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Seismic Analysis of Alternate Outrigger System

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Abstract

In regions characterized the concept of construction sequence analysis, explain that this method involves analyzing a structure's behavior over time, considering the chronological order of construction stages. Introduce the crucial aspects of time-dependent effects, specifically creep and shrinkage, explain that these factors cause deformations in concrete over time and can significantly influence the structural behavior of buildings. In this study deals with non-linear construction stage analysis of G+14 structure as well as involved outrigger system property, reduce the displacement of structure and increase stiffness of structure.

Keywords: Outrigger system, displacement, conventional, Response spectrum.

INTRODUCTION

Outrigger is a term and method in the design of tall structures that refers to one of the best ways to meet the design requirements of such structures. It is a structural system that connects the inner core wall to the outer edge columns by horizontal cantilever arms that are very rigid and bend-resistant. These arms are usually deep beams with a depth equal to the height of one floor. A belt truss, which can be a reinforced wall or a steel beam, is used to connect the edge columns.

The core wall and the edge column are connected by these arms using the belt truss. The outrigger system is used to make the high-rise structure more resistant to sideways forces, such as earthquakes and wind. This system is usually used for high-rise buildings that are thin. Outrigger arms can be on one side or both sides of the structure, as shown in Figure 1. The core wall is braced by the outrigger arms, which reduce the impact of sideways forces and make the core wall stiffer.

This project aims to delve into Outrigger arms are used to brace the core wall and make it more resistant and rigid to the sideways forces. Belt truss connects the edge column to the core wall and helps to decrease the sideways movement by changing the tension and compression. This means that when the structure faces sideways forces, it will bend and create tension on one side and compression on the other side, as shown in Figure 2.

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The structure with outrigger has less bending than the structure without outrigger. Outrigger also reduces the pressure on the structure from sideways forces like wind and cyclone. This is shown in Figure 2.

AIM AND OBJECTIVES

1. To study the seismic behaviour of multi-storeyed building with outrigger system by Response spectrum method.
2. To Compare the Displacement, Storey shear and Storey drift of the buildings using ETABS software.

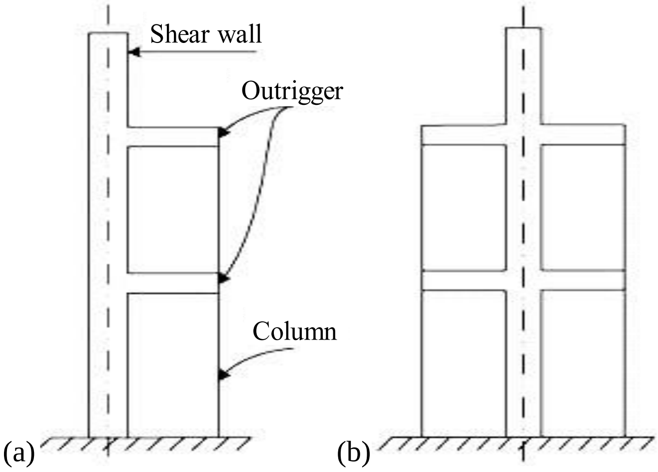

Figure 1. Outrigger in single side and outrigger in two sides.
(a) outrigger in single side, (b) outrigger in two sides.

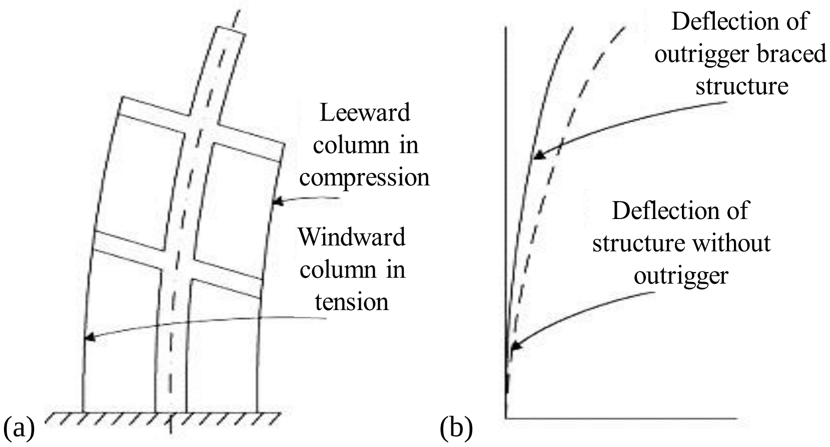

Figure 2. Outrigger under lateral loads and compressive deflection of structure.
(a) outrigger under lateral loads, (b) comparative deflection of structure.

