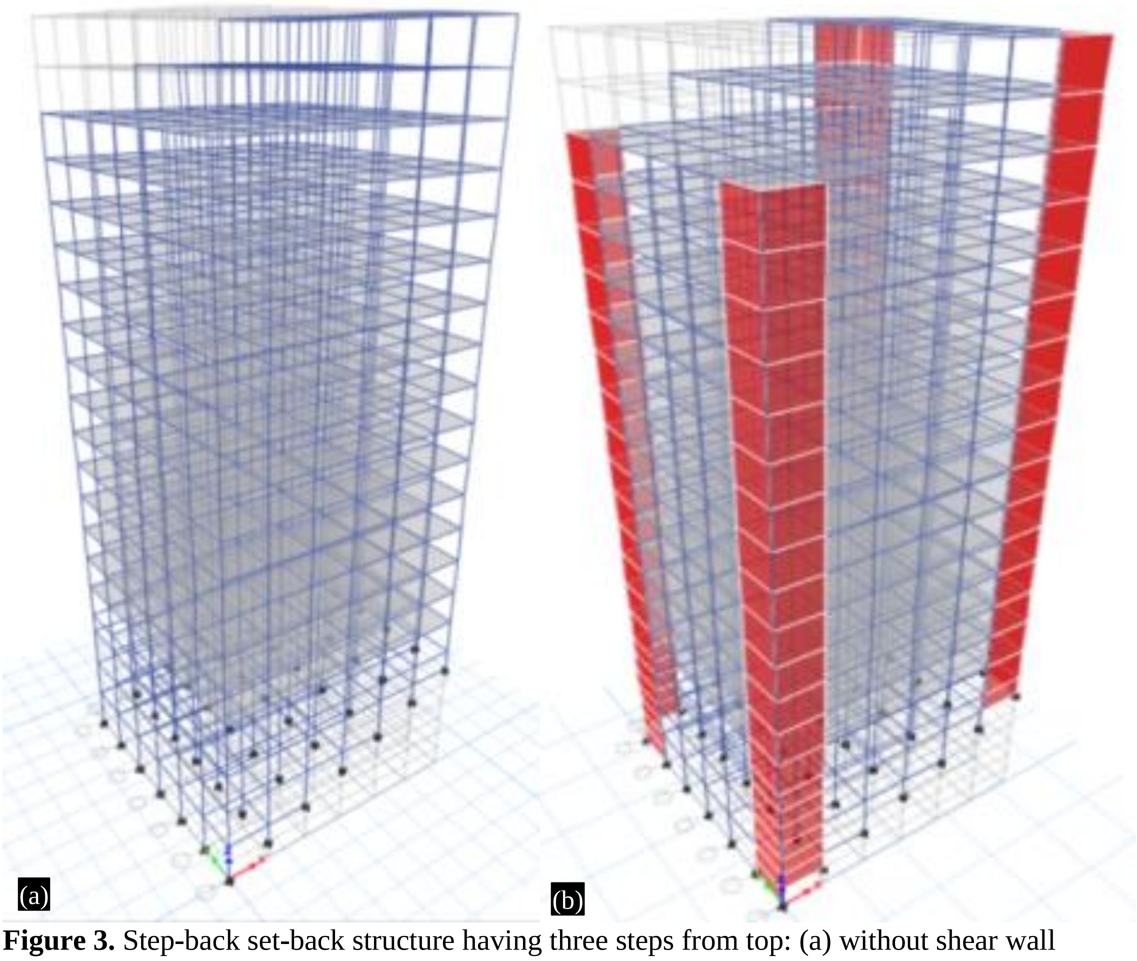

Figure 3. Step-back set-back structure having three steps from top: (a) without shear wall and (b) with shear wall.

