Comparison of Seismic Behavior of RCC High Rise Structure with and Without Outrigger and Belt Truss System

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Abstract
In the present era, there is more demand for high-rise buildings. The growing demand for high-rise buildings brings new difficulties and comes up with new safety precautions. With an increase in height of structure, its rigidity reduces; making it difficult to withstand earthquake and wind effects, hence some preventative structural systems must be used. The outrigger and belt truss systems are most effective systems for high-rise buildings. The external columns in an outrigger system are joined to the main inner core with trusses at various floor levels to minimize storey drift and the rotating action of the core produced by seismic and wind forces. In a belt truss system, all external columns that are located at the perimeter are joined together. This study investigates the comparison of the behaviour of high-rise buildings with and without an outrigger system, and belt truss system for all seismic zones with different types of soil. This study is carried out for 40 story buildings using response spectrum analysis. Analysis of the building is carried out by using ETABS 2018 software. The results are in the form of seismic responses like storey displacement, storey drift, base shear are studied.

Keywords: *belt truss System; outrigger system; seismic loads; storey displacement; wind loads*

1. Introduction

Since ancient times, people have always been attracted to tall buildings for their height. The wealth and power of countries have been discovered to be frequently reflected through the impressive and majestic constructions, from the building of ancient pyramids to the present-day high-rise structures. High-rise buildings are now viewed as representations of economic power and leadership [3]. Buildings become more difficult to meet serviceability requirements while also losing some of their architectural impacts as they go taller due to the wind and seismic forces that cause lateral displacement and storey drift. Numerous methods, such as bracing, isolation, dampers, outriggers and belt truss system are available to overcome these issues or challenges. Among these methods, the outrigger and belt truss system has been found to be efficient at resisting off lateral forces. This can effectively protect the structures from wind and seismic forces [1]. According to the latest IS 1893:2016 standards, the Indian territory is divided into four seismic zones, namely zone II, III, IV, and V. Analysis of the buildings based on seismic zones and soil types is required as building height increases [5]. Outrigger structural systems can be divided into two categories: conventional outrigger systems and virtual outrigger systems. In a conventional outrigger system, the outrigger trusses are directly attached to the perimeter columns of the structure and shear walls at the core. However, in a virtual outrigger system, the shear wall is left unattached and only the outer periphery columns are connected by outrigger trusses [2].

1.1 Outrigger System

Although models of high buildings with horizontal and vertical load bearings have been developed recently systems with a shear wall system at the centre of the structure plan and columns at the exterior of the plan are recommended. Beams and flooring provide the interface between the central shear wall and the frame columns on the outer. To strengthen the collaboration and interaction between these two bearing elements, stiff horizontal elements, often made of steel or concrete are positioned between the shear wall and the columns at the specific level of the building. The main purpose of these structural components together referred to as the outrigger system, is to improve the mutual interaction between the frame columns and the shear wall, particularly by increasing the bending rigidity and lateral stiffness against horizontal loads. The outrigger system in a building can be used on one or more floors [6].

1.2 Belt Truss System

Conventional outrigger concepts translate moments in the core into a vertical couple in the columns by using outrigger trusses that are directly attached to the core and outboard columns. Without a physical link between the outrigger trusses and the core, the "virtual" outrigger concept achieves the same transfer of overturning moment from the core to elements outboard of the core. Many of the issues posed by the usage of outriggers are avoided by removing a direct link between the trusses and the core. The fundamental idea behind the virtual outrigger concept is to transfer moment in the form of a horizontal couple from the core to trusses or walls that are not directly connected to the core using floor diaphragms, which are normally very stiff and resistant in their own plane. The horizontal couples are subsequently transformed into vertical couples in columns or other structural elements outside the core by the trusses or walls. Virtual outriggers can be effectively used with belt trusses and basement walls [6].