LITERATURES REVIEW

Mohammed Sanaullah Shareef et. al (2022) the studies today's era of rapid urbanization and modernization, the demand for tall buildings with multistory is steadily increasing. As buildings become taller and narrower, the field of structural engineering faces growing challenges in ensuring their stability. Among the various structural systems employed in tall buildings, the outrigger system stands out as an efficient solution. This study seeks to evaluate the effectiveness of outrigger shear walls and determine the optimal placement of outriggers in multistory structures subjected to lateral loads. The outrigger system is crucial for providing additional stiffness and damping, serving as a structural safeguard against severe earthquake and wind conditions. The research focuses on dynamic analysis, examining two regular buildings, one with 36 storeys and the other with 50 storeys. These buildings, situated in seismic zone V, maintain a consistent area of 900 square meters (30 meters by 30 meters) and a typical storey height of 3 meters. The analysis is conducted using ETABS 2018 software. By studying the dynamic behavior of high-rise structures equipped with outrigger systems, this research aims to enhance our understanding of their performance under various loading conditions. This knowledge can ultimately inform the design and construction of safer and more resilient tall buildings [1].

Gurkirat Singh et. al (2022) By investigated, there's a growing demand for tall structures that not only stand out with unique designs but also prioritize stability and safety. However, the pursuit of architectural innovation often introduces irregularities in structural design, increasing vulnerability to instability.

To address this challenge, modern engineering employs advanced techniques such as shear walls, belt walls, and dual systems. These methods provide effective solutions to enhance the stability of buildings with unconventional shapes and designs.

This study focuses on analyzing the structural performance of G+9 composite frame structures of various shapes. Utilizing ETABS software, we conduct both static and dynamic analyses, considering seismic loads through the Response Spectrum method. Additionally, parameters such as story drift, story displacement, and base shear are examined to assess the effectiveness of outriggers and belt trusses in improving structural stability.

By investigating these aspects, we aim to gain valuable insights into optimizing the design of tall structures to ensure both aesthetic appeal and structural integrity in the face of seismic events [2].

Kiran Kamath et. al (2022), studied of the experiment was to check how well outriggers can lower the lateral loads on tall buildings. A outriggere outrigger system that had a normal and a virtual outrigger at different levels was suggested. By varying the stiffness of the outrigger arm, the building's height, the outrigger beam and belt wall, and the core, the outrigger outrigger system's static and dynamic behavior was examined. The ideal outrigger locations were established after the outrigger outrigger system was exposed to wind and seismic loads. The static wind and earthquake response were computed using Indian Standard codes, whereas the dynamic behavior was evaluated using nonlinear time history analysis. For the parametric investigation, analytical models of 40, 60, and 80 stores with building heights of 140 m, 210 m, and 280 m, respectively, were utilized.

The optimal locations for the outrigger outrigger system were determined using the reaction from the absolute maximum interstory drift ratio, roof displacement/(displacement roof), roof acceleration (acc roof), and base bending moment. The optimal location for the outrigger outrigger system was determined using a performance index criterion, which took into account the combined effects of the acc roof, disp roof, and ISD max under each load. Compared to the thickness of the outrigger and the core, the outrigger arm's length had the greatest effect on the outrigger outrigger system's performance, suggesting that extending the arm's length can increase the outrigger's rigidity [3].

Arsalan Alavi (2021), provided, the method was based on the idea of a uniform deformation distribution. This idea came from the minimum-compliance optimization, in which the structure’s layout was made as stiff as possible with a given amount of material. The authors showed the resulting procedure with a simplified hand-calculation algorithmic framework, which could help estimate the element sizes and evaluate the structural behavior at the preliminary design stage. To show how the proposed method worked in practice, they used the algorithm to design a structure with one outrigger. The comparison of the results showed that the proposed method was quite accurate.

1. The numerical example demonstrated that the curvature does not change in the design domain, indicating that the normal stress is nearly constant along the height of the structure, so validating the suggested method.
2. Looking at the design diagram shows that the method accurately estimates the location of the inflection point, where the core elements need the smallest dimension.
3. Because of a reversed moment at the outrigger position, the size of elements just below the outrigger drops suddenly [4].

