Turkish Journal of Computer and Mathematics Education *Vol.13 No.03 (2022), 360-371*

Research Article

Seismic Performance Analysis on Different Plan Configuration of Multi-Storeyed Building Using Rocking Shear Wall

Devyani Mali[1], Jagruti Patil[2], Ankita Thorat[3]

[1]Post Graduate Student, Dr. Vishwanath Karad MIT World Peace University, Pune, 411038, India
[2]Assistant Professor, Dr. Vishwanath Karad MIT World Peace University, Pune, 411038, India
[3]Assistant Professor, Dr. Vishwanath Karad MIT World Peace University, Pune, 411038, India

Abstract: Over the last few years, Studies have noted damaging avoidance design ideology as an alternative to conventional design ideas, as these are an intrinsically significant detriment. In order to achieve this, the self-centering damage avoidance rocking system, an approach for restricting seismic forces to structures coupled with energy dissipating technology and restoring force systems has been developed. The seismic behavior of rocking mechanisms on precast segmental bridge abutments, shear walls, and steel braced frames have been the subject of several research. A few works have recently explored the behavior of the rocking systems, although there are still questions regarding the specifics and responsiveness of this system. Thus, the purpose of this paper is to examine the application of rocking shear walls in G+14 multi-storeyed residential buildings with a variety of plan configurations, such as rectangular, C-shape, and T-shape, all of which have the same floor area, as well as to investigate the nature of the earthquake-exposed structure by using non-linear time history analysis. Using well-known FEM integrated software called ETABs 2018, the analysis and modelling for SMRF building (three cases of rocking structures, three cases of conventional shear walls, and three reinforced concrete bare frames) is carried out in seismic zone III of India as mandated by IS 1893 (Part-1)-2016. It is concluded that structures with rocking shear walls will perform better in terms of all seismic characteristics like storey drift, storey displacements and base shears than structures with traditional shear walls.

Keywords: Rocking Shear Wall, Self-Centering Tools, Energy Dissipation, Nonlinear Time History Analysis.

1. Introduction

Researches have revealed recently that employing rocking mechanisms will lessen the damage that structures sustain during major earthquakes. The base rocking system is anticipated to reduce damage and enhance post-earthquake serviceability demand in compare to conventional seismic design methods, which leave structures intrinsically vulnerable to damage and incur devastating financial losses due to repair or replacement along with downtime. Accordingly, damage avoidance design (DAD) philosophy has been proposed by researchers [1]. To effectively manage larger lateral force requirements and nonlinear destabilization following devastating seismic events, such an approach was already incorporated with swaying, structural elasticity, post tensioning equipment, and energy absorption tools. For the purpose of assessing the seismic response of rocking mechanisms with regards to self-centering equipment, energy dissipation devices, impact at the base, fundamental values and distribution of the relevant design requirements, a significant number of computational and experimental research has been carried out. The bulk of documented works have emphasized the dynamic excitation of precast bridge abutments, while only a few studies have concentrated on the seismic efficacy of precast rocking shear walls with rocking at the base. Rocking action at the base is provided by base-rocking wall systems. The foundation and wall are joined by post-tensioned (PT) tendons. The wall panel's base or sides are where the energy dissipating components are mounted. Fig. 1 represents this system's essential behavioral components in a schematic manner. The pioneer research on Self-Centering Base-Rocking (SCR1) wall systems was done by **Perez (1998)** at the Lehigh University [2]. He demonstrated how these systems could be more beneficial than the traditional wall systems.

According to [3], the majority of mid-rise structure demands are governed by modes 1 and 2; whereas, higher modes primarily influence the building's behavior in high-rise structures. As per **Wiebe (2013)** [4], higher modes have detrimental consequences on high-rise base-rocking structures. Also, it was demonstrated that these impacts could seriously affect the building if they were not considered throughout the planning stage. However, developing the structure to counteract these impacts might lead to an uneconomical design. **Wiebe (2013)** [4] proposed multiple-rocking walls that provide the rocking movement at several story levels as a solution to this problem. He demonstrated how the structure is helped to deform in accordance with the higher-mode shapes by the multiple-rocking behavior. The higher-mode produced forces in the wall are then relieved as a result of this flexibility. Researchers **Wiebe, C. Christopoulos (2009)** [5] and **Khanmohammadi, Sajad Heydari (2015)** [1] looked into how several rocking wall systems could reduce the effects of higher modes. They demonstrated that the shear and moment demands are increased when the rocking wall technology is used in tall buildings. Utilizing a multiple-rocking mechanism over height, however, decreases the requirements. Fig. 2 depicts this occurrence schematically.