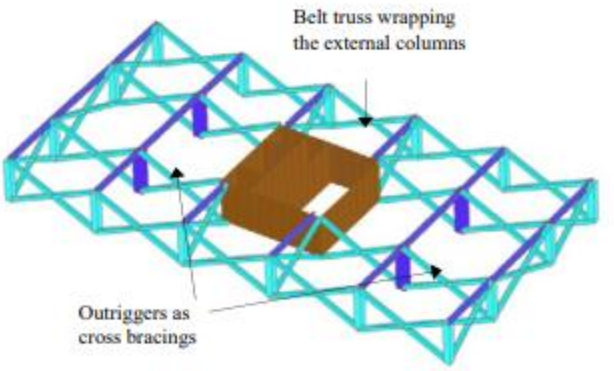


Figure 1. 3D View of Outrigger and Belt Truss

Fig. 1 shows the 3D view of outrigger and belt truss [4].

2. Objective of the Study

The following are the objectives of this study.

1. To analyze a 40 storied RCC high rise building provided with and without outrigger, belt truss system and combination of outrigger with belt truss system considering its location in different earthquake zones and different soil types by using ETABS software.
2. To study the seismic behavior of high-rise building provided with and without outrigger, belt truss system and combination of outrigger with belt truss system.
3. To suggest the most effective system from the outrigger, belt truss system and combination of outrigger with belt truss system.

3. Details of structure

This study deals with the analysis of 40 storey high rise structures in ETABS software by using response spectrum analysis. The structure is provided with and without outrigger, belt truss system and combination of these two systems considering all seismic zones (Zone II, III, IV and V) and different types of soil (hard, medium and soft). In this work steel material is utilized for the outrigger and belt truss. For the outrigger inverted V-shaped truss is used whereas for belt truss X-shaped truss is used. Outriggers and belt trusses are provided at three different locations like 10^{th}, 20^{th} and 30^{th} floor levels of the building. Seismic analysis of building is carried out as per IS-1893, part 1 (2016). Wind analysis of building is carried out as per IS-875, part 3 (2015).

Table 1. Geometrical Data of Building

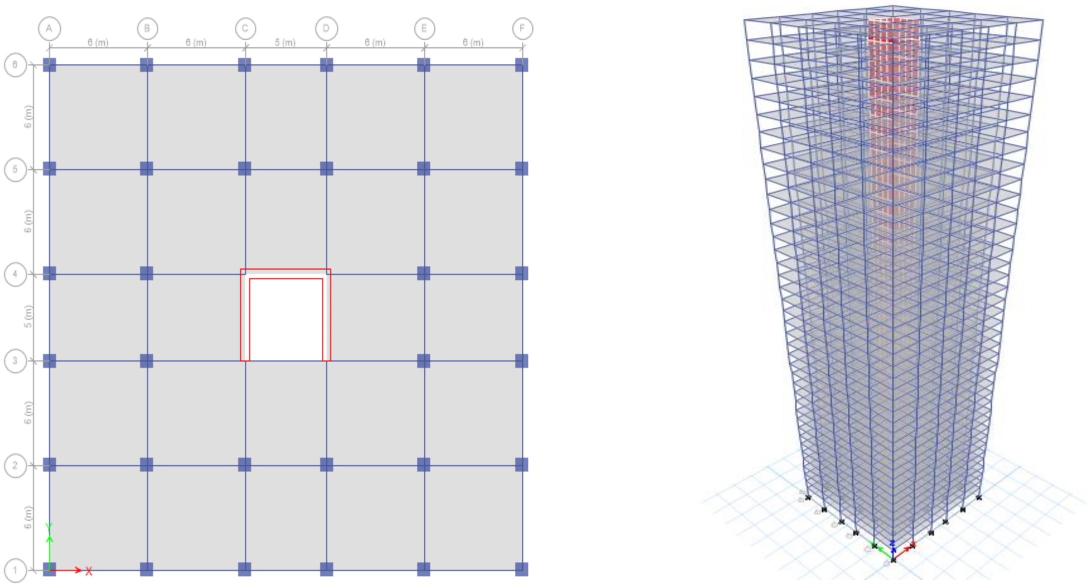
Number of Bays in X-Direction	5
Number of Bays in X-Direction	5
Dimensions of Building	29mX29m
Typical Storey Height	3.15m
Bottom Storey	4m
Total Height of Building	126.85m