In this studied, Furthermore, optimal outrigger positions were identified to achieve maximum reduction in top displacement. Additionally, the research proposed criteria for determining the maximum height of tall buildings based on displacement limits, considering the number of outriggers and their positions. To facilitate practical application, the study provided curves for preliminary design stages, offering guidance on allocating top displacement and determining the required number of outriggers based on building height and a suggested rigidity factor. This factor demonstrated significant influence on core-outrigger systems in tall buildings [5]. Lilin Wang et al (2021), studied suggested a straightforward engineering technique for quickly determining the quantity and placement of outriggers in extremely tall structures. The sensitivity vector algorithm, or SVA, was first presented. which adhered to restrictions about the maximum interstory drift while using the vector dot-product approach to determine the optimal outriggers in extremely tall buildings. The SVA was subsequently verified using the exhaustive search algorithm (ESA) and tested on a very tall building with wind load management. The optimal outriggers for an extremely tall building in a high-seismic region were then determined using the SVA. The findings demonstrated that position and number, not just number, were important factors in determining the optimal outrigger arrangement.

Adding more outriggers could lower interstory drift near the added outrigger but could raise interstory drift in other areas. The sensitivity vector algorithm was a useful tool for outrigger finding, not only for wind load in single-mode cases but also for seismic loads affected by multiple modes. This flexibility is very helpful for the early design stages of super-tall buildings. The proposed SVA was applied to a 138-story 623-meter super- tall building under the constraint of maximum interstory drift. The target 138-story 623-meter composite structure had a central core wall, mega columns, corner posts, outrigger trusses, and belt trusses, and was a typical mega frame core wall structural system with eight possible outriggers. Since the structure was sensitive to wind, the goal was to keep the maximum interstory drift under the wind load. In the structural design of this project, the stiffness design used a 50-year return period wind load, which was about 47.0 m/s in wind speed and 4% in damping ratio. The wind load for stiffness design was close to the level of a 20-year return period wind load, with a gradient wind speed of 43 m/s and a damping ratio of 1.5%. The parameters for the target building were a shape factor of 1.0, a Strouhal number of 0.15, a damping ratio of 4%, a basic wind pressure of 0.6 kN/m^2, and a terrain roughness of type D. The study mainly looked at the effect of outrigger installation on structural stiffness, without considering wind-structure interaction for simplicity. More details about this 138-story building could be seen in Ref. [4]. It's important to note that, for the concrete structure part of the super-tall building over 250 meters in height, the maximum interstory drift had to be less than 1/500. [6] represented an outrigger was a stiff beam that connected external columns to the shear wall. When the structure was subjected to wind stress, the outrigger and column stopped the core from spinning, which greatly decreased the base moment and lateral deflection.

The study looked at a 60-story reinforced concrete structure that was subjected to lateral load both with and without an outrigger system. Models with no outriggers, one outrigger, two outriggers, and three outriggers underwent a three-dimensional study. By adjusting the outrigger position within the framework, the optimal placement for a single, double, and triple outrigger was identified. The 20th floor from the top of the structure was the ideal site for an outrigger system, which reduced deflection by 10.2%.

In comparison to the structural model without outriggers, deflection decreased by 16% for a triple outrigger system and 11.5% for a double outrigger system at the optimal level. Additionally, it found that when a triple outrigger system was used, the maximum storey drift fell by 11% [7].

Both static and dynamic analyses of a high-rise structure under lateral loads. In the first phase, static analysis had been done on four different structural systems, such as the moment-resisting frame, building frame, and the outrigger braced frame (OBF) system. The investigation had shown that the outrigger braced system had given the best control for high-rise structures under the same static loading conditions. These findings had come from an analytical procedure that had emphasized the efficiency of the bracing system. In the next phase, dynamic analysis had been carried out to evaluate the vibration response of the tall building. In this situation, the outrigger system had been contrasted with Pendulum Tuned Mass Dampers (PTMD). A parametric analysis had been performed, looking at the benefits of the outrigger system in terms of lowering top displacement and drift response in the structure. The results had pointed out a significant improvement, with a decrease of 33% in the case of one outrigger and 60% with two outriggers in the top displacement and drift response of the structure. This change in response had been confirmed through analytical solutions applied to both the top and middle parts of the structure. The outriggers had shown an acceleration reduction ability of 40%, while PTMD had reached a reduction of 35%. Both static and dynamic analyses had shown that the outrigger braced frame (OBF) had been a good supplement to the sway frame, enhancing the structural performance of high-rise buildings significantly. Using dynamic and static methods, the design showed that the response was cut by 35% with one outrigger and by 60% with two outriggers, according to the analytical solution. The numerical solution revealed that the response dropped by 37% with one outrigger and by 58% with two outriggers. Both solutions agreed with previous studies [8].