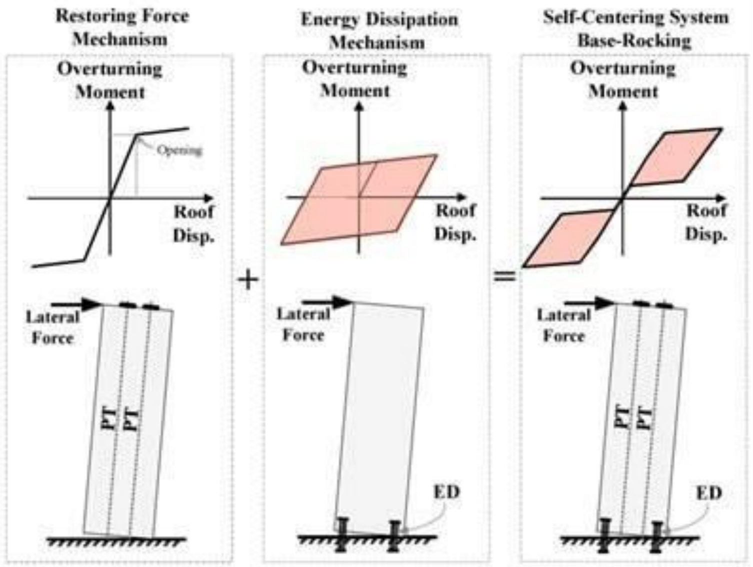
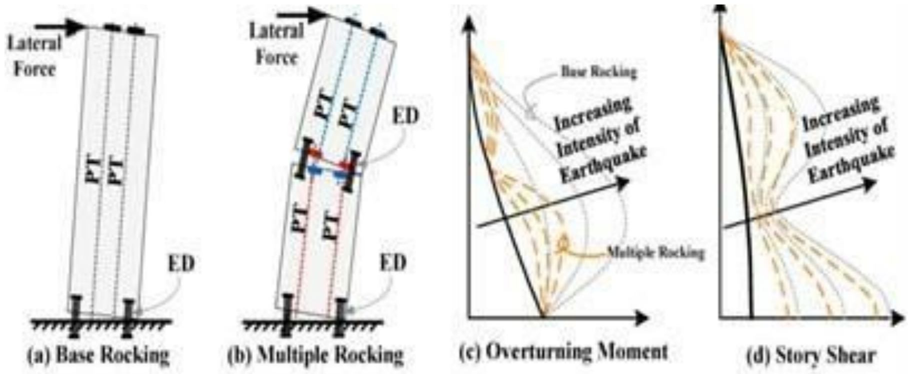


Fig.1 Behavior of self-centering systems [6].



(a) Base Rocking (b) Multiple Rocking (c) Overturning Moment (d) Story Shear

Fig.2 A graphical representation of the force requirements of base rocking and numerous rocking walls [6].

Previous research investigated at how different ground motions affected self-centering rocking devices. The controlled rocking cores (CRCs) based on the dependability of far-field ground motions were examined by **Rahgozar and M. Pouraminian (2021)** [7]. Their findings demonstrated that mid-rise CRCs have a higher failure risk than low-rise models. both far-field (FF) and near-field (NF) earthquake ground movements, the CRCs are effective at limiting peak displacements and mitigating residual damage [8]. Rocking wall systems were examined by **Nazari, S. Sritharan, S. Aaleti (2017)** [9] under FF and NF seismic recordings. At the design base seismic level, they demonstrated that these systems behave in a generally satisfactory manner. Nonetheless, these walls exhibit maximum lateral displacements above the permitted limitations as determined by NF seismic recordings at the maximum level regarded to be an earthquake. **Saeed Parsafar and Abdolreza S. Moghadam (2017)** [10] discussed the use of an inventive shear wall technology with fixable connections. The suggested SC-RRCSW concept integrated the benefits of higher early stiffness with significant energy dissipation given by the base rocking technology. **Guiyun Xia (2020)** [11] proposed a continuous model for the initial survey of a rocking shear panel structural system. This model can be used for clamped or rocking shear wall structural designs as well as fixed or pivoted structure well with connecting beam fastened or pivoted at the ends. The rocking shear wall structural frame's shear force and moment distributions become more uniform than the clamped structures.

One of the most prevalent structural solutions in an earthquake-prone area is a reinforced concrete special moment-resistant frame with shear walls. It has been noted that recent large-magnitude earthquakes cause significant damage to these systems, particularly to the shear wall components. Researchers from all over the world have developed self-centering devices using rocking motions as a solution to this issue. **Housner (1963)** [12] was the first to look at the idea of rocking movement in engineering structures after analyzing how such systems behaved after the May 1960 Chile seismic event. Many structures unexpectedly swayed on their bases during this event without falling. The key features of these techniques are their ease of self-stabilization following a significant seismic event and the expected reduction in damage to the main load-bearing components. Employing such systems, though, involves considerable difficulties in practical construction and could not be cost-effective. To this purpose, researchers have attempted in recent years to alleviate such shortages by adding a few energy-dissipating components that may be coupled to the primary structural systems. This will ensure that the main structure is safe and unharmed and the most of the damage will be centered at these energy dissipating devices, which can be readily fixed or replaced after the seismic event. There hasn't been a thorough investigation of the effectiveness of several rocking panels over the height of shear walls or reinforced concrete structures, despite the fact that the earthquake behavior of rocking techniques for bridge abutments and shear walls was previously thoroughly documented. Moreover, to assess the effectiveness of numerous rocking mechanisms, a finely tuned and concise nonlinear model must be used at the rocking segments and across the height of the structure; in addition, to create entirely different framework damage avoidance design ideology, all the considered design criteria that affect a building's performance should be examined. Thus, the precise model of rocking systems was used in the current research to perform an extensive analysis.

Additionally, the effectiveness of deploying multiple rocking sections on structures with shear walls was examined for the G+14 multistorey residential buildings with a variety of plan configurations, such as rectangular, C-shape, and T-shape, all of which have the same floor area and numerous rocking portions on each second story. The nonlinear time history analysis and modelling for SMRF building (three cases of rocking structures, three cases of conventional shear walls, and three reinforced concrete bare frames) is carried out in seismic zone 3 of India as mandated by IS 1893 (Part-1)-2016. The results were contrasted between traditional shear wall systems and RC bare frames in terms of all seismic properties, including base shears, base displacements, and storey drift.