Table 2. Material Properties

Grade of Concrete	M40, M50
Grade of Reinforcement	Fe500
Unit Weight of Concrete	25kN/m^3
Unit Weight of Brick	20kN/m^3

Table 3. Specification of Structure

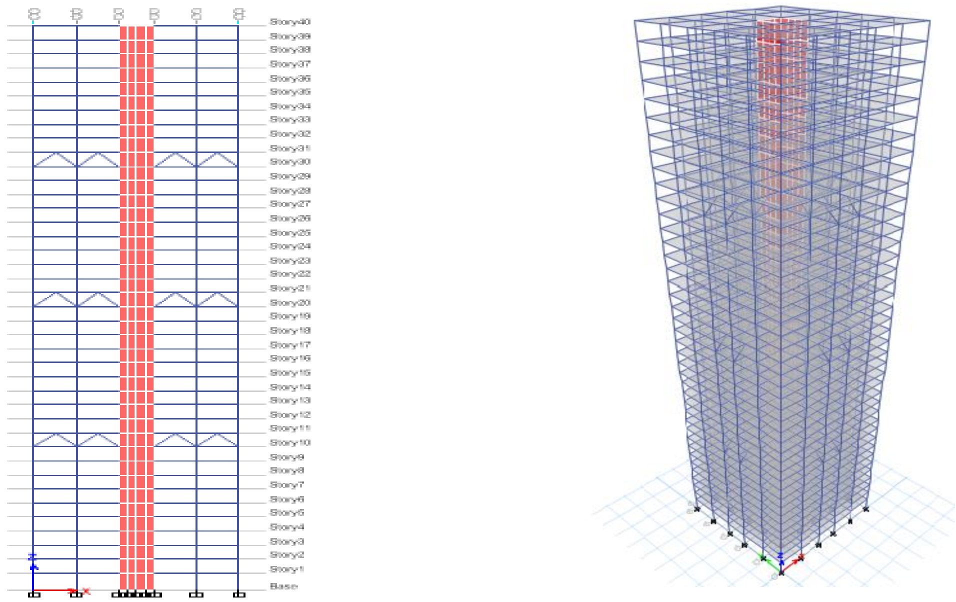
Type of structure	RCC Framed Structure (40 Storied)
Size of column	0.8mX0.8m (31st-40th floor, M40) 1.0mX1.0m (Base-30th floor, M50)
Size of beam	0.5mX0.75m
Slab thickness	0.125m
Central shear wall core thickness	0.5m
Wall thickness	0.23m (External), 0.15m (Internal)
Steel outrigger	0.4mX1.0m (Box Section)
Earthquake load	As per IS-1893, part 1 (2016)
Wind load	As per IS-875, part 3 (2015)
Live load	3kN/m^2
Seismic zones	II, III, IV, V
Importance factor	1.2
Response reduction factor	3
Types of soil	Soft, Medium, Hard
Basic wind speed	39, 44, 47, 50 m/s
Terrain category	II



(a) Plan view **(b) 3D elevation view**

Figure 2. Plan View and 3D Elevation View of Building Model without Outrigger System