SYSTEM DEVELOPMENT

In the present work G+15 multistorey building is considered for analysis using ETABS software according to IS 1893-2016 and IS 16700-2017. For present work response spectrum method and time history analysis by considering Bhuj earthquake data is used.

A G+15 multistorey RCC framed structure is modelled with floor height of 3.5m using ETABS software and the element sizes are changed according to the design requirements. The model is analyzed with four different framed system i.e., one is RCC framed structure, a shear wall, outrigger system and outrigger system with shear wall. The geometric parameters for models are considered as shown in Table 1 [9–13].

Table 1. Geometric parameters of model.

Type of structure	SMRF
No. of storeys	G+15
Overall height of building	53.5m
Floor dimensions	16 m × 18 m
Grade of Steel	Fe500
Grade of Concrete	M40
Column dimensions	500 mm × 650 mm and 800 mm × 800 mm
Beam dimensions	300 mm × 650 mm and 300 mm × 700 mm
Slab thickness	150 mm
outrigger dimension	ISLB550
Shear wall thickness	230 mm
Extemal wall thickness	230 mm
Internal wall thickness	150 mm
Bottom storey height	4.5 m
Typical storey height	3.5 m

Load Consideration

The loads which are considered for this analysis are Dead loads, Live loads from IS code 875:2015 and Earthquake loads from IS code 1893:2016

Dead load: IS code 875 part 1 (Code of practice for design loads- DEAD LOAD)

1. The dead load includes the self-weight of the beam, column and slab.
2. Floor finish = 1.5 kN/m^2 (page no. 29 IS code 875 part 1)
3. Terrace water proofing = 1.5 kN/m^2
4. External wall loads on periphery = 7.22 kN/m^2 Load calculation,
   External Wall load = External wall thickness × unsupported length of wall × Unit weight of concrete hollow block
5. Internal wall load = 3.2 kN/m^2

Live load: IS 875 part 2 (Code of practice for design loads- IMPOSED LOAD)

1. Live load on all floors = 3 kN/m^2
2. Live load on top floor = 2 kN/m^2

Earthquake Load: IS Code 1893:2016 (Criteria for Earthquake Resistant Design of Structure)

1. Seismic zone = IV
2. Importance factor = 1.2
3. Response reduction factor, R = 4
4. Type of soil = medium soil

Plan and 3D View of Structure in ETABS Software

Response Spectrum Method

A graph that summarizes a building's response over a broad variety of time periods is referred to as a "spectrum" in this context. There are several kinds of constructions that can benefit from linear elastic response spectrum analysis. Response spectra are curves that, when taking into account a specific seismic ground motion or a group of such motions, show the peak response of a single- degree-of-freedom system in terms of displacement, velocity, and acceleration against its natural frequency.

The figures below show the inclusion of G+14 reinforced concrete structures. Visualize a response spectrum as a graphic depiction of the dynamic response of a sequence of increasingly longer cantilever pendulums, each with increasing natural periods, subjected to a common lateral seismic motion at the base of the structure (Figures 3–7).

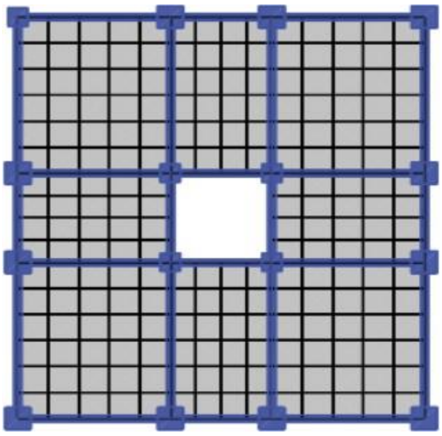

Figure 3. Plan and 3D view of structure in ETABS mode Rcc structure.

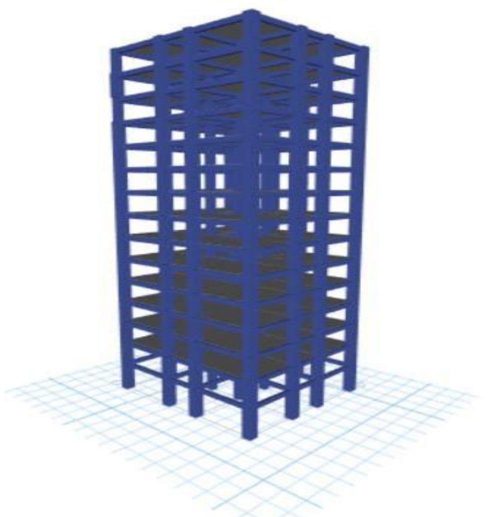

Figure 4. 3D view of structure in ETABS mode Rcc structure.