1.1 Rocking Nature and Nonlinear Modelling

A rocking shear wall has two purposes: to decrease or completely eliminate drift intensity and offering adequate support for energy dispersion components. For the purpose of allowing for unrestricted rotation and relieving demands for bending moments, the linkage of the base rocking mechanism is disconnected at the contact surface. It is broadly acknowledged that rocking sections reduce shear-induced sliding movement. As a result, models of rocking behavior are roughly nonlinear, flexible, and possess minimal material nonlinear characteristics and dissipate energy due to hysteric behavior. Although this behavior has been safe, it does not provide sufficient stress-strain energy to meet seismic demands. Hypothetically, this mechanism seems secure till extreme deflections or toe wrecking just at base lowers lateral stiffness and after that destabilization is unavoidable. A dissipation energy device must be added in order to address this response insufficiency. Additionally, it is important to consider where to place and what kind of energy absorbing equipment to use. Meanwhile, the present work did not concentrate on such issues. The hysteretic behavior will alter when any dissipation energy device is used, going from almost elastic or flexible nonlinear towards flag-shaped characteristics. Furthermore, a device has often been typically developed to restore the structure to its original position following earthquakes. The self-centering and yielding lateral force properties have both been greatly enhanced by the introduction of post-tensioning cables. The current paper evaluated all pertinent rocking segment mechanisms across the elevation of the shear walls. Designing the movement of the neutral stress axis between contact surfaces is a crucial key factor in designing rocking segments. A number of 100 mm and 20 mm no-tension spring elements that are placed all over the contact surface are defined to represent contact behaviors and shifts in neutral axes. For the purpose of determining the force-displacement characteristics of springs, the area for every spring has been evaluated from the area of the prestressing cable. The spring force is calculated from the effective diameter of the spring and minimum tensile strength as per the IS 1785 (Part 1) 1983. This model would take into account neutral stress axes shifting and interface separation, which was also predicted to enhance the outcomes. In the current study, energy dissipation components that have been simulated by mild reinforcing steel were modeled by placing different springs in specific positions and connecting them to the base or bottom section using a horizontally fixed beam. Four number of post-tensioned vertical spring elements (2 numbers of 100 mm length in the top portion and 2 numbers of 20 mm length in the bottom portion from both sides of the central neutral axis) were used instead of post-tensioned cables. Other 8 numbers of (each 100 mm from top and 20 mm length from the bottom portion of rocking shear wall) vertical spring elements which are other than post-tensioned were employed and total of 10 numbers of horizontal spring elements were placed from both faces of rocking shear wall to the columns. The exterior sides of the panels were considered to link up vertically and horizontally to the beam and column faces of that specific storey by all post-tensioning instruments used in the current investigation. Rocking shear wall or rocking sections were provided on alternate stories or on every second storey of building. Depending upon yielding stress and elastic modulus, the yielding strain in this instance had already been determined. It should be noted that no shear displacement has been taken into account during the rocking portions and that the in-plane shear characteristics of wall sections had considered to be flexible in order to reduce complications in the results and analysis. Out-of-plane characteristics has been Elastic behavior has been depicted for out-of-plane properties. as elastic behavior. Choosing the characteristics of vertical post-tensioned springs to meet the requirement for unrestricted rotation and liberating bending moment to overcome the constraint of using post-tensioning cables and to install an energy dissipation device to compensate for the lack of hysteretic energy production needed to meet seismic demands which can be the gap analysis for this research.

2. Objectives of the Study

- To analyze the SMRF structures using nonlinear time history analysis for base shear, storey displacements, and storey drifts in various plan geometries, including rectangular, C-shaped, and T-shaped.
- To compare the outcomes with the performance of multi-story buildings (RC bare frame) with traditional and rocking shear walls installed at the corner edges.
- To investigate how buildings with identical floor areas but differing plan configurations respond to rocking sections installed at every second storey of the building.

3. Methodology

The analysis is conducted for a (G+14) reinforced concrete special moment-resisting frame building with identical floor area and rectangular, C-shaped, and T-shaped geometries. To undertake a nonlinear time history analysis, the building of (G+14) has been modelled using a rocking shear wall and conventional shear wall with all necessary parameters. For each model, the outcomes of base shears, storey drifts, and storey displacements are computed and compared. In order to comprehend how the building will respond to earthquakes, ETABS software was used to construct it as a 3D space frame model. Columns and beams are modelled as frame elements for modelling purposes. Using the link or support springs property, post-tensioned springs (vertical) and other types of post-tensioned springs (vertical and horizontal) are installed. The support condition is fully fixed. For this work, the Bhuj Earthquake with a 5% damping is taken into consideration.

Table 1. Specifications of Structure

Parameters	**Details**
Type of structure	Multistorey RC frame (G+14)
Floor area	245 m²
Height of building	45 m
Floor to Floor height	3 m
Size of Beams	250 mm x 500 mm
Size of Outer corner columns Size of Outer mid columns Size of Inner mid columns	C1 250 mm x 600 mm C2 250 mm x 700 mm C3 250 mm x 750 mm
Thickness of Slab	150 mm
Type of soil	Type-III (medium soil)
Damping	5 %
Support conditions	Fixed
Importance Factor, I	1.2
Response Reduction Factor, R	5
Seismic zone	Zone III
Zone factor	0.16
Grade of concrete	M30
Grade of steel	Fe 500

Table 2. Load Details

Loads on the structure	Value
Floor Finishing Load	1.5 KN/m²
Imposed load on floors	3.0 KN/m²
Imposed load on roof	1.5 KN/m²
Wall load on beams	12.5 KN/m
Equivalent lateral loads	As per IS 1893 (Part1):2016

3.1 Structural Modelling

In this study, comparison of nine models of (G+14) storey building having same floor area provided without and with rocking shear wall (and also conventional shear wall) at corner edges on every second storey of building are to be considered.

1. Structure A: Rectangular structure without shear wall.
2. Structure B: Rectangular structure provided with conventional shear wall.
3. Structure C: Rectangular structure provided with Rocking shear wall.
4. Structure D: T-shape structure without shear wall.
5. Structure E: T-shape structure provided with conventional shear wall.
6. Structure F: T-shape structure provided with Rocking shear wall.
7. Structure G: C-shape structure without shear wall.
8. Structure H: C-shape structure provided with conventional shear wall.
9. Structure I: C-shape structure provided with rocking shear wall.