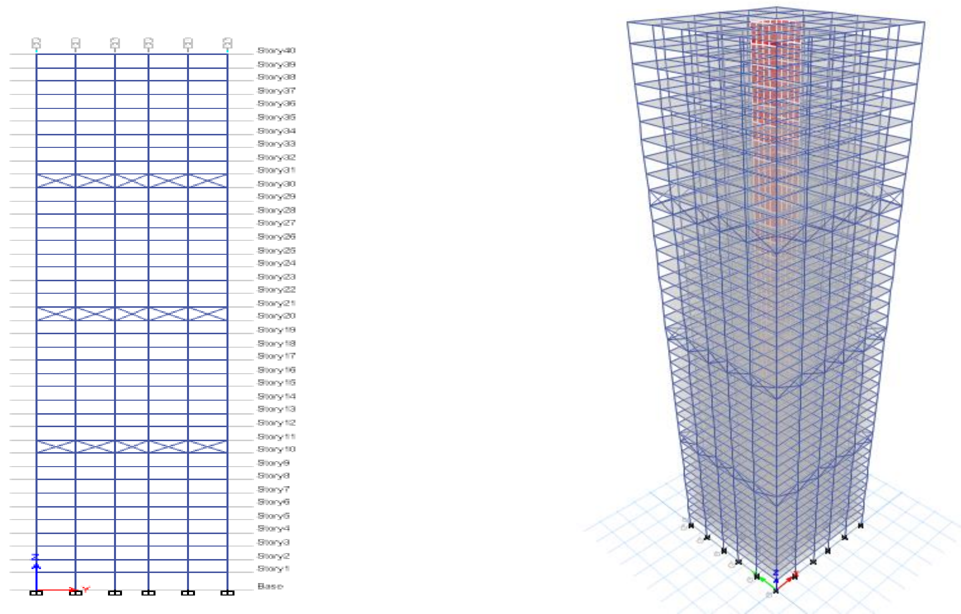
Fig. 2 shows the plan and 3D view of 40 storied RCC high rise structure without outrigger system.



(a) Sectional elevation view **(b) 3D elevation view**

Figure 3. Plan View and 3D Elevation View of Building Model with Outrigger System

Fig. 3 shows the plan and 3D view of 40 storied RCC high rise structure with outrigger system.



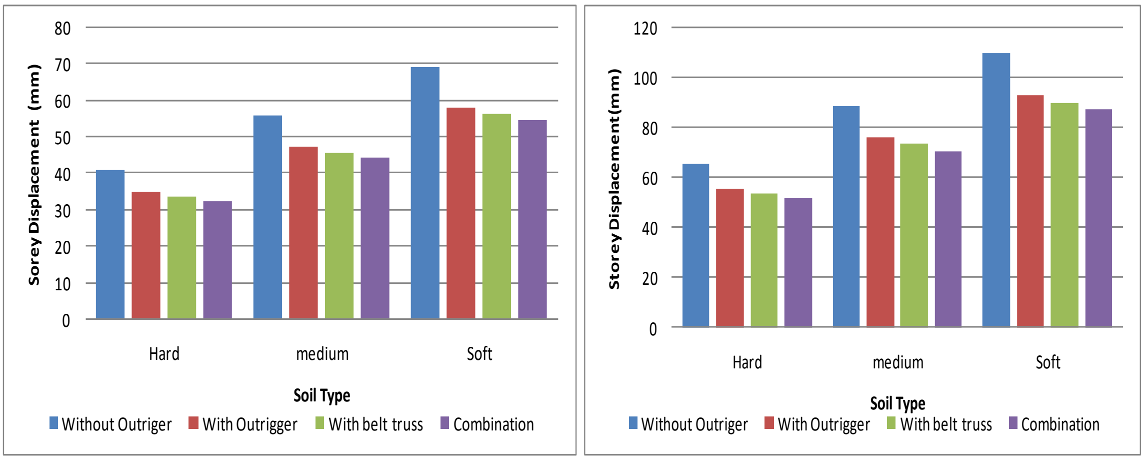
(a) Sectional elevation view **(b) 3D elevation view**

Figure 4. Plan View and 3D Elevation View of Building Model with Belt Truss System

Fig. 4 shows the plan and 3D view of 40 storied RCC high rise structure with outrigger system.

