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STRUCTURAL SYSTEMS OF HIGH RISE BUILDINGS

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Abstract These high-rise structure should be effective to stand against various lateral loads such as earthquake load and wind load in both static and dynamic ways. A building with just shear wall is only functional up to certain height limit. As the building height increases the effect of the shear wall decreases affecting the stiffness of the building. This leads to the need of introduction of outrigger beams between the core wall and the perimeter columns which often is used to provide sufficient lateral stiffness to the structure. Adopting the outrigger beam in the design at the optimum position is of lesser concern due to the aesthetic view of the floor, mostly it will be added to the location where the floors are used less or is used for mechanical floors. So the topology becomes a productive importance to design an optimum building. Random trials were employed to identify a suitable system to react efficiently under lateral load. This study aims to investigate the most efficient topology for the structure under the consideration of lateral loads, analyse the structure, compare the results with the traditional framing system for the structure. The numerical problem of building with G+50 story is examined in structural analysis programme with optimum location of outrigger beams at 13th story, 25th story and 37th story to review the increase in lateral stiffness, a decrease in displacement, story drift and time period are reported as compared to traditional framing system.

Keywords- *Tall Building, Outrigger System, Belt Truss, Topology, Gust Load.*

Outrigger system are rigidly attached to the core are designed to withstand the overturning moments by increasing the stiffness and strength by connecting it with the core that acts as a spine of the structure. These gives pronounced effect where the lateral forces are desperate. These are also beneficial when it engages the perimeter columns that otherwise acts only as the gravity columns. The building acts as a cantilever and the outriggers tied with acts as stiff arms that engages perimeter column, in which the shear wall at the core tries to tilt which induces the tension-compression in the columns causing couple as shown in Figure 1.1 which then increases the overturning stiffness which can also be called as restoring moment acting in the core.

Performance of the outrigger also depends upon the locations in the building, the number of levels provided, topology of the outrigger braces and the material used to design. The outrigger system is designed to control lateral deflections, storey drift, time period and simultaneously increase in stiffness and strength of the structure for the comfort of the occupants during the highest lateral loads. Due to connection of the outer columns with the outrigger system, reduces the overturning moments and resulting in lateral deformation at the top floors. The system works by applying force to the core and resulting in the counteracting rotation.

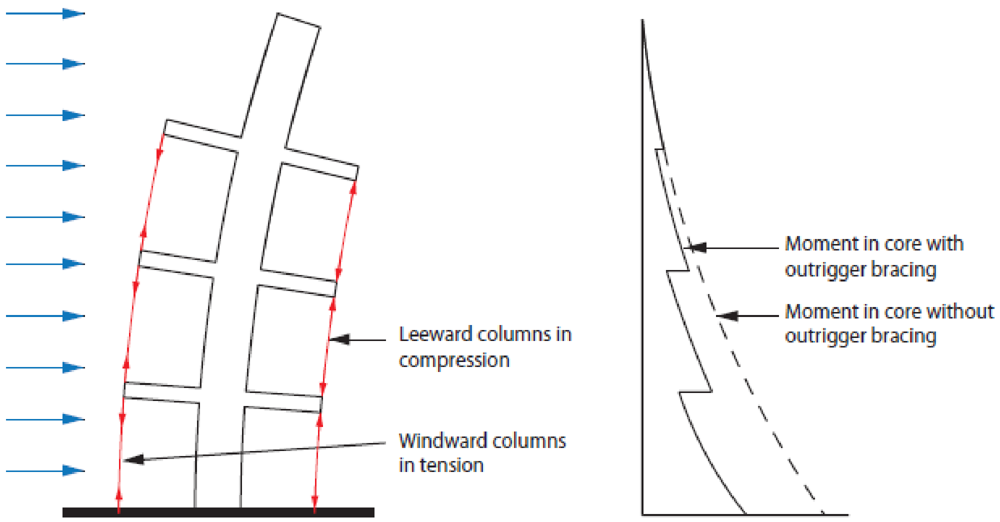


Figure 1: Interaction of core and outriggers.