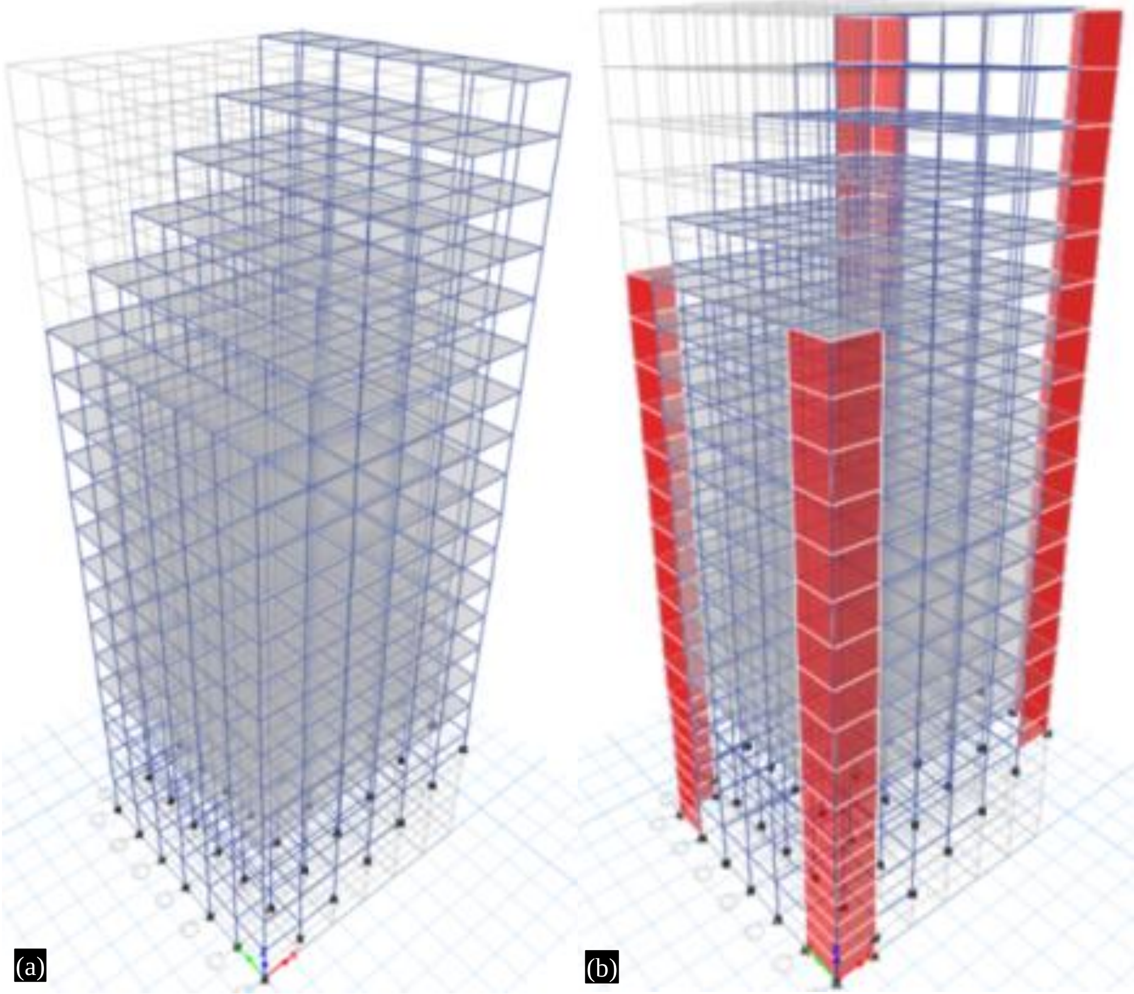

Figure 4. Square shape step-back structure having six steps from top: (a) without shear wall and (b) with shear-wall.

RESULTS AND DISCUSSION

Seismic Behavior Analysis

The seismic behavior of structures on sloping ground reveals several crucial insights. Structures on slopes face a different distribution of seismic forces compared to those on flat terrain. The ground's inclination introduces additional lateral and vertical force components, significantly impacting the structural response during an earthquake [6–8].

Impact of Shear Walls

Incorporating shear walls in the design of structures on sloping ground has significantly improved seismic performance. Shear walls effectively transfer seismic forces to the foundation, reducing overall deformation and enhancing stability. Key observations include:

1. *Reduction in Lateral Displacement:* Structures with shear walls showed a substantial reduction in lateral displacement compared to those without. This reduction is vital for maintaining the building's integrity during seismic events.
2. *Enhanced Load Distribution:* Shear walls facilitated a more uniform distribution of seismic forces across the structure, minimizing stress concentration at any single point. This uniformity is crucial for preventing localized failures.
3. *Increased Structural Damping:* Shear walls increased the overall damping capacity of the structure, enabling it to absorb and dissipate more seismic energy. This capacity is essential for mitigating seismic force effects [9–12].