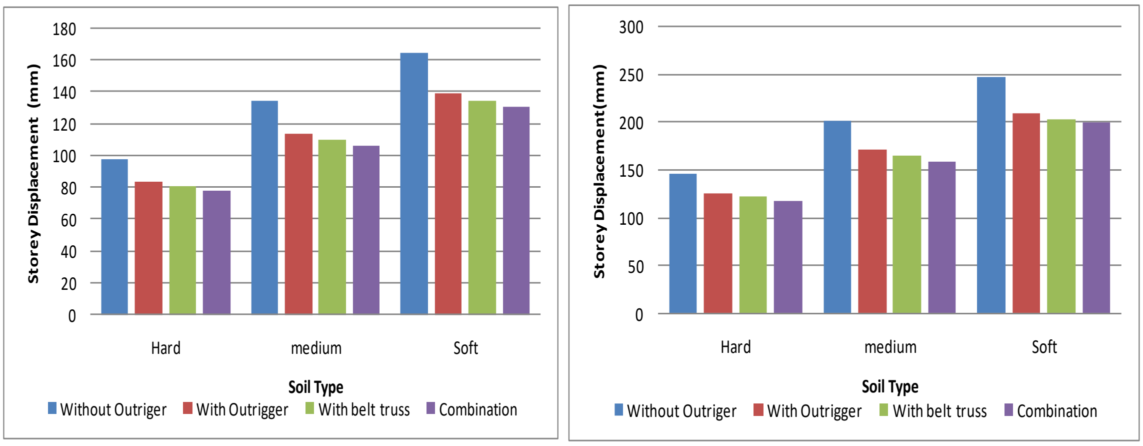
4. Results and Discussion

4.1. Storey Displacement Due to Seismic Loads



(a) Zone II (b) Zone III

Figure 5. Storey Displacement for Zone II and Zone III

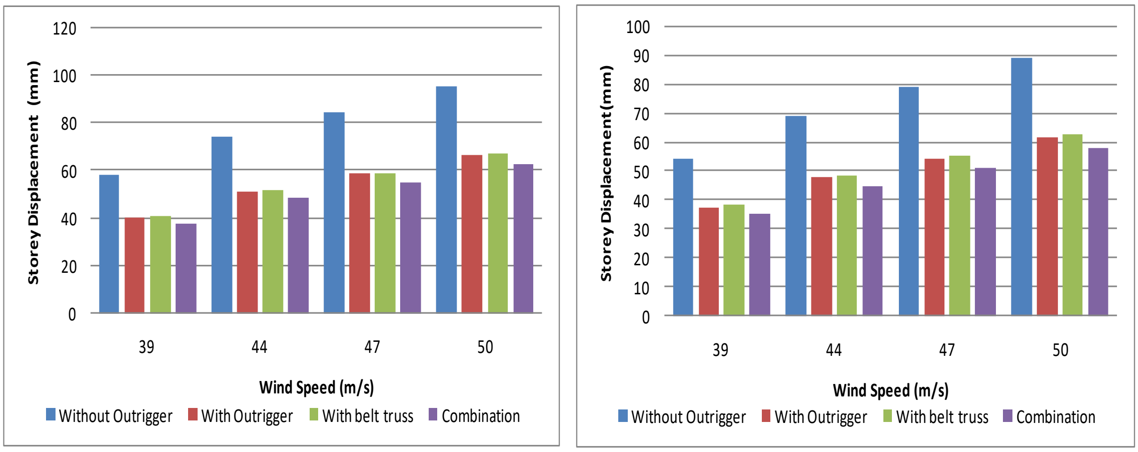


(a) Zone IV (b) Zone V

Figure 6. Storey Displacement for Zone IV and Zone V

Figs. 5 and 6 show the maximum storey displacement for different earthquake zones considering different soil types for building models with and without outrigger system, belt truss system and combination of outrigger with belt truss system. Storey displacement is increased in all models when zone changes from zone II to zone V as well as when soil type changes from hard to soft. For zone II, the values of storey displacement decrease by 15 to16%, 17 to19% and 20 to 22% for building with an outrigger, belt truss and its combination respectively. For Zone III, the values of storey displacement decrease by 15 to16%, 17 to18% and 20 to 21% for building with an outrigger, belt truss and its combination respectively. For zone IV, the values of storey displacement decrease by 14 to16%, 17 to19% and 20 to 22% for building with an outrigger, belt truss and its combination respectively. For zone V, the values of storey displacement decrease by 14 to16%, 17 to19% and 19 to 22% for building with an outrigger, belt truss and its combination respectively. The maximum percentage reduction is observed in building models provided with combination of outrigger with belt truss system for all zones.