[Choi et al. (2012)]

Literature review

The study of K-style outrigger under seismic performance by **Nie et al. (2013)** finite-element analysis and the experimental study was carried out to evaluate the behavior of the joints between concrete core and steel outrigger in high-rise buildings. The preliminary study was carried by elaborately modelling the joints and the failure modes and hysteresis behavior was checked. Specimens with two different joint details were tested under cyclic load and the mechanism for stress distribution and several factors such as energy dissipation, ductility and rigidity degradation was checked. Design of the specimens were based on Chinese standards.

Study by **Ho (2016)** shows the outrigger topology and behavior. Different topologies K-type, Inclined Brace, Inverted-V and Chevron type were considered. The outrigger was installed using height of 2 storeys. They were fabricated as square hollow section and universal beam of some specific sizes. The connections of outrigger with core were rigid due to larger weight of the members in the construction. The robustness factor was considered for the critical load and geometric nonlinear analysis was carried considering vertical displacement and stiffness. Graphical comparison was done by suing Load vs. Displacement to find design load capacity. Based on the results for both the sections and types of outrigger the best found was K-style.

In the study by **Balling et al. (2014)** skyscraper model (SSM) using dominant degree of freedom and super element was developed and utilized in a spreadsheet a preliminary design of high-rise building with outrigger system and belt trusses. The SSM was used to examine and to get optimal response of the linear and nonlinear gravity, wind, and seismic loads for a building with 100-storey skyscraper. From the obtained results the SSM were compared to the results obtained from a detailed finite element model (DFEM), and the difference in the results was observed to be less than 1% in the displacement and 6% in the maximum stress. The SSM shown the proper deflected shape of the core along with the curvature of skyscrapers with outrigger system and belt trusses. The process of execution, preparation of data, extraction of data, and its optimization were found to be much quick in the SSM than in the DFEM.

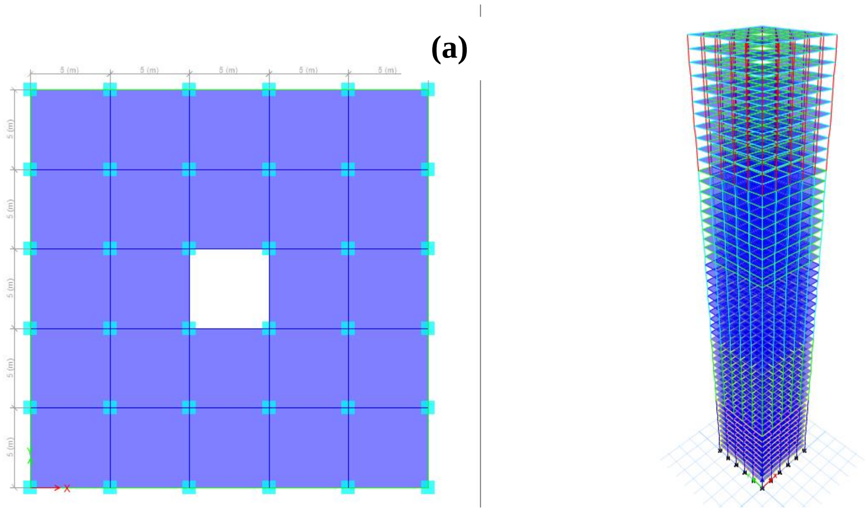
Lee et al. (2014) in their study parameterized floor-wise outrigger using Simple Isotropic Penalization (SIMP) and was defines as a design variable. Software based on finite element method ANSYS was used to model 201 m high building and iterative analysis was performed to find the optimum position of the number of systems under wind load. Based on uniform building code conditions of wind acting was defined for leeward and windward side. The model with 1 outrigger, 2 numbers, 3 numbers and 4 numbers were analyzed and graph for sensitivity against floor were plotted to find the optimum location of the outrigger.