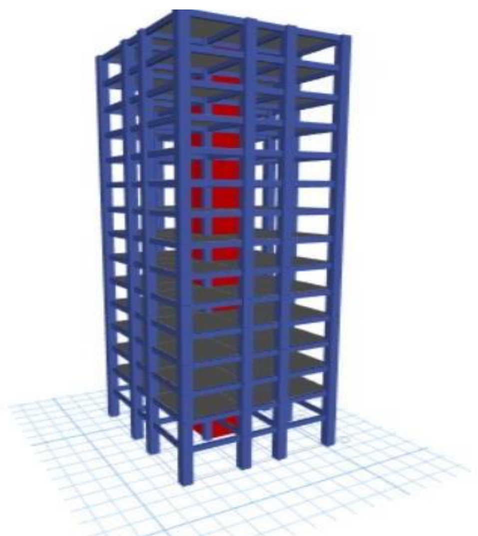

Figure 5. 3D view of structure in ETABS mode shear structure.

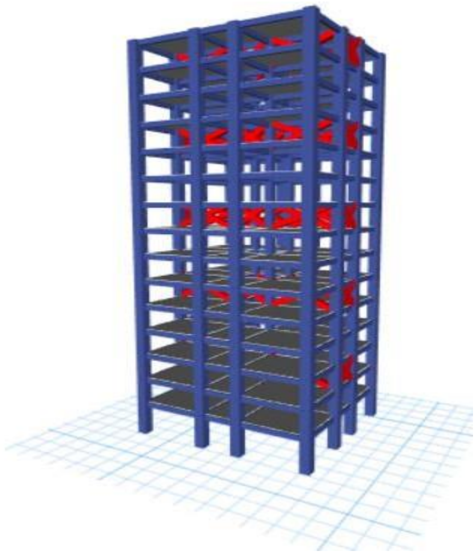

Figure 6. 3D view of structure in ETABS mode shear structure.

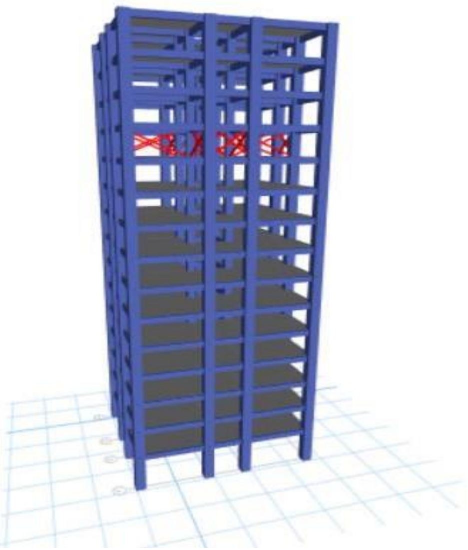

Figure 7. 3D view of structure in ETABS mode One floor outrigger.

RESULTS AND DISCUSSION

Storey Stiffness

The stiffness of each storey in the X direction for both RCC framed structures and outrigger structures has been compared and is presented in tabulated form, as well as visually represented in Figure 8.

The comparison of storey stiffness in X direction in zone IV between RCC and OUTRIGGER framed structures reveals significant insights into their performance regarding maximum storey stiffness. Show in figure 8. In outrigger system increase the stiffness other than conventional. Stiffness 25% are increase in outrigger system.

