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Optimal Configuration of Diagrid and Outrigger Structural Systems for Tall Buildings

Ekta Mathasuriya[1], Dr. Rajul K. Gajjar[2], Prof. Poonam I. Modi[3]

[1]Post Graduate student, Applied Mechanics Department, L.D. College of Engineering, Gujarat, India

[2]Principal, L.D. College of Engineering, Gujarat, India

[3]Assistant Professor, Applied Mechanics Department, L.D. College of Engineering, Gujarat, India

Abstract: Demand for High Rise structures has become so exponentially high that effective and advanced form of structural systems needs to be studied in detail so as to choose the best suitable structure in a given scenario. Structural system for a tall building should be configured so as to maximize its structural efficiency. The present study aims to evaluate the optimal configurations of structural systems- Diagrid and Outrigger for tall buildings. A 42 m x 42 m size regular floor plan is considered for analysis. Analysis of diagrid and outrigger structural system for tall steel building of 60 storey subjected to lateral loading is carried out in E-tabs software by considering the possible variation in both the systems (i.e. Angles for diagrid system and topology for outrigger system). Response spectrum analysis for earthquake loading and gust factor method for dynamic along wind response is considered for analysis of structure. Comparison of analysis results is presented in terms of top storey displacement, inter-storey drift, structural steel quantity and first mode time period. Based on the analytical results, the optimum configuration of diagrid and outrigger structural system is identified. It was found that the diagrid system having variable density and conventional outrigger with belt-truss having X topology gives optimal configuration for respective systems. It is also concluded that the performance of the diagrid structural system surpasses the Outrigger structural system.

Keywords: Diagrid, Conventional Outrigger, Virtual Outrigger, belt-truss, Topology, Structural System, Cost efficiency.

I. INTRODUCTION

In last few decades, high-rise buildings are found to be most appropriate solution to cater to problems of land scarcity and increased rates in all areas of urbanization. Lateral loading due to wind or earthquake along with gravitational loading are governing factors in the design of high-rise buildings.

With evolution in technology, engineers during the last five decades have developed and incorporated several new lateral load resisting structural systems (bundled-tube, diagrid, outrigger systems, etc.) in many high-rise buildings to satisfy the safety, serviceability, and aesthetic criteria and simultaneously minimizing the material used.

Recently, the diagrid structural system as exterior system and outrigger structural system as interior system is extensively used for tall steel buildings because of its better structural efficiency and economical in terms of steel tonnage than other structural systems.

Diagrid structure as an exterior lateral load resisting system, consists of inclined diagonal columns on the exterior periphery of building. Due to inclined columns lateral loads are resisted by axial action of the diagonal.

Outrigger as an interior lateral load resisting system, concept is to make one unit of outer periphery and core of building by providing large deep beam known as stiff outriggers and belt truss at one or more levels. The belt truss tied the peripheral column of building while the outriggers connect them with main or central shear wall.

II. MODELLING AND ANALYSIS

A. *Building Configuration*

The 60 storey outrigger and diagrid steel building having 42m x 42m square plan with section view of core is shown in Fig. 1 and fig. 2 respectively. In diagrid systems, pair of braces is situated on the facade of the building with 7 meter spacing along the perimeter. In outrigger structure external vertical columns are spaced at 14 meters along the periphery. The outriggers are provided at top floor and at 2/3rd height i.e. at 40th floor. Typical storey height is 3.5 m and total height of building is 210m. For analysis the braces and outriggers are modeled by truss elements and beams and columns is modeled by beam elements.

The design dead load and live loads on floor slab are 3.75 kN/m^2 and 2.5 kN/m^2 respectively. The dynamic along wind loading is computed based on the basic wind speed of 39 m/sec and terrain category IV as per IS:875 (III)-2015 (Gust factor method)

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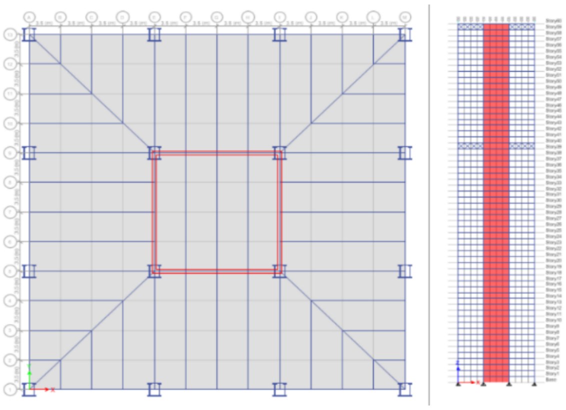

Fig. 1 Typical Floor Plan and Sectional view (Outrigger System)

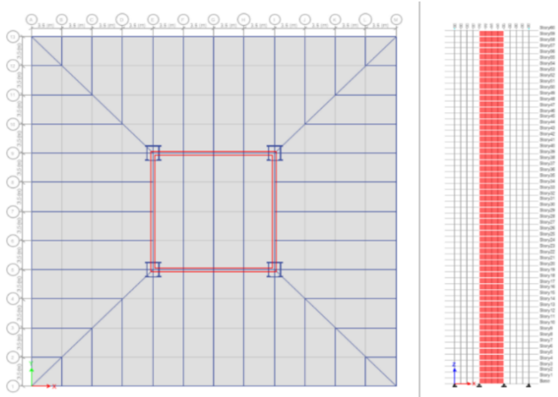

Fig. 2 Typical Floor Plan and Sectional view (Diagrid System)