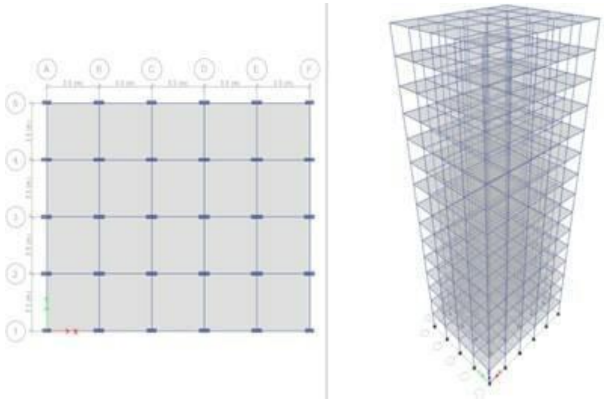


Fig.3 Structure A

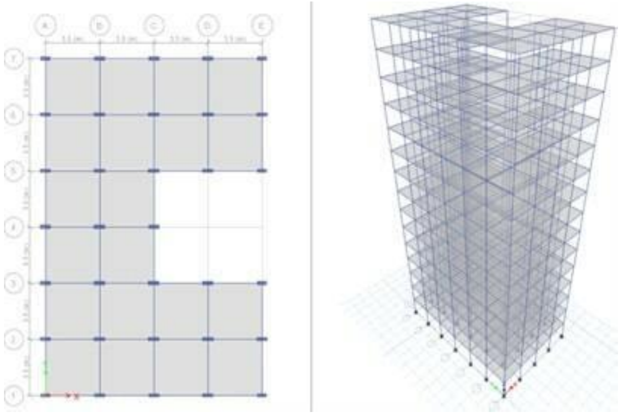


Fig. 4 Structure B

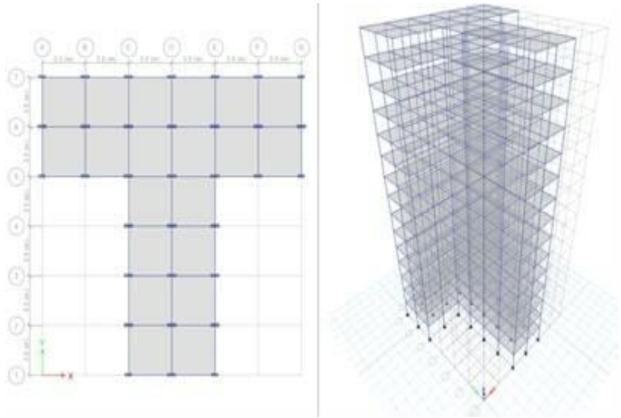


Fig. 5 Structure C

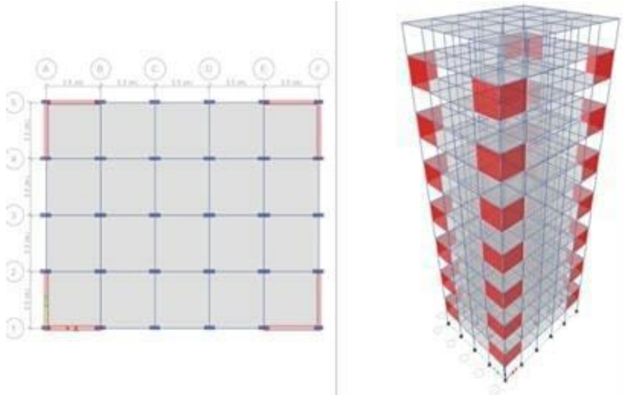


Fig. 6 Structure D

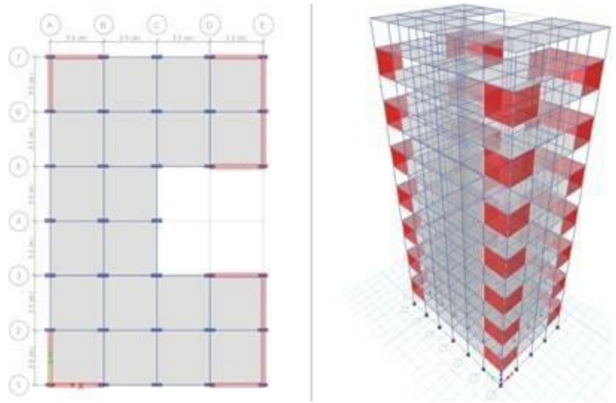


Fig. 7 Structure E

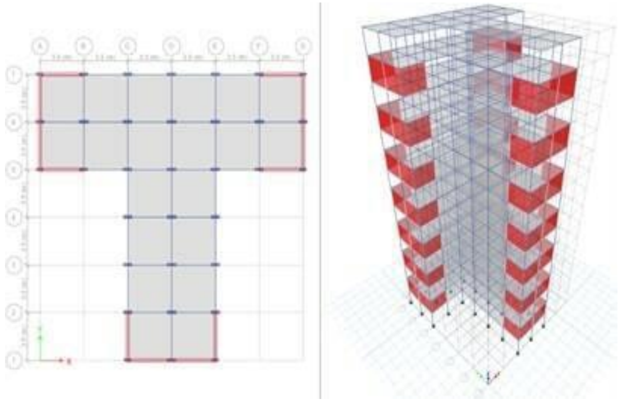


Fig. 8 Structure F

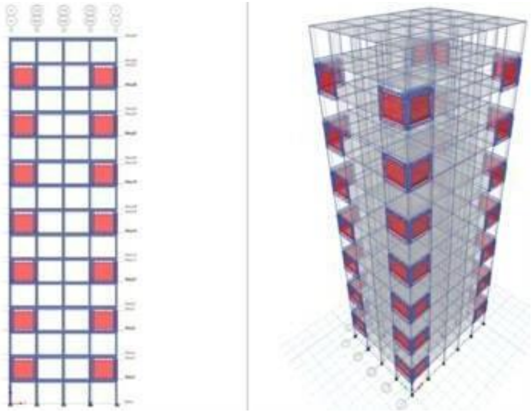


Fig. 9 Structure G

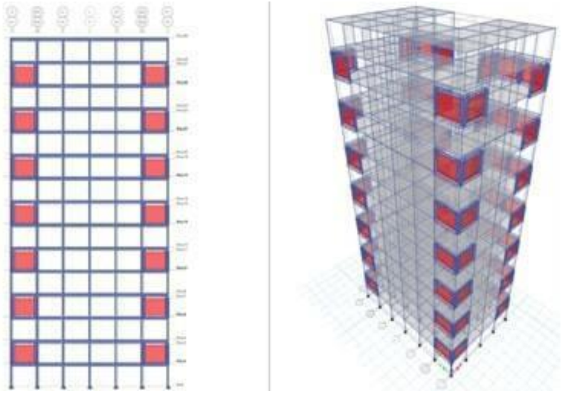


Fig. 10 Structure H

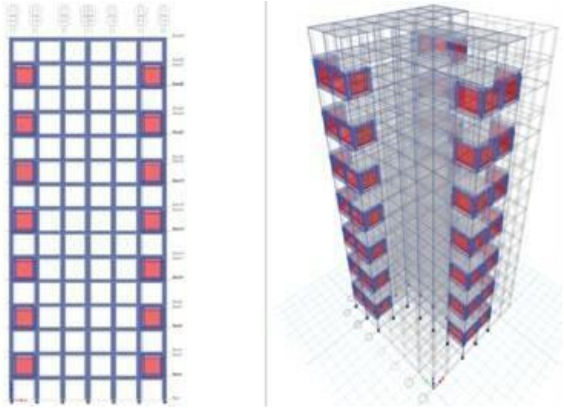


Fig. 11 Structure I

4. Results

A comparative study is done to evaluate effectiveness of rocking sections provided at every second storey of the structure of different plan configurations like rectangular, C-shape and T-shape having same floor area. The non-linear time history method is used to examine 9 models for seismic zone 3 in accordance with IS 1893:2016 (Part1). The considerable fluctuation in seismic characteristics such as base shear, storey drifts, storey displacement with regard to reinforced concrete bare frame, conventional shear wall and rocking shear wall are obtained and discussed in this section.

4.1 Storey Displacements