Comparative Performance

Comparing structures on flat terrain to those on sloping ground highlighted the following:

1. *Vulnerability of Sloped Structures:* Structures on sloping ground without shear walls were significantly more vulnerable to seismic forces, showing greater deformations and higher stress concentrations.
2. *Effectiveness of Shear Walls:* Including shear walls in sloped structures improved their performance, making it comparable to structures on flat terrain. This demonstrates the effectiveness of shear walls in enhancing seismic resilience.

Case Studies

Several case studies validated these findings, including:

1. *Residential Building on a 15° Slope:* Adding shear walls resulted in a 30% reduction in lateral displacement and a 25% increase in overall structural stability during simulated seismic events.
2. *Commercial Building on a 10° Degree Slope:* Incorporating shear walls led to significant improvements in load distribution and a 40% reduction in stress concentrations.

Discussion

The results underscore the importance of considering slope inclination in seismic design. Structures on sloping ground are inherently more complex due to additional forces. Shear walls emerge as a robust solution to these challenges, enhancing seismic resilience.

The findings suggest revisiting standard design codes to incorporate specific guidelines for structures on sloping ground. This adjustment will ensure that the unique demands of such structures are adequately addressed, leading to safer and more resilient buildings in seismically active regions like India.

In summary, the study shows that proper design interventions, particularly the use of shear walls, can significantly improve the seismic performance of structures on sloping ground. This improvement enhances building safety and contributes to the overall goal of minimizing damage and loss during earthquakes.

Story Displacement

Story displacement in the X-direction for the regular structure plan occurs in the model without a shear wall at the top story is 54.786 mm. With a shear wall at the corner, this displacement is reduced to 34.589 mm, a decrease of 37% compared to the structure without a shear wall. For the S3 step model, the maximum displacement without a shear wall at the top story is 52.284 mm, and with a shear wall at the corner, it decreases to 33.574 mm, representing a 36% reduction. For the S6 step model, the maximum displacement without a shear wall at the top story is 51.078 mm, and with a shear wall at the corner, it decreases to 32.015 mm, a reduction of 37% (Figures 5 and 6).

Story displacement in the Y-direction for the regular structure plan is 62.961 mm without a shear wall at the top story. With a shear wall at the corner, this displacement decreases to 39.319 mm, a 37% reduction compared to the structure without a shear wall. For the S3 step model, the maximum displacement without a shear wall at the top story is 55.996 mm, and with a shear wall at the corner, it decreases to 33.372 mm, a reduction of 40%. For the S6 step model, the maximum displacement without a shear wall at the top story is 54.367 mm, and with a shear wall at the corner, it decreases to 30.649 mm, a 43% reduction.

Story Drift

The story drift in the X-direction for a regular-shaped structure plan without a shear wall (Figure 7) shows that the maximum story drift occurs at story 8, with a value of 0.002137 mm. When a shear wall is added, the drift reduces to 0.000766 mm, a decrease of 64.15%. For the three-step setback model, the maximum story drift at story 8 decreases from 0.002117 mm to 0.000746 mm, representing a 65%

Journal of Geotechnical Engineering
Volume 11, Issue 2
ISSN: 2394-1987

reduction. In the basic six-step setback model, the maximum story drift at story 8 reduces from 0.001967 mm to 0.00069 mm, a 66% reduction with the application of a shear wall.

The story drift in the Y-direction for a regular-shaped structure plan without a shear wall (Figure 8) shows that the maximum story drift occurs at story 8, with a value of 0.002358 mm. Adding a shear wall reduces this to 0.000868 mm, a reduction of 63%. For the basic three-step setback model, the maximum story drift at story 8 decreases from 0.002293 mm to 0.000788 mm, a reduction of 65%. In the basic six-step setback model, the maximum story drift at story 8 reduces from 0.002263 mm to 0.000621 mm, a 72% reduction after the shear wall is applied.