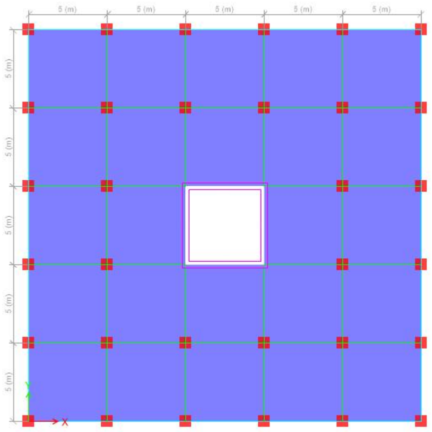
In the study of optimum design of outriggers for tall buildings using alternative nonlinear programming by **Kim (2017)** proposed alternative method between integer nonlinear and real number nonlinear programming to obtain results by solving mixed integer nonlinear programming. Likewise, a quadratic interpolation method was used to get a differentiable and function of semi-continuous constraint using the discrete analysis results from the analysis using finite element method. Three models showing various tall buildings types with different outriggers were modelled to obtain the optimum design of the outrigger, which is subject to various constraints of lateral displacement. The conclusion form the results obtained demonstrated that if the number of outriggers system used are increased, the total volume required gets decreased. However, the outcome of the outrigger system was almost the similar when the number of the outrigger installed was more than two. The optimum position of the outriggers was slightly higher than those obtained from the analytical solutions with simplified assumptions.

Methodology

Various cases for the analysis are carried out as stated below with various combinations of materials and different outrigger topologies. The model for conventional system and the building with X-Style, K-Style and Inverted V-Style are as shown below in Figures 6.1 (a),

(a)





(b)

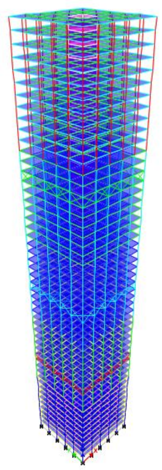
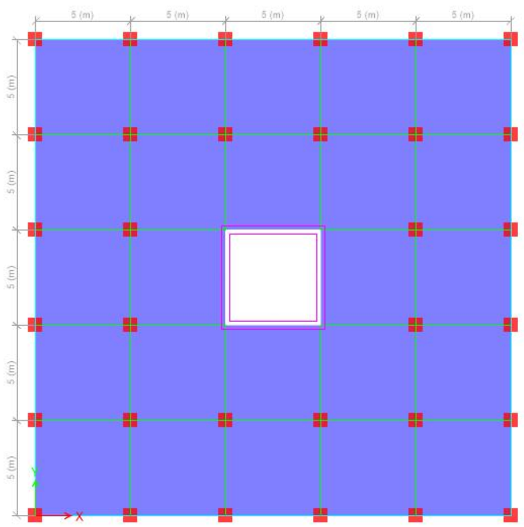
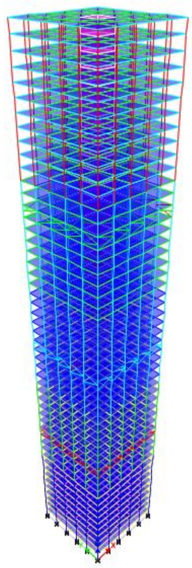
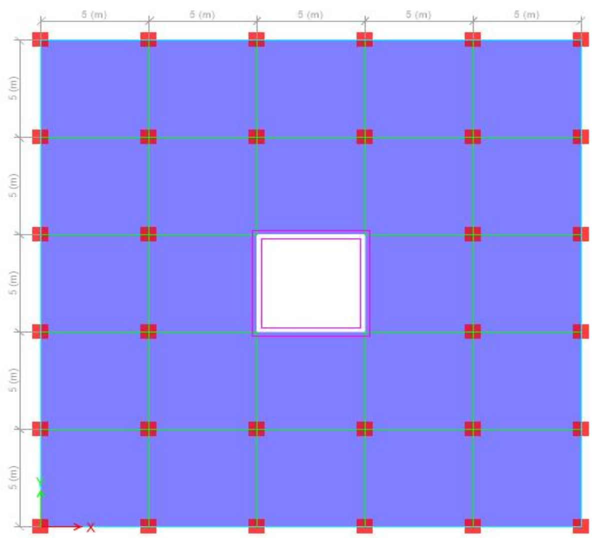


Figure 2 (a) Plan and 3D Model of Conventional System, **(b)** Plan and 3D Model with X-Brace Outrigger System