The deflection or horizontal movement of a single story in context to the foundation or ground level of the structure is known as storey displacement. For all structures, the displacement of the storeys rises from the bottom to the top. It has been found that as storey height rises, the storey displacement also rises. Compared to other shapes of models, the displacement for the rectangular, T-shaped and C-shaped (without shear wall or RC bare frame) model is greater and the displacements for rocking shear wall models are slightly lower than all conventional shear wall models both in x direction and in y direction.

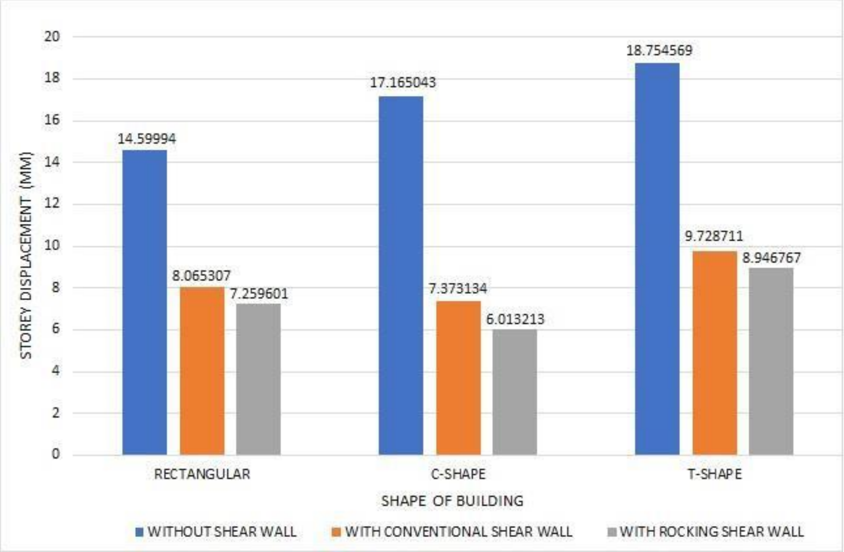


Fig. 12 Maximal Storey Displacement in X-Direction

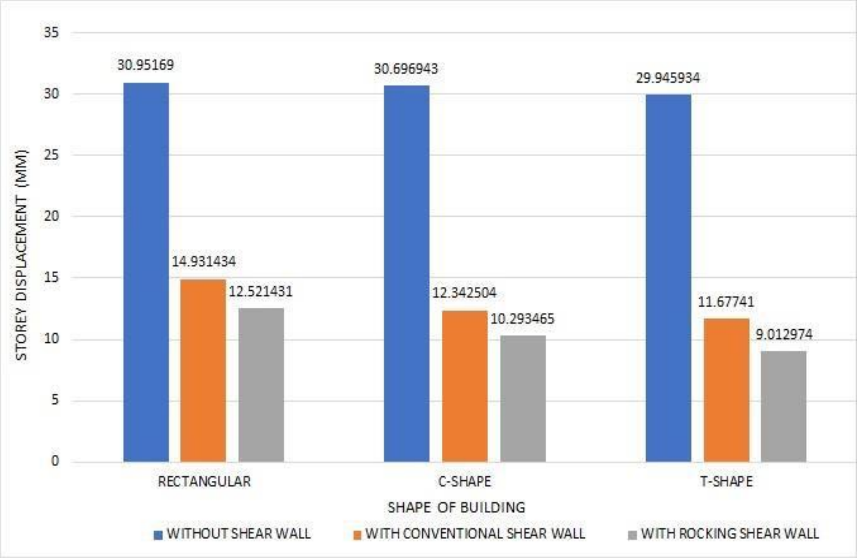


Fig. 13 Maximal Storey Displacement in Y-Direction

4.2 Storey Drifts

Storey drift refers to a floor's horizontal displacement in relation to the floor above or below. For our research work, the maximum permitted displacement to the structure is 0.004H at top, or 180 mm according to IS 1893:2016. While the storey drifts in RC bare structures with rectangular shapes differed slightly, those with C- and T-shaped shapes differed widely in the x-direction. As it can be identified, contrast to conventional shear wall structures and RC bare frames, rocking shear wall constructions depict lower drift values on both the X and Y axes.