4.2. Storey Displacement Due to Wind Loads

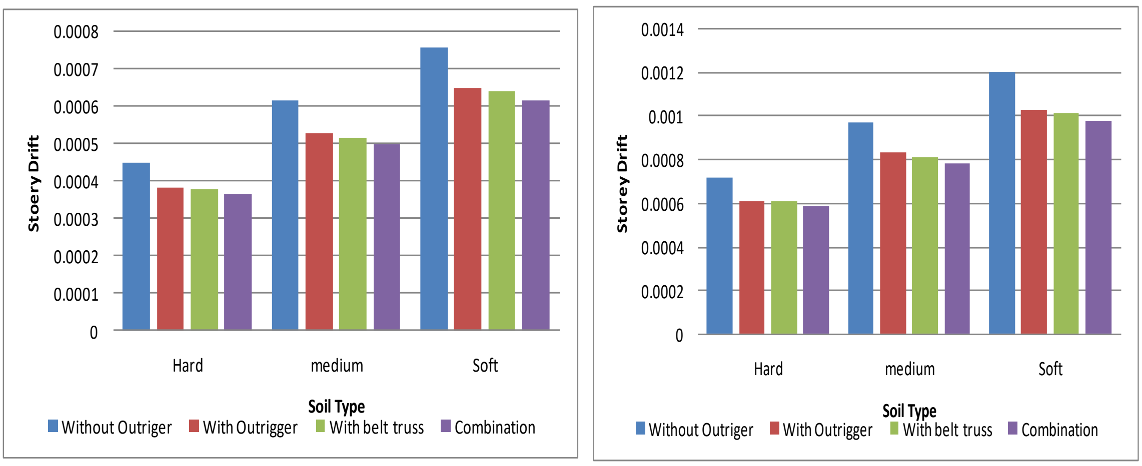


(a) Wind load in X-direction (b) Wind load in Y-direction

Figure 7. Storey Displacement for Wind Load in X and Y-Direction

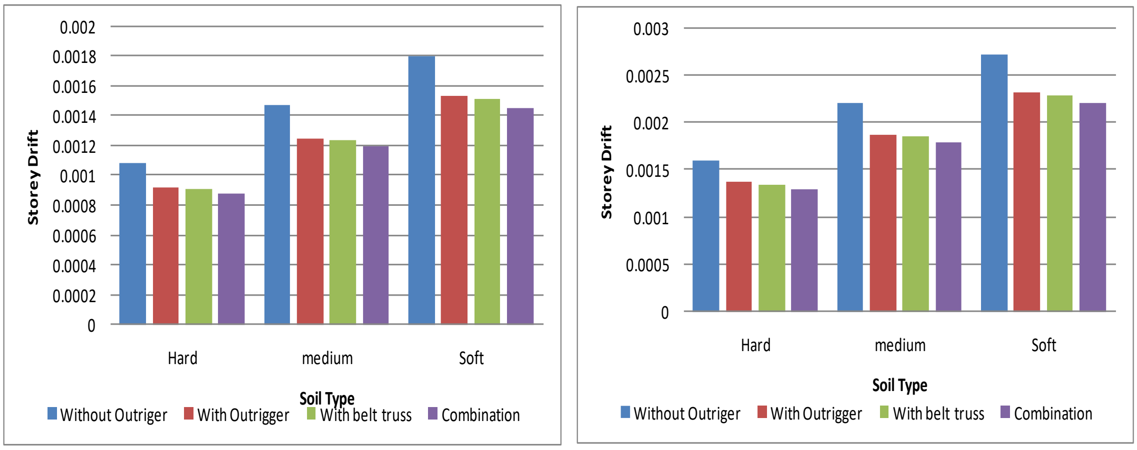
Fig. 7 shows the maximum storey displacement for wind load in X and Y-direction for building models with and without outrigger system, belt truss system and combination of outrigger with belt truss system. The percentage reductions in storey displacement for wind load in X-direction are 30.48%, 29.98%, and 34.69% for building with an outrigger, belt truss and its combination respectively. The percentage reductions in storey displacement for wind load in Y-direction are 31.02%, 29.58%, and 34.96% for building with an outrigger, belt truss and its combination respectively. For the building models with belt truss system show the least percentage reduction as compared to outrigger system.