(a) **(b)**



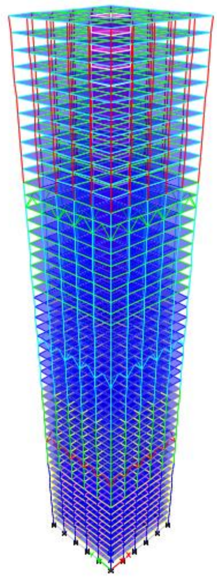


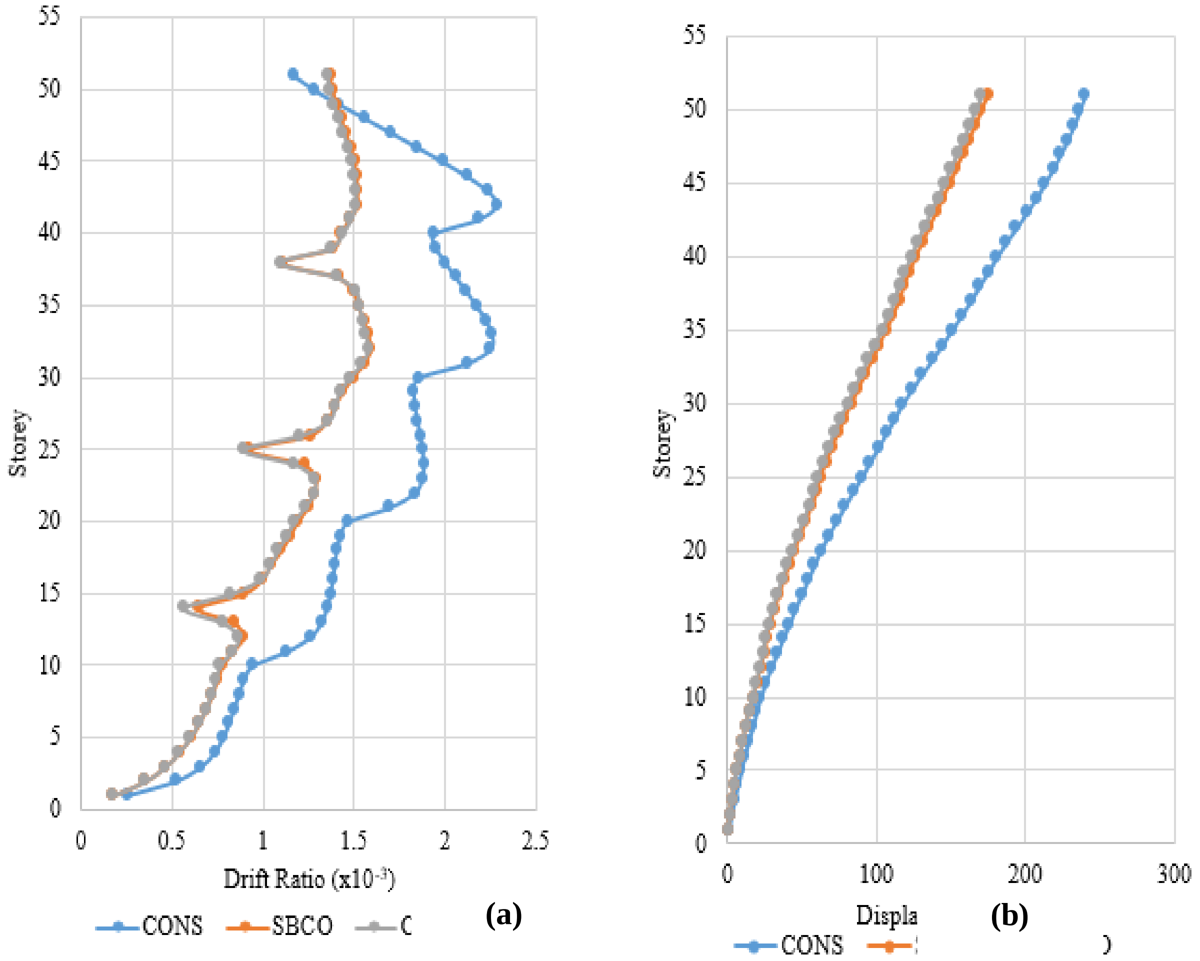
Figure 3 (a) Plan and 3D Model with K-Brace Outrigger System, **(b)** Plan and 3D Model with Inverted V-Brace Outrigger System

The buildings are modelled in ETABS by using drawing command initially column and beams are drawn and then the slabs and shear wall are drawn. Later, meshing is provided to the members and once the errors are checked out of the model and analyzed.