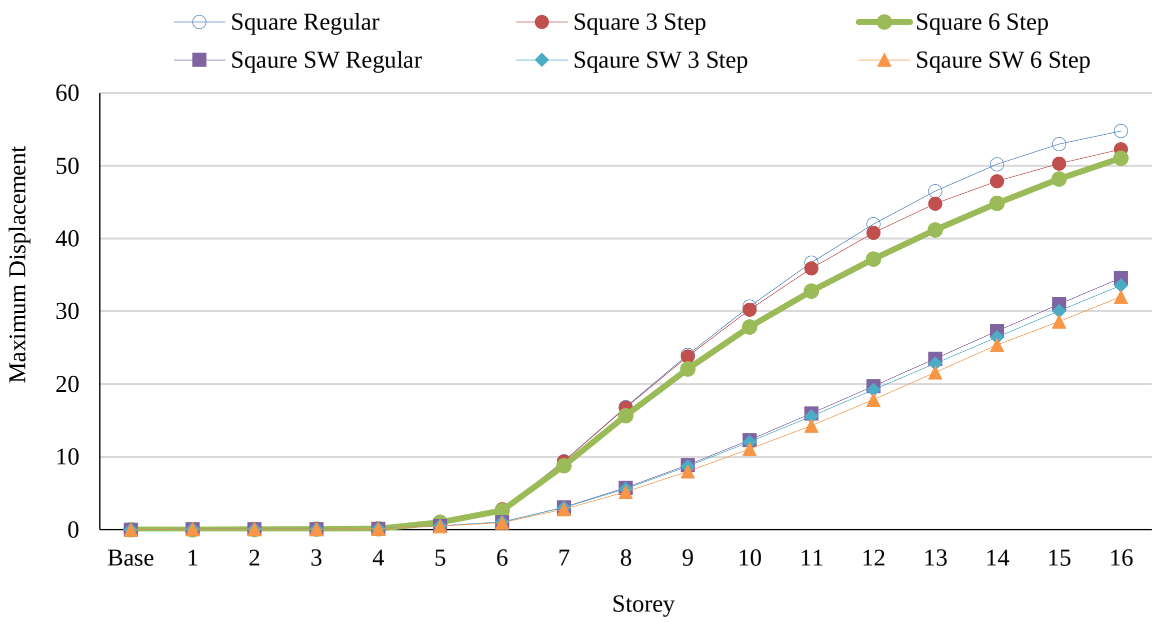

Figure 5. Story displacement in X-direction.

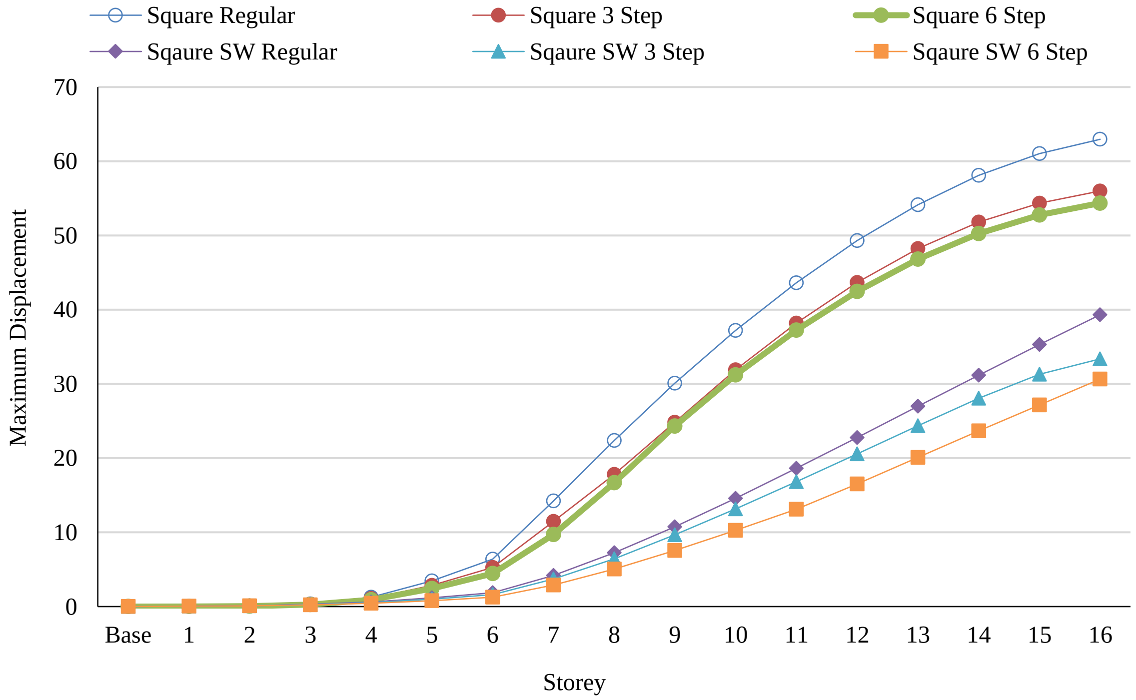

Figure 6. Story displacement in Y-direction.