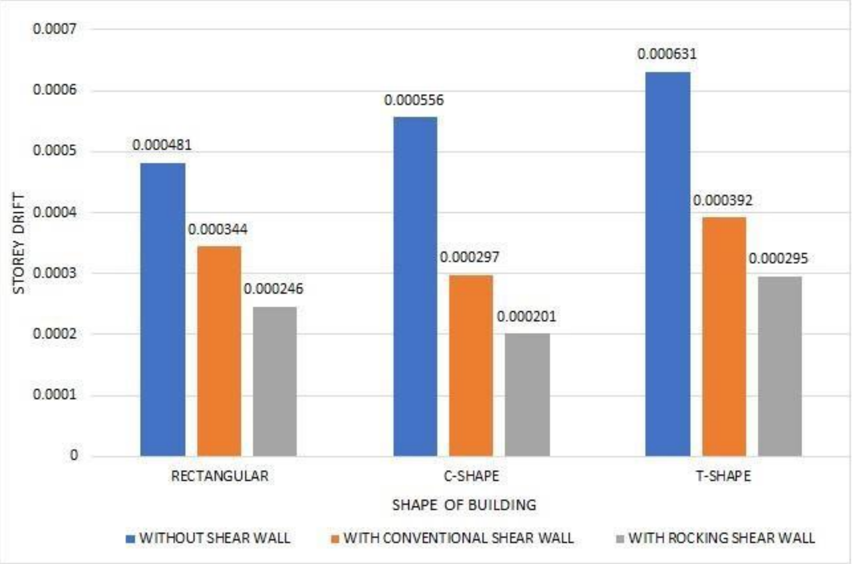


Fig. 14 Maximal Storey Drift in X-Direction

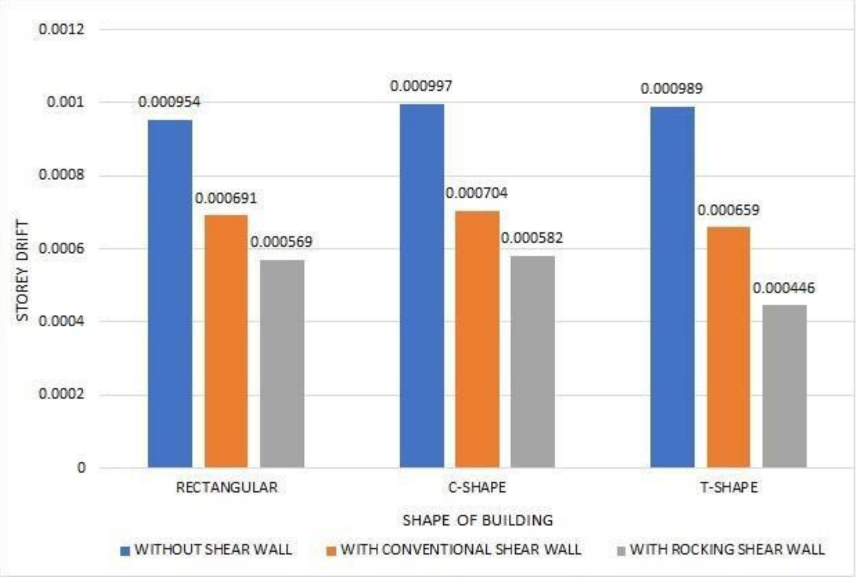


Fig. 15 Maximal Storey Drift in Y-Direction

4.3 Base Shears

The highest predicted lateral force from seismic activity on the foundation of the building is measured as base shear. Base shear reduction minimized the seismic response of building and improved the stability of the structure during an earthquake. It shows that the base shear in rectangular model with rocking shear wall has lesser values than other shapes of conventional shear wall and without shear wall models in both the x and y directions. The values of base shear are more in C-shaped and T-shaped building having conventional shear wall when correlated with rectangular building, indicating that these structures are much more vulnerable to lateral forces and therefore need consistent strength.