Result and Discussion

Case I: Comparison for behaviour of concrete belt truss and concrete outrigger (CBCO), Steel belt truss and concrete outrigger (SBCO) with conventional system along X and Y direction for conventional system and X- brace.

Figure 4 (a) Maximum Storey Drift, **(b)** Maximum Storey Displacement



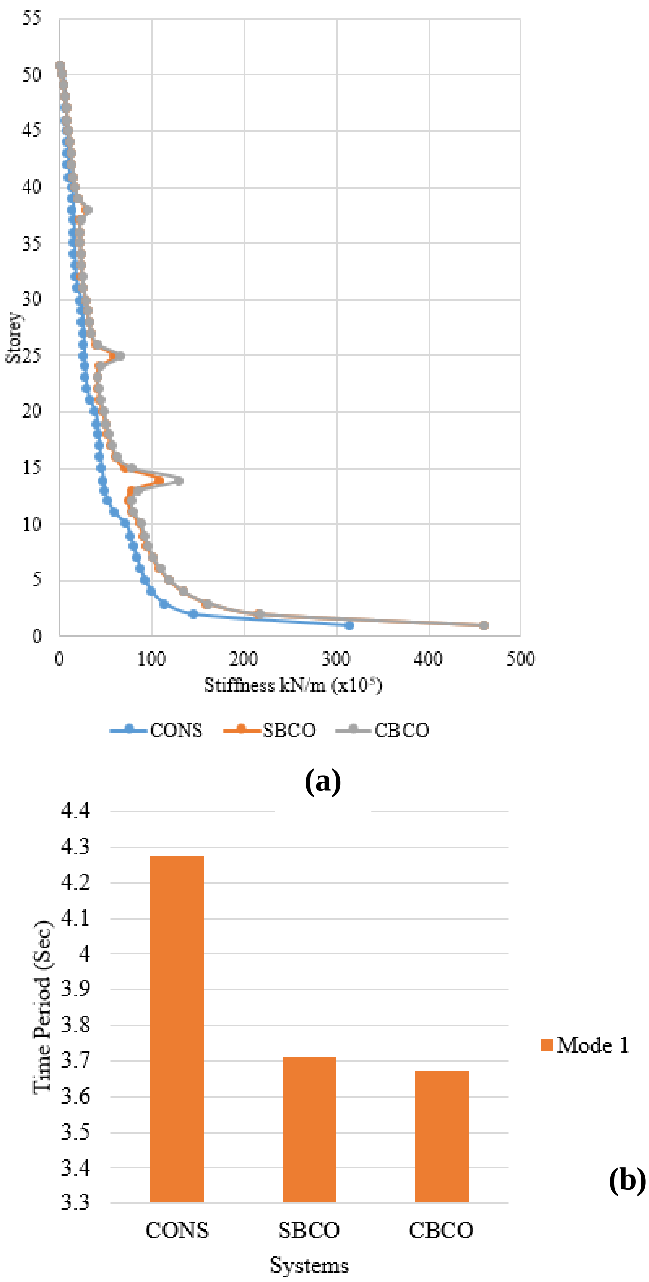
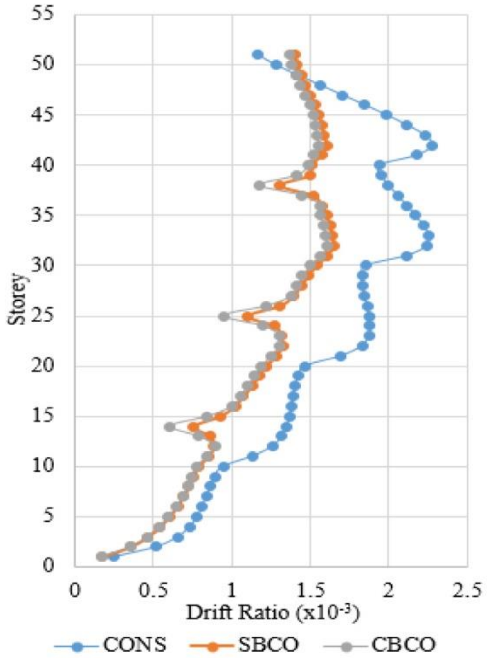