4.3. Storey Drift



(a) Zone II (b) Zone III

Figure 8. Storey Drift for Zone II and Zone III

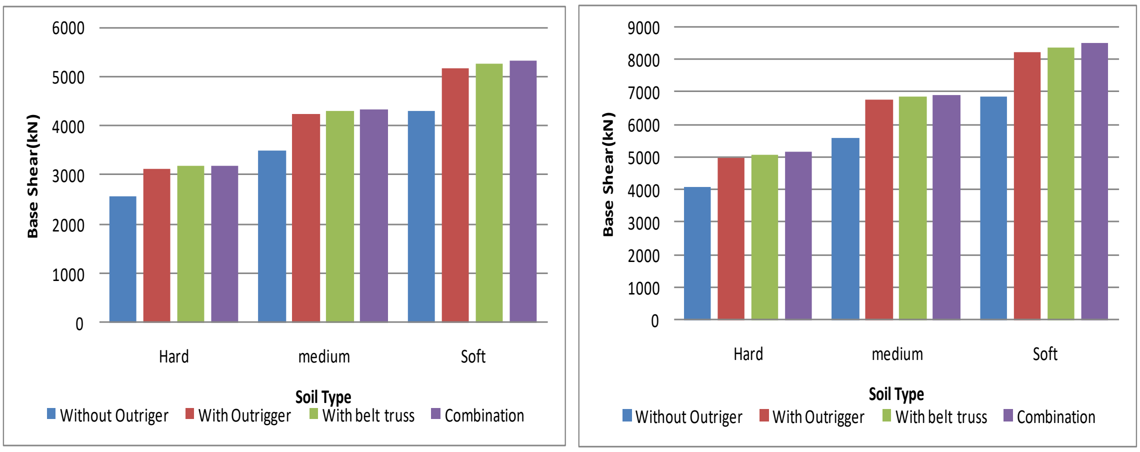


(a) Zone IV **(b) Zone V**

Figure 9. Storey Drift for Zone IV and Zone V

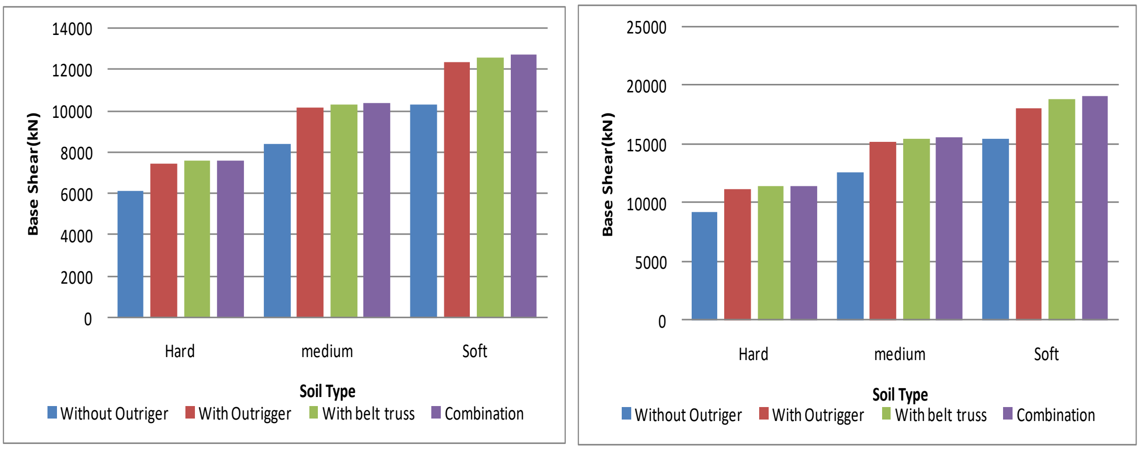
Figs. 8 and 9 shows the maximum storey drift for different earthquake zones considering different soil types for building models with and without outrigger system, belt truss system and combination of outrigger with belt truss system. Storey drift is increased in all models when zone changes from zone II to zone V as well as when soil type changes from hard to soft. For zone II, the values of storey drift decrease by 13 to 14%, 15 to 16% and 18 to 19% for building with an outrigger, belt truss and its combination respectively. For Zone III, the values of storey drift decrease by 14 to 15%, 15 to 16% and 17 to 18 % for building with an outrigger, belt truss and its combination respectively. For zone IV, the values of storey drift decrease by 13 to 15%, 15 to 17% and 17 to 19% for building with an outrigger, belt truss and its combination respectively. For zone V, the values of storey drift decrease by 14 to 15%, 15 to 16% and 17 to 19% for building with an outrigger, belt truss and its combination respectively. The maximum percentage reduction is observed in building models provided with combination of outrigger with belt truss system for all zones.

4.4. Base Shear



(a) Zone II **(b) Zone III**

Figure 10. Base Shear for Zone II and Zone III



(a) Zone IV **(b) Zone V**

Figure 11. Base Shear for Zone IV and Zone V