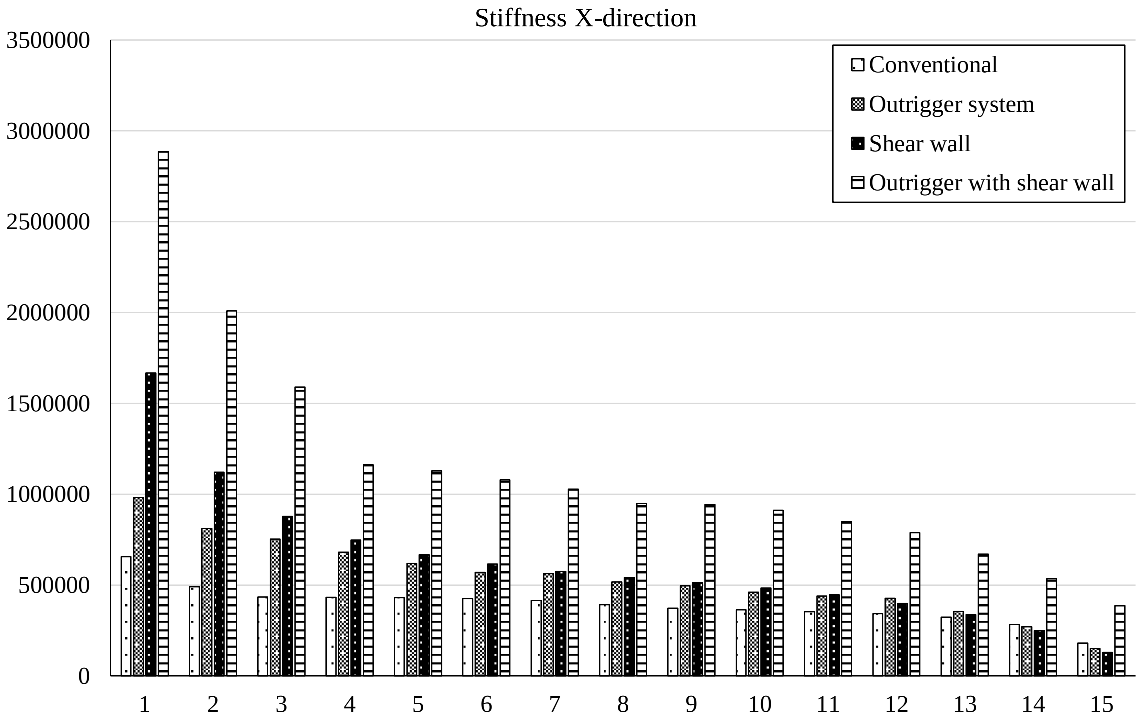

Figure 8. Storey stiffness.

Storey Shear

The comparison of storey shear in RCC and OUTRIGGER structure in X direction in zone IV is presented in tabulated format and also represented the same in graphical form in Figure 9.

The comparison of storey shear in X direction in zone IV between RCC and OUTRIGGER framed structures reveals significant insights into their performance regarding maximum storey shear. figure 9 shows maximum storey shear to be 1885.30 kN for the RCC framed structure i.e. model 1. The model 2 shows a reduction in storey shear by 9.88% which brings the value to 1699.03 kN. The model 3 also showcase the reduction in storey shear by 8.79% as compared to model 1, the maximum storey shear of model 3 is 1719.43 kN. The model 4 shows the maximum reduction in storey shear by 11.61%, and maximum storey shear of model 4 is 1666.28 kN. These reduction in storey shear is due to increase stiffness and reduction of dead load due to lower section sizes.

Storey Displacement

The storey displacement of RCC and OUTRIGGER structures in X direction in zone IV are compared and presented in tabulated form and also represented in graphical format.

The tabulated result and graphical representation are shown in Figure 10.

figure 11, it is found that maximum displacement in X direction in zone-IV for RCC framed structure i.e. is model 1 is 58.23 mm, and because of increase in stiffness in OUTRIGGER framed structure maximum displacement is decreased. In model 2 the maximum storey displacement is 46.52 mm which is 23.3% reduction as compared to model 1. The maximum storey displacement in model 3 is 42.85 mm which is 18.25% reduction only as compared to model 1. The model 4 shows the maximum reduction in storey displacement as 36.0 mm which is 25.95% as compared to model 1. Also, the difference between model 4 and model 2 small, the model 4 present only 3.5% reduction in displacement as compared to model 2.