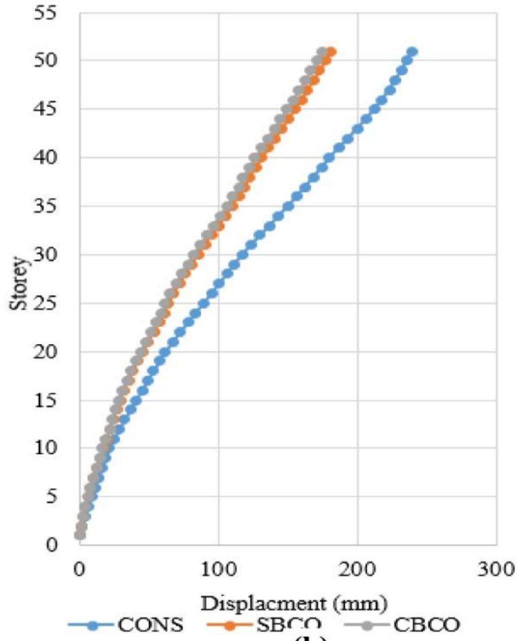
Figure 5 (a) Maximum Storey Stiffness, **(b)** Time Period

When the conventional system is engaged with outrigger system with combination of steel belt and concrete outrigger system and concrete belt and concrete outrigger system as per the results shown in Figure 6.3 (a), 6.3 (b), 6.4 (a) and 6. 4(b) the reduction of 33.3 % in drift ratio, 28.8 % in displacement, 14.07 % in time period and increase in 56.77 % in stiffness.

Case II: Comparison for behaviour of concrete belt truss and concrete outrigger (CBCO), Steel belt truss and concrete outrigger (SBCO) with conventional system along X and Y direction for conventional system and K- brace.



(a)



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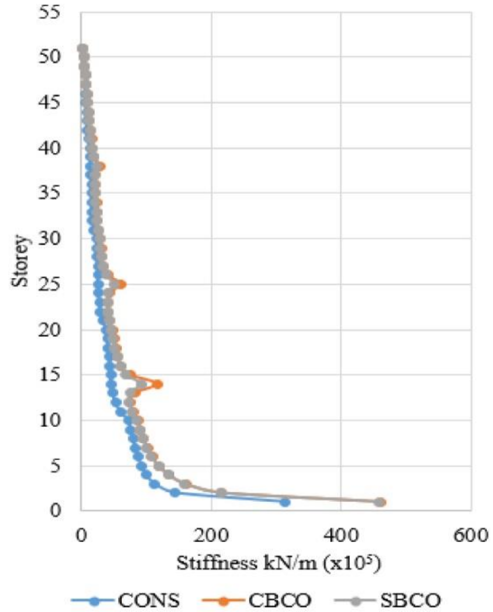


(b)

(c)

Figure 6 (a): Maximum Storey Drift, (b) Maximum Storey Displacement, (c) Maximum Storey Stiffness

When the conventional system is engaged with outrigger system with combination of steel belt and concrete outrigger sy

stem and concrete belt and concrete outrigger system as per the results shown in Figure 6.5 (a), Figure 6.5 (b) and Figure 6.5(c) the reduction c **(a)** 72 % in drift ratio, 25.85 % in displacement, and increase in 61.6 % in stiffness and 9.57 % in base shear.