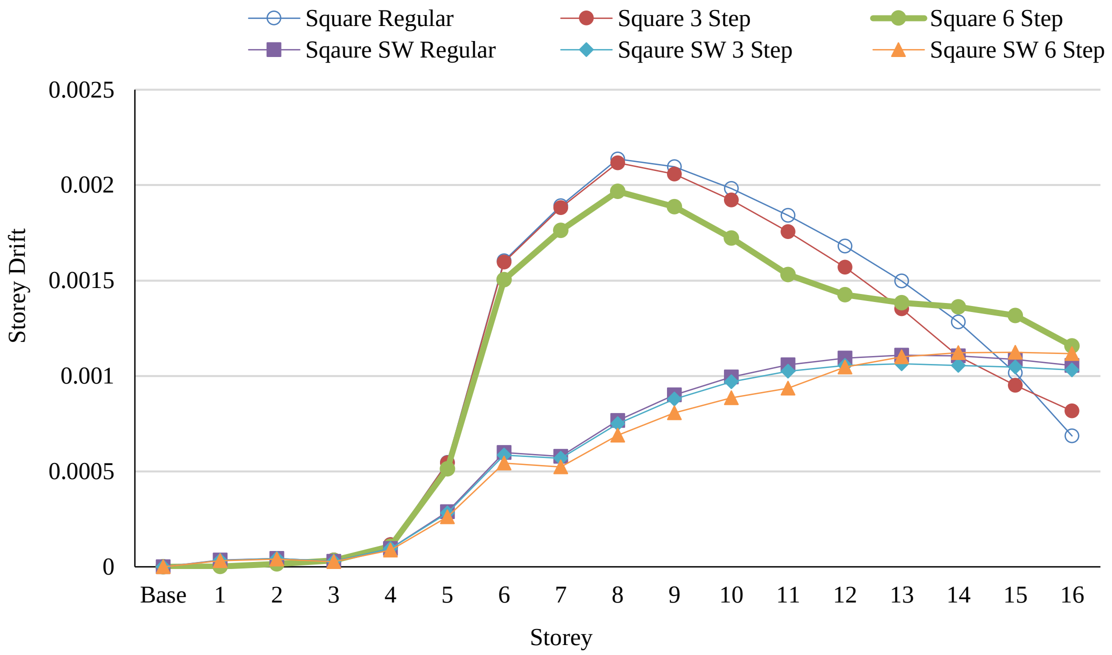

Figure 7. Story drift in X-direction.