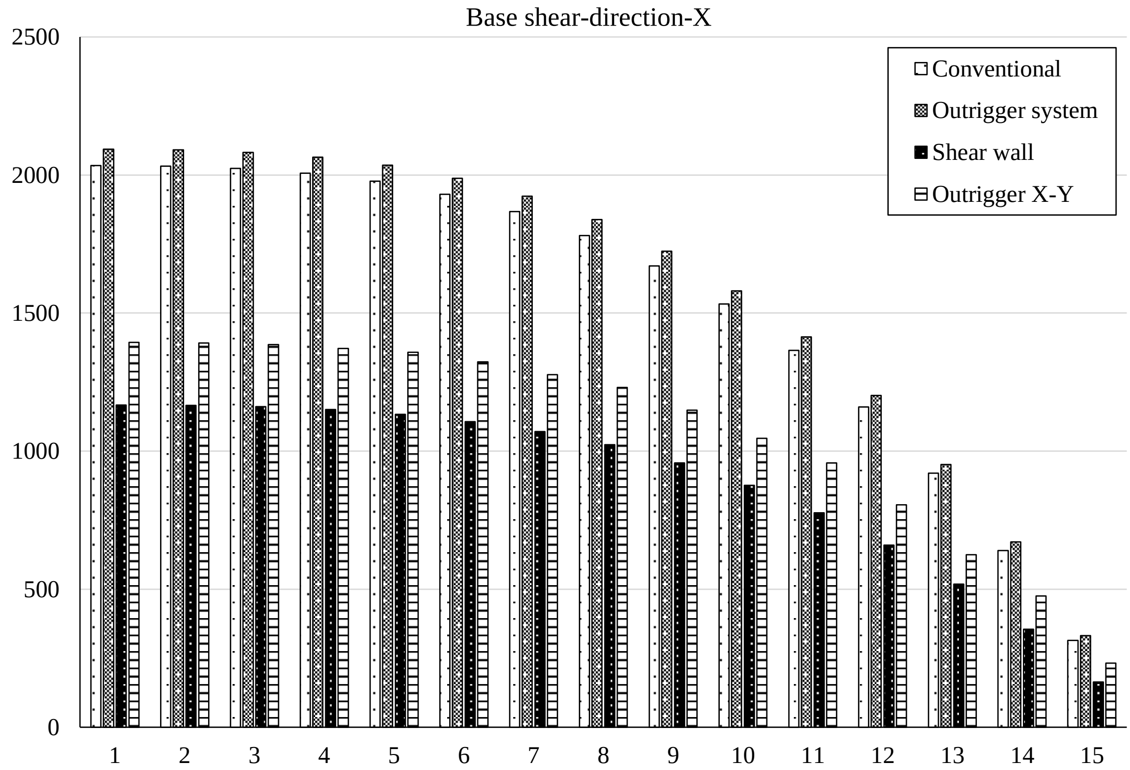

Figure 9. Storey shear.

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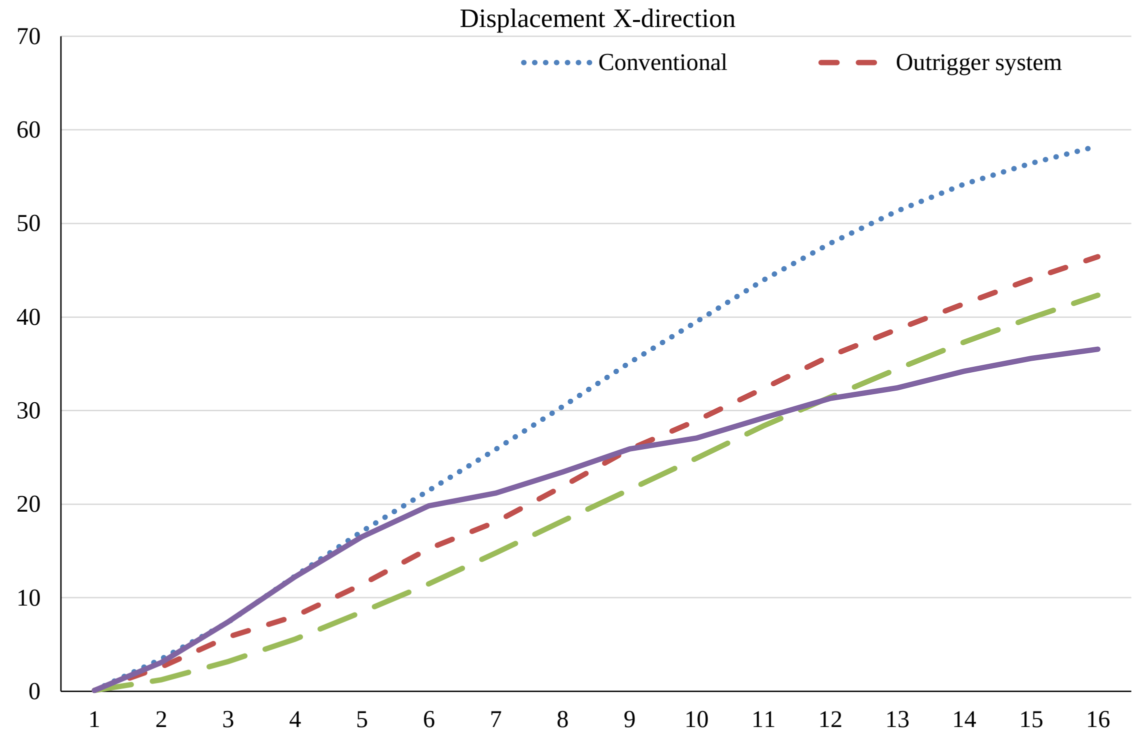

Figure 10. Storey displacement.