Figs. 10 and 11 show the base shear for different earthquake zones considering different soil types for building models with and without outrigger system, belt truss system and combination of outrigger with belt truss system. The base shear is an estimate of the maximum expected lateral force on the base of the structure due to seismic activity. It depends on the seismic zone, soil material and lateral force equation in IS 1893:2016.The dead weight of the structure increases the base shear increases. The percentage increase in base shear for the outrigger system is 18 to 22%, for the belt truss is 22to 24%, and for the combination of the outrigger with belt truss is 23 to 24%.

5. Conclusions

The following conclusions are drawn from the proposed study

- From the software analysis, it is observed that the maximum reduction in storey displacement due to seismic forces for combination of outrigger with belt truss system is obtained as up to 21%, for outrigger it is obtained as up to 16.5% and for belt truss system it is obtained as up to 18%.
- From the software analysis, it is observed that the maximum reduction in storey displacement due to wind load for the combination of outrigger with belt truss system is obtained as up to 35%, for outrigger it is obtained as up to 31% and for belt truss system it is obtained as up to 30%.
- From the software analysis, it is observed that the maximum reduction in storey drift due to seismic forces for combination of outrigger with belt truss system is obtained as up to 19%, for outrigger it is obtained as up to 15% and for belt truss system it is obtained as up to 17%.
- From the analysis results, it is observed that the outrigger system and belt truss are more efficient in resisting the wind load as compared to the seismic forces.
- From analysis results, it is concluded that the combination of the outrigger with belt truss system is more efficient in reducing displacement than only outrigger and belt truss system

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