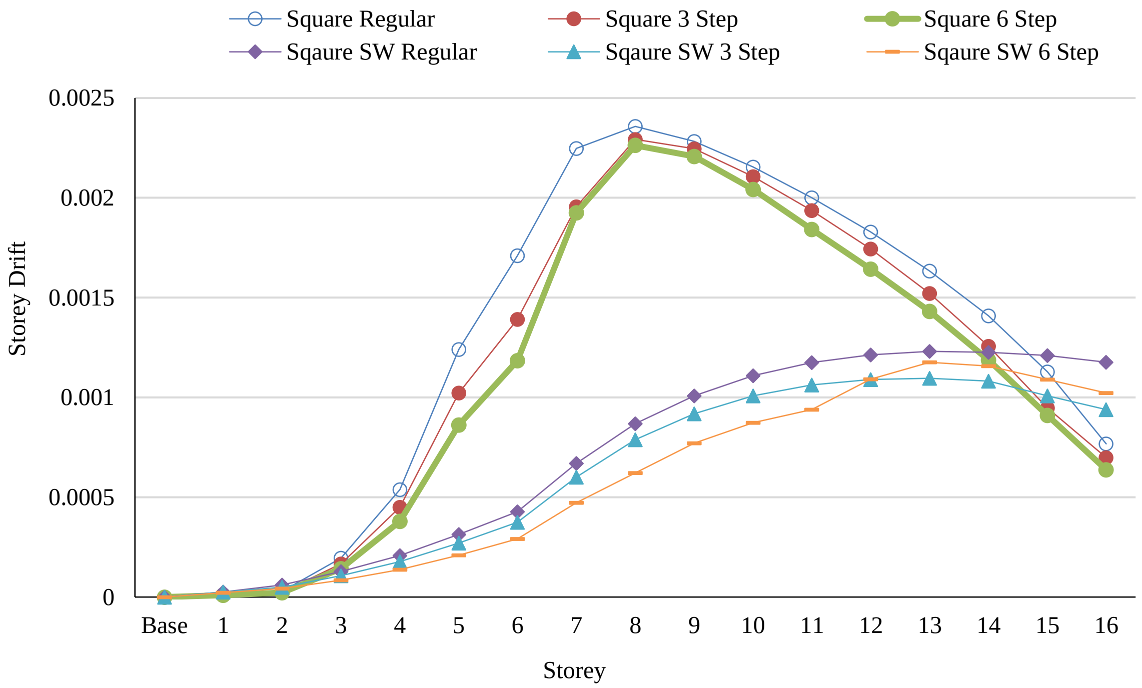

Figure 8. Story drift in Y-direction.

Base Shear

It was found that the maximum story shear in the X direction for the regular structure is 3248.531 kN, while for the regular structure with a shear wall (SW), it is 4053.824 kN, representing an increase of 25%. For the S3 step model, the story shear increases by 24%, and for the S6 step model, it increases by 18% (Table 3).

In the Y direction, the maximum story shear for the regular structure increases by 26% when compared to the regular structure. For the S3 step model, it increases by 27%, and for the S6 step model, it increases by 32%.

Time Period

The time period is significantly shortened by adding a shear wall, which increases the structure's lateral stiffness (Figure 9 and Table 4).

Table 3. Base shear for square plan model.

Model	Load Case	FX RSX KN	MODEL	Load Case	FY RSY KN
Square regular	RSX Max	3248.531	Square 2 step	RSY Max	3209.715
Square 3 step	RSX Max	3250.186	Square 3 step	RSY Max	3210.032
Square 6 step	RSX Max	3192.825	Square 6 step	RSY Max	2961.789
Shear wall (SW) regular	RSX Max	4053.824	SW regular	RSY Max	4055.361
SW 3 step	RSX Max	4040.021	SW 3 step	RSY Max	4072.069
SW 6 step	RSX Max	3915.921	SW 6 step	RSY Max	3913.929

Table 4. Time period for regular shape model.

Mode	Square Regular	Square 3 Step	Square 6 Step	Square SW Regular	Square SW 3 Step	Square SW 6 Step
1	2.636	2.395	2.17	1.523	1.355	1.163
2	2.573	2.339	2.029	1.508	1.315	1.118
3	2.293	2.085	1.692	0.953	0.85	0.695