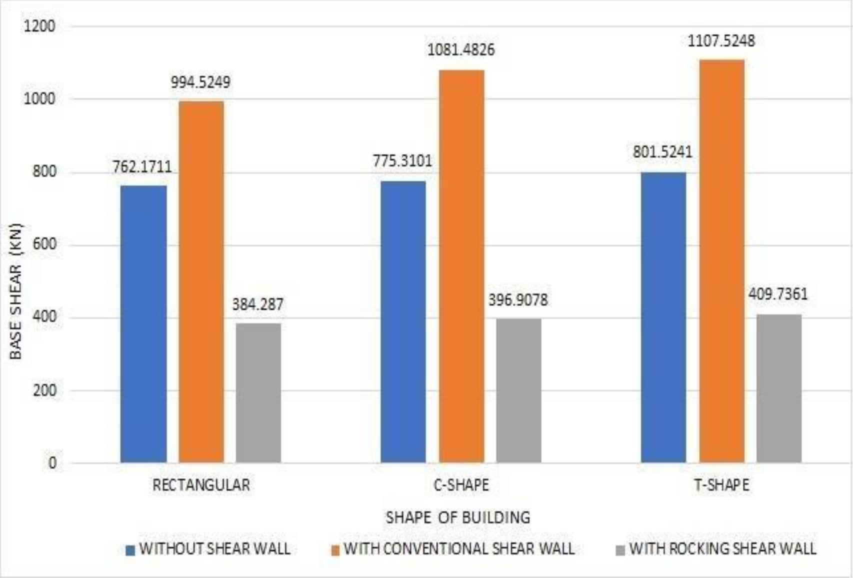


Fig. 16 Maximal Base Shear in X-Direction

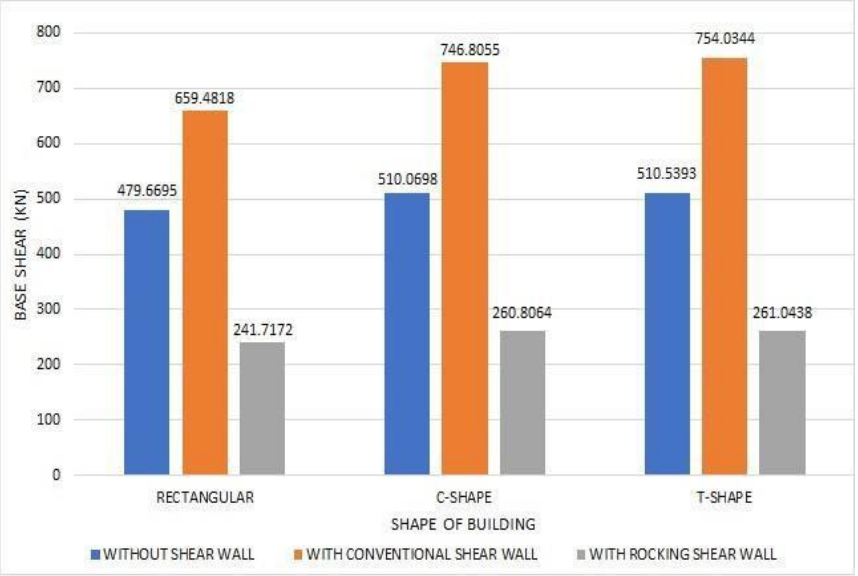


Fig. 17 Maximal Base Shear in Y-Direction

5. Conclusion

Multiple nonlinear history analyses were performed in this research to examine the consequences by employing several rocking sections across the height or elevation of shear wall constructions. In order to do this, nine model (G+14) were chosen and developed for three RC bare frame, three structures with conventional shear wall and three structures with rocking shear wall. The plan geometries with same floor area included rectangular, C-shape, and T-shape. The responses of the considered buildings were examined using accurate and enhanced models. The major conclusions of the analysis were as follows:

- In comparison to a structure without a shear wall, the storey displacement for conventional shear wall structures in the X-direction is reduced by 44.75% for rectangular model, 57.04% for C-shape model, and 48.12% for T-shape model. The reduction in the Y-direction for the rectangular model is 51.75%, for the C-shape model it is 59.79%, and for the T-shape model it is 61%. With reference to the RC bare frame in the X-direction, the decrement for rocking shear wall structures is 50.27% for rectangular model, 64.96% for C-shape model, and 52.29% for T-shape model, while the reduction is 59.54% for rectangular, 66.46% for C-shape model, and 70% for T-shape model in the Y-direction.
- The displacement for the rectangular, T-shaped, and C-shaped (without shear wall or RC bare frame) models is higher than for the conventional and rocking shear wall models, and the displacements for all rocking

shear wall models are slightly lesser than for all conventional shear wall models in both the x and y directions. This is because rocking sections are provided at every second floor of the building.

- Up until a certain point, storey drift is exactly proportional to storey height; however, as building height rises, storey drift tends to drop. Storey drifts for all the nine models are within permissible limits as per IS 1893-2016 (Part-1) that is less than 180mm.

- In relation to RC bare frame models, the percentage decrease of storey drift for conventional shear wall models is observed to be 28.48% for rectangular model, 46.58% for C-shape model, and 37.87% for T-shape model in X-direction. However, in Y-direction, these percentages drop to 27.56% for rectangular model, 29.38% for C-shape model, and 33.36% for T-shape model. In the X-direction, the percentage decline in storey drift for rectangular, C-shaped, and T-shaped rocking shear wall models is 48.85%, 63.84%, and 53.24%, respectively when correlated with RC bare frame models. The Y-direction performance of the rectangular, C-shape, and T-shape models is 40.35%, 41.62%, and 54.9%, respectively.

- All rocking shear wall models have been found to have base shear percentage decreases of 48 to 50% while all conventional shear wall models had percentage increases of 30 to 40% in both the X and Y directions in relative to the RC bare frame. In other words, base shear is maximum for rectangular RC bare frame as well as conventional shear wall model and minimum for all rocking shear wall model.

- The results show that the characteristic base shear seems to have the highest value in conventional shear wall buildings when referred to other RC bare frames susceptible to more lateral forces, implying that these buildings demand consistent strength.

- In both regular and irregular buildings, the presence of a rocking shear wall significantly reduces base shear (10 to 20%), storey drift (up to 20%) and roof displacement (up to 10%) along both X and Y-directions as contrasted to the conventional shear wall buildings. In comparison to structures without shear walls or RC bare frames, it also lessens the base shear (48 to 50%), storey drift (40 to 63%), and storey displacement (50 to 70%) along both the X and Y directions.