(c)

(a)

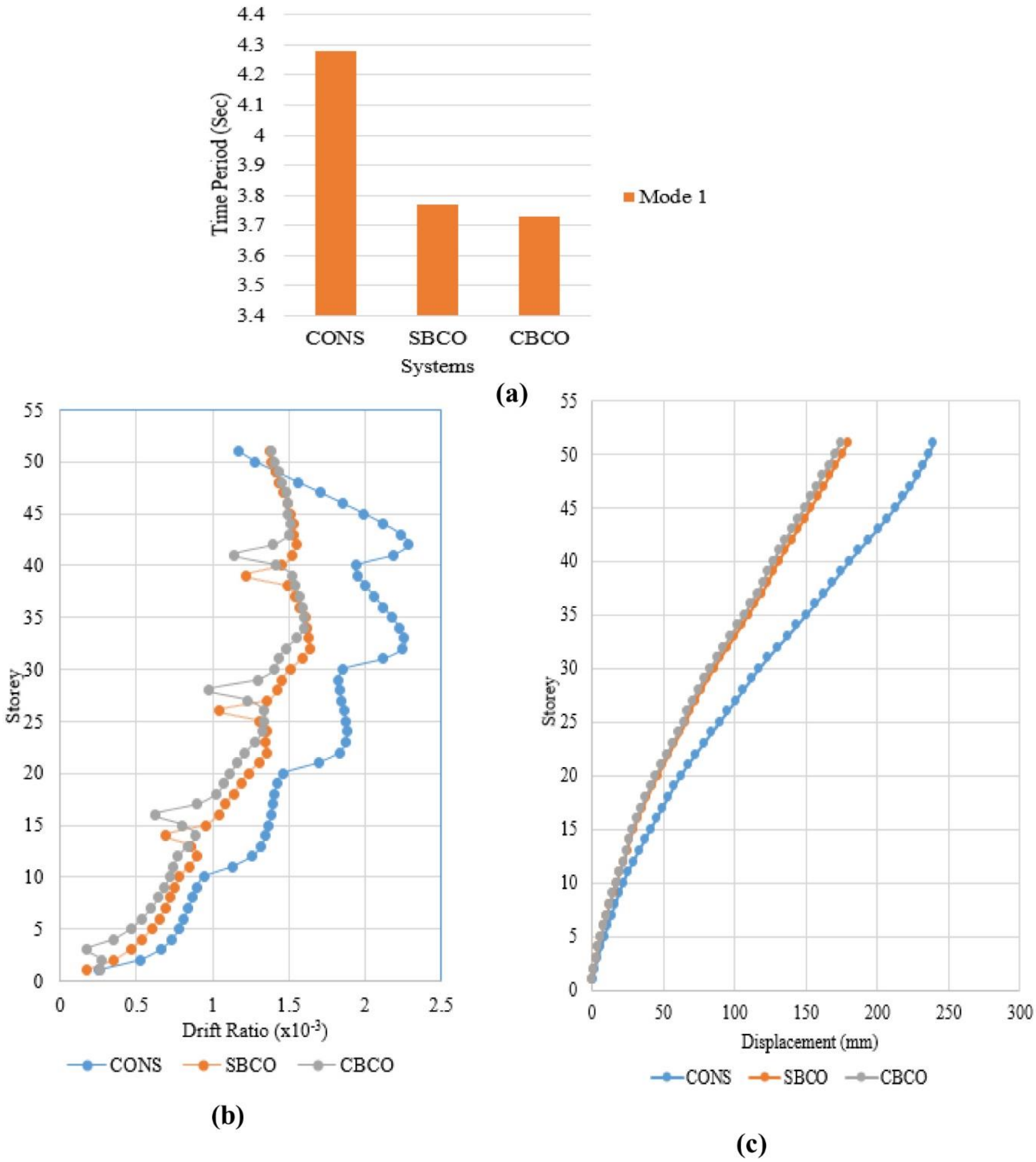
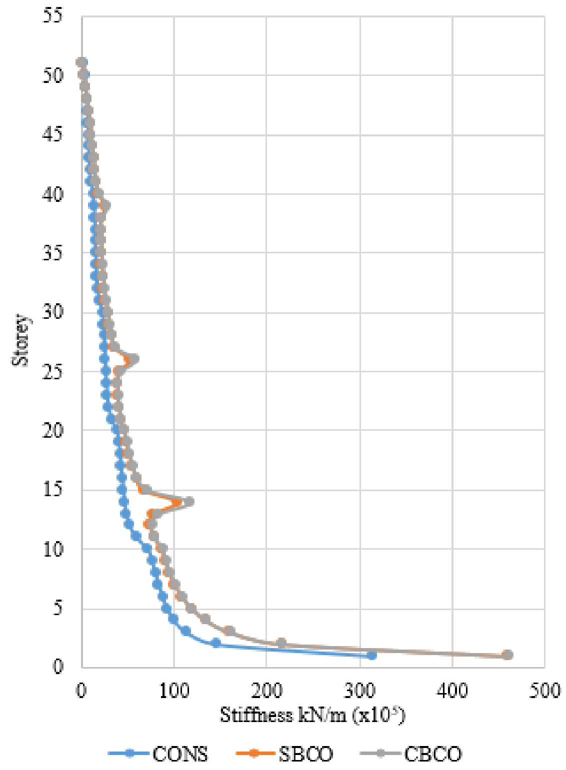
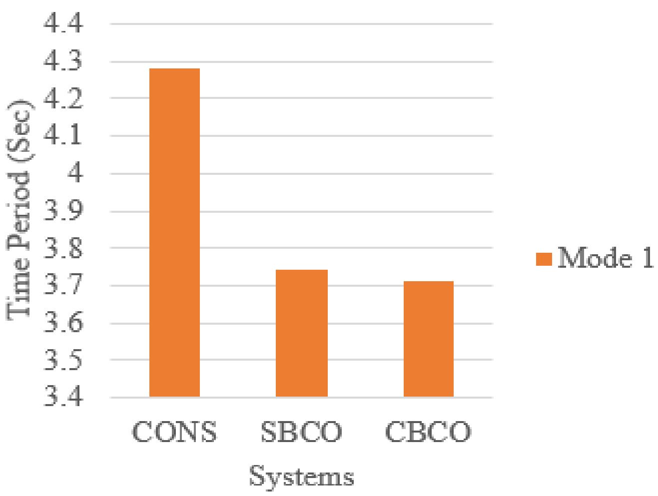