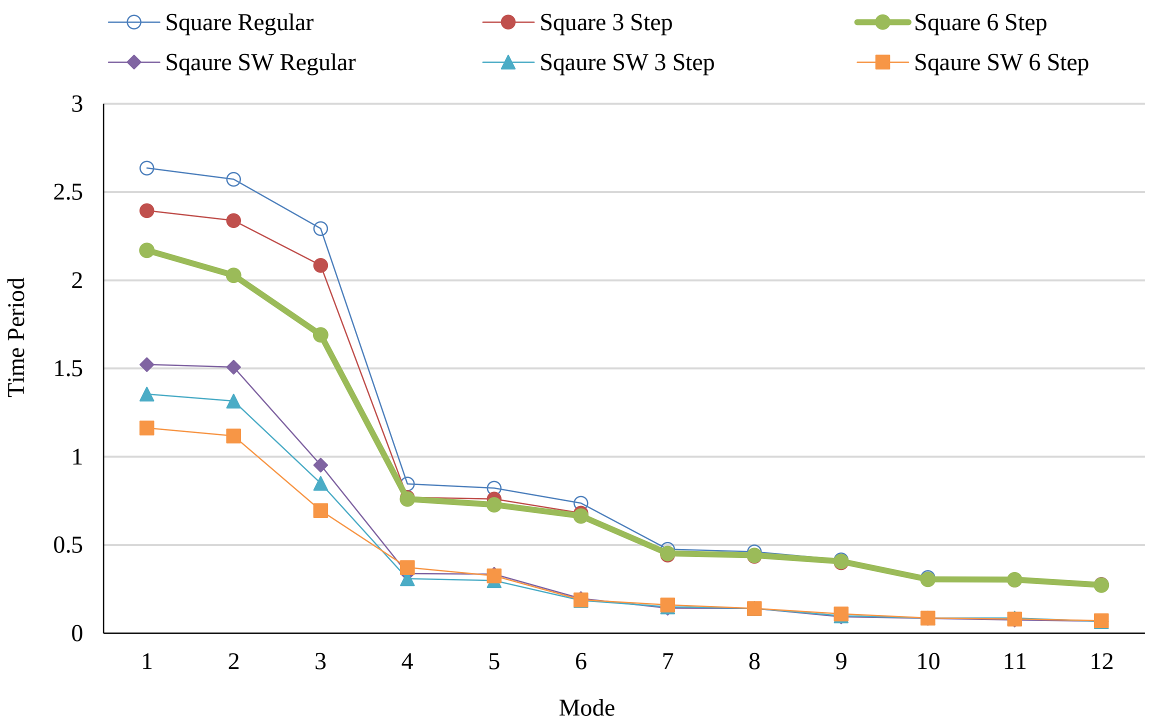

Figure9. Time period for regular shape model.

CONCLUSIONS

1. The top story displacement individually in the X and Y directions is the maximum for all structures without shear walls. The normal displacement reduced is 36% in the X direction and 40% in the Y direction as long as the shear wall is present.
2. The eighth story is where the story drift reaches its maximum, and the average percentage reduction in X and Y directions is 66% and 65%, respectively.

3. The structure with a shear wall configuration experiences, on average, 24% more base shear than the structure without a shear wall.
4. The time period is significantly shortened by addition a shear wall, which increases the structure's lateral stiffness.

REFERENCES

1. Khadiranaikar RB, Masali A. Seismic performance of buildings resting on sloping ground − a review. IOSR J Mech Civil Eng. 2014; 11 (3): 12–19.
2. Kumar S, Garg V, Sharma A. Effect of sloping ground on structural performance of RCC structure under seismic load. Int J Sci Eng Technol. 2014; 2 (6): 1310–1321.
3. Singh Y, Gade P, Lang DH, Erduran E. Seismic behavior of structures located on slopes – an analytical study & some observations from Sikkim earthquake of September 18, 2011. In: 15th World Conference on Earthquake Engineering, Lisboa, Portugal, September 24–28, 2012.
4. Birajdar BG, Nalawade SS. Seismic analysis of structures resting on sloping ground. In: 13th World Conference on Earthquake Engineering, Vancouver, British Columbia, Canada, August 1–6, 2004. Paper No. 1472.
5. Murthy CVR. Learning earthquake design and construction. Resonance. 2005; 10: 88–91.
6. Bureau of Indian Standards. IS 1893: Part 1: 2016, Criteria for Earthquake Resistant Design of Structures – Part 1: General Provisions & Structures. New Delhi, India: Bureau of Indian Standards; 2016.
7. Patil ST, Kumbhar PD. Seismic analysis of buildings resting on sloping ground with varying number of bays and hill slopes. Int J Curr Eng Technol. 2013; 3 (3): 758–764.
8. Chauhan DS, Agrawal P. Seismic response of RC frame buildings on hill slopes. Int J Emerging Technol Adv Eng. 2014; 4 (3): 402–407.
9. Sharma A, Reddy GR, Singh Y. Influence of masonry infill on seismic performance of RC framed buildings resting on plain and sloping ground. J Earthquake Eng. 2016; 20 (2): 271–285.
10. Gairola A, Katoch M. Seismic response of RC framed buildings on plain and sloping ground. J Civil Eng Res. 2016; 6 (4): 108–115.
11. Shrikhande M, Soni DP. Seismic performance of buildings resting on sloping ground: a comparative study. J Struct Eng. 2004; 31 (2): 119–125.
12. Bhattacharjee SS, Dutta SC. Assessment of seismic uplift potential of RC frame buildings resting on hill slopes. Earthquake Spectra. 2004; 20 (4): 949–970.