References

[1] Mohammad Khanmohammadi and Sajad Heydari, “Seismic behavior improvement of reinforced concrete shear wall buildings using multiple rocking systems,” Engineering Structures, pp. 577–589, 23 June 2015.
[2] Yahya Kurama, Stephen Pessiki, Richard Sause and Le-Wu Lu, “Seismic Behavior and Design of Unbonded Post-Tensioned Precast Concrete Walls,” PCI Journal, vol. 44, Issue 3, pp. 72-89, May-June 1999.
[3] L. Wiebe, C. Christopoulos, “A cantilever beam analogy for quantifying higher mode effects in multistorey buildings,” Earthquake Engineering Structural Dynamics, vol. 44, Issue 11, pp. 1697–1716, 2015.
[4] L.D.A. Wiebe, “Design of Controlled Rocking Steel Frames to Limit Higher Mode Effects,” University of Toronto, 2013.
[5] L. Wiebe, C. Christopoulos, “Mitigation of higher mode effects in base-rocking systems by using multiple rocking sections,” J. Earthq. Eng. 13 (1 SUPPL. 1) (2009) 83–108.
[6] Esmaeil Mohammadi Dehcheshmeh and Vahid Broujerdian, “Determination of optimal behavior of self-centering multiple-rocking walls subjected to far-field and near-field ground motions,” Journal of Building Engineering, Vol. 45, 103509, January 2022.
[7] N. Rahgozar, M. Pouraminian, “Reliability-based seismic assessment of controlled rocking steel cores,” J. Build. Eng. 44 (2021) 102623.
[8] A. Mohajeri, N. Rahgozar, A.S. Moghadam, “Pulse-like near-fault ground motion effects on controlled rocking steel cores,” in, Structure 31 (2021) 1072–1083.
[9] M. Nazari, S. Sritharan, S. Aaleti, “Single precast concrete rocking walls as earthquake force-resisting elements,” Earthq. Eng. Struct. Dynam. 46 (5) (2017) 753–769.
[10] Saeed Parsafar and Abdolreza S. Moghadam, “Development of a rocking R/C shear wall system implementing repairable structural fuses,” Int. J. Struct. Eng. (2017) 9:247–258.
[11] Guiyun Xia, “Performance analysis of rocking shear wall-frame structure,” John Wiley & Sons Ltd., 2 March 2020.
[12] Housner GW, “The behaviour of inverted pendulum structure during earthquake,” Bull Seismol Soc Am 1963;53(2):403–17.
[13] Palermo A, Pampanin S, Marriott D, “Design, modeling, and experimental response of seismic resistant bridge piers with posttensioned dissipating connections,” J. Struct. Eng. 2007;133(11):1648–61.
[14] Y. Zhou, R. Li and X. L. Lu, “Earthquake-resilient tall buildings using rocking walls,” 15th World Conference on Earthquake Engineering LISBOA, 2012.

[15] Mohd Asha'ari Masrom, Nor Hayati Abdul Hamid, "Review on the rocking wall systems as a self-centering mechanism and its interaction with floor diaphragm in precast concrete structures," Latin American Journal of Solids and Structures, ISSN 1679-7825, 15 July 2020.

[16] B.A. Mohr and S. K. Harris, "The Shocking Secrets of Rocking Shear Walls," ASCE and ATC, 2015.

[17] Sandesh Aher, David Mar and Prof. Geoffrey Rodgers, "Rocking walls with lead extrusion dampers protect formerly homeless seniors from earthquake risks," 17th U.S.-Japan-New Zealand Workshop on the Improvement of Structural Engineering and Resilience.

[18] Piotr Adam Bońkowski, Zbigniew Zembaty and Maciej Yan Minch, "Engineering analysis of strong ground rocking and its effect on tall structures," Soil Dynamics and Earthquake Engineering, Vol. 116, January 2019, pp. 358-370.

[19] D. Pennucci, G. M. Calvi & T. J. Sullivan, "Displacement- Based Design of Precast Walls with Additional Dampers," Journal of Earthquake Engineering, vol. 13, Issue S1, pp. 40–65, 14 April 2009.

[20] Leikune F. Aragaw and Paolo M. Calvi, "Comparing the performance of traditional shear wall and rocking shear wall structures designed using the direct displacement-based design approach," Bulletin of Earthquake Engineering, 5 November 2019.

[21] Shaik Akhil Ahamad and K.V. Pratap, "Dynamic analysis of G + 20 multi storied building by using shear walls in various locations for different seismic zones by using Etabs," Materials Today: Proceedings, 3 August 2020.

[22] R. Kourkoulis, F. Gelagoti and I. Anastasopoulos, "Rocking Isolation of Frames on Isolated Footings: Design Insights and Limitations," Journal of Earthquake Engineering, 16:374–400, 2012.

[23] K. Sahami, S. Veismoradi, P. Zarnani and P. Quenneville, "Seismic Performance of Rocking Concrete Shear Walls with Innovative Rotational Resilient Slip Friction Joints," Pacific Conference on Earthquake Engineering and Annual NZSEE Conference, 2019.

[24] V. Broujerdian, E. Mohammadi Dehcheshmeh, "Development of fragility curves for self-centering rocking walls subjected to far and near field ground motions," Sharif J. Civ. Eng. (2021).

[25] IS:1893-2016 (Part-1), ''Criteria for Earthquake Resistant Design of Structures", Bureau of Indian Standards, New Delhi.

[26] ETABS, manual., Linear and Nonlinear Static and Dynamic Analysis and Design of Three-Dimensional Structures, Computers and Structures Inc, Berkeley, California, U.S.A, 2004.

[27] IS: 875 (Part 1)-1987, "Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures - Dead Loads," Bureau of Indian Standards, New Delhi.

[28] IS: 875 (Part 2)-1987, "Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures - Imposed Loads," Bureau of Indian Standards, New Delhi.

[29] IS: 875 (Part 3)-1987, "Code of Practice for Design Loads (Other Than Earthquake) for Buildings and Structures - Wind Loads," Bureau of Indian Standards, New Delhi.