Storey Displacement in Y Direction in Zone IV

The storey displacement of RCC and OUTRIGGER structures in Y direction in zone IV are compared and presented in tabulated form and also represented in graphical format. The tabulated result and graphical representation are shown in Figure 11.

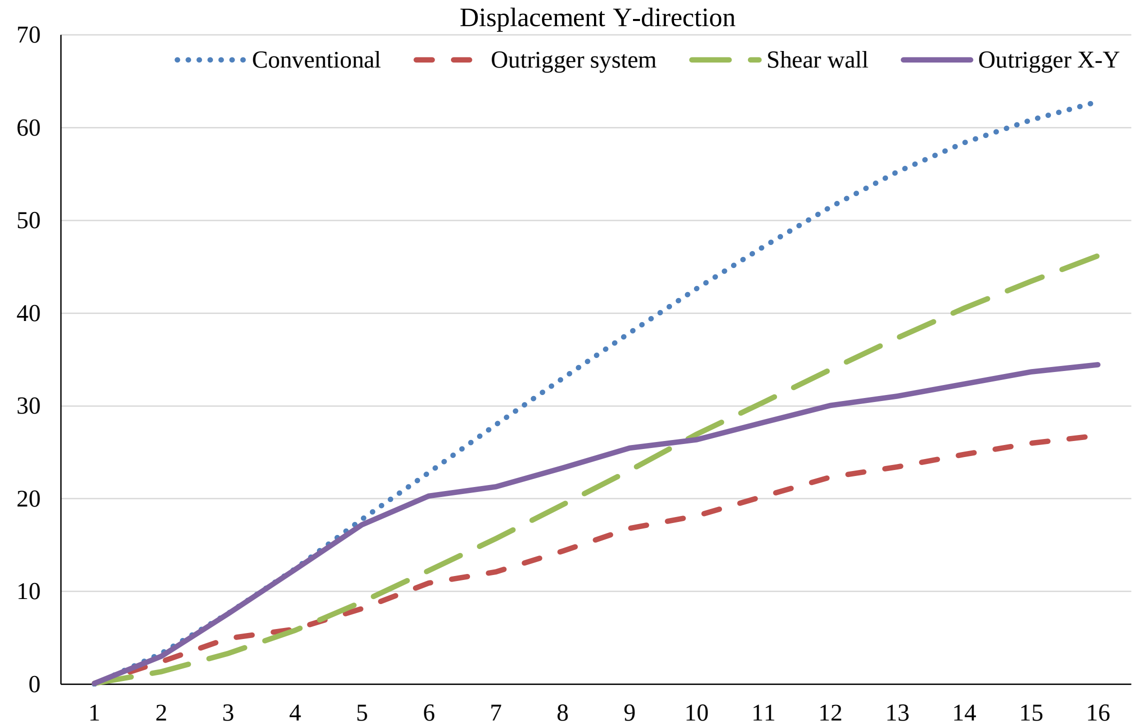

Figure 11. Storey displacement in Y direction in zone IV.

figure 11, it is found that maximum displacement in Y direction in zone-IV for RCC framed structure i.e. is model 1 is 62.874 mm, and because of increase in stiffness in OUTRIGGER framed structure maximum displacement is decreased. In model 2 the maximum storey displacement is 58.23 mm which is 21.89% reduction as compared to model 1. The maximum storey displacement in model 3 is 46.85 mm which is 17.12% reduction only as compared to model 1. The model 4 shows the maximum reduction in storey displacement as 37.0 mm which is 34.03% as compared to model 1. Also, the difference between model 4 and model 2 small, the model 4 present only 4% reduction in displacement as compared to model 2.

CONCLUSIONS

The recent literary work done with regard to without outrigger, with outrigger are reviewed and the following observations are drawn.

Conclusion

1. Lateral load resisting systems are essential for buildings, as they can withstand lateral forces more effectively than traditional building systems.
2. The structure's performance depends on the material, the module size, and the shape of the building.
3. The load types and the number of stories affect how systems work. The structure's shape limits the number of stories that some systems can handle well.
4. Different structures may need different lateral load resisting systems. The best system depends on the structure and is not the same for all. Therefore, each structure should be tested with different systems before choosing one.

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