Figure 7 (a) Time Period, **(b)** Maximum Storey Drift, **(c)** Maximum Storey Displacement



(a)



(b)

Figure 8 (a) Maximum Storey Stiffness, **(b)** Time Period

Case III: Comparison for behaviour of concrete belt truss and concrete outrigger (CBCO), Steel belt truss and concrete outrigger (SBCO) with conventional system along X and Y direction for conventional system and Inverted V- brace. When the conventional system is engaged with outrigger system with combination of steel belt and concrete outrigger system and concrete belt and concrete outrigger system as per the results shown in Figure 6.6 (b), Figure 6.6 (c), Figure 6.7 (a) and Figure 6. 7 (b) the reduction of 33.93% in drift ratio, 27.3 % in displacement, 13.27 % in time period and increase in 54.37 % in stiffness against gust load.

Conclusions

The research presented in this thesis has main objectives for reduction of drift ratio limit, displacement limits, reduction of time period that does not matches the natural time period of the building, weight of the structure, constructional difficulties, architectural problems and base shear into the consideration as per the standard codes the design of the building is done which can resist all the lateral loads in specified parameters.

Table 7. 1 Comparison of Results

Parameters	X-Brace	K-Brace	Inverted V-Brace	Final Model
Decrease in Drift Ratio (%)	28.8	27.3	26.95	25.85
Decrease in Displacement (%)	30.86	29.85	28.56	32.57
Decrease in Time Period (%)	14.13	12.85	13.27	11.1
Increase in Stiffness (%)	62.9	58.6	56.89	63.92

Form the present study as per the comparison shown in Table 7.1 following conclusions are made:

- Concrete belt truss and concrete outrigger systems is best suited material that reduces the drift ratio, displacement and time period by increase in stiffness.
- X-Style system is found to be best in all the used topologies which increases the ductility and energy absorption capacity of the building.
- After increasing the number of outrigger storey the stiffness was increased and also lead to the reduction of weight of the building of about 5% compared to the building with outrigger system without changing the sizes of frame elements.
- Compared to conventional frame system building with outrigger provides more safety.

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