B. Different configurations for outrigger structural system

TABLE I: DIFFERENT CONFIGURATIONS FOR OUTRIGGER STRUCTURAL SYSTEM

Sr. No.	Acronyms	Model Configuration
1	OC1X	Conventional outrigger with shear wall core and X topology
2	OC1V	Conventional outrigger with shear wall core and V topology
3	OC2X	Conventional outrigger with braced core and X topology
4	OC2V	Conventional outrigger with braced core and V topology
5	OBC1X	Conventional outrigger with belt truss with shear wall core and X topology
6	OBC1V	Conventional outrigger with belt truss with shear wall core and V topology
7	OBC2X	Conventional outrigger with belt truss with braced core and X topology
8	OBC2V	Conventional outrigger with belt truss with braced core and V topology
9	BC1X	Virtual outrigger with shear wall core and X topology
10	BC1V	Virtual outrigger with shear wall core and V topology
11	BC2X	Virtual outrigger with braced core and X topology
12	BC2V	Virtual outrigger with braced core and V topology

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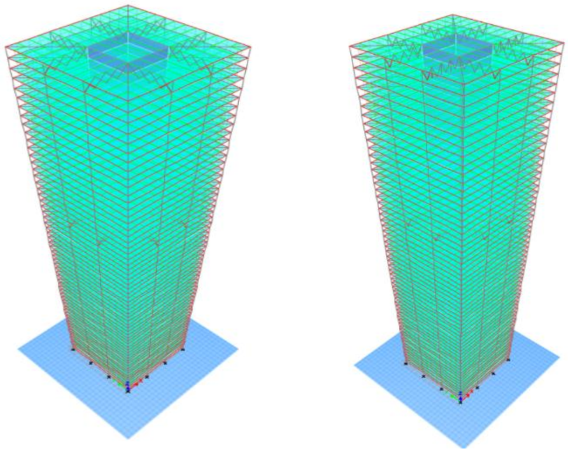

Fig. 3 Conventional Outrigger (OC1X, OC1V)

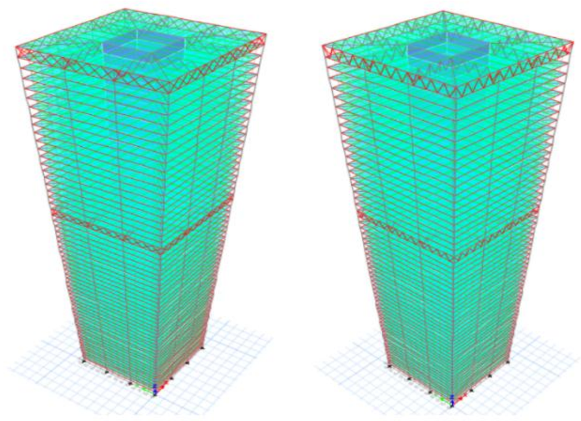

Fig. 4 Conventional Outrigger with Belt-truss(OBC1X, OBC1V)

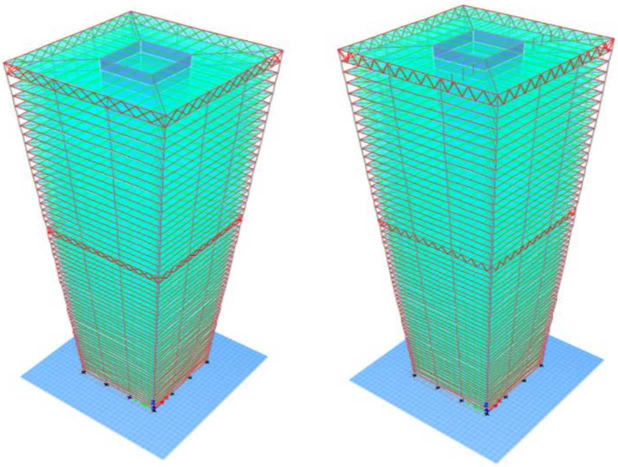

Fig. 5 Virtual Outrigger (BC1X, BC1V)

C. Different configurations for Diagrid structural system

TABLE II: DIFFERENT CONFIGURATIONS FOR OUTRIGGER STRUCTURAL SYSTEM

Sr. No.	Acronyms	Model Configuration
1	DC1A	Diagrid with shear wall core and constant angle
2	DC1V	Diagrid with shear wall core and vertical angle variation
3	DC1d	Diagrid with shear wall core and varying density
4	DC1H	Diagrid with shear wall core and horizontal angle variation
5	DC1HV	Diagrid with shear wall core and combined horizontal and vertical angle variation
6	DC2A	Diagrid with braced core and constant angle
7	DC2V	Diagrid with braced core and vertical angle variation
8	DC2d	Diagrid with braced core and varying density
9	DC2H	Diagrid with braced core and horizontal angle variation
10	DC2HV	Diagrid with braced core and combined horizontal and vertical angle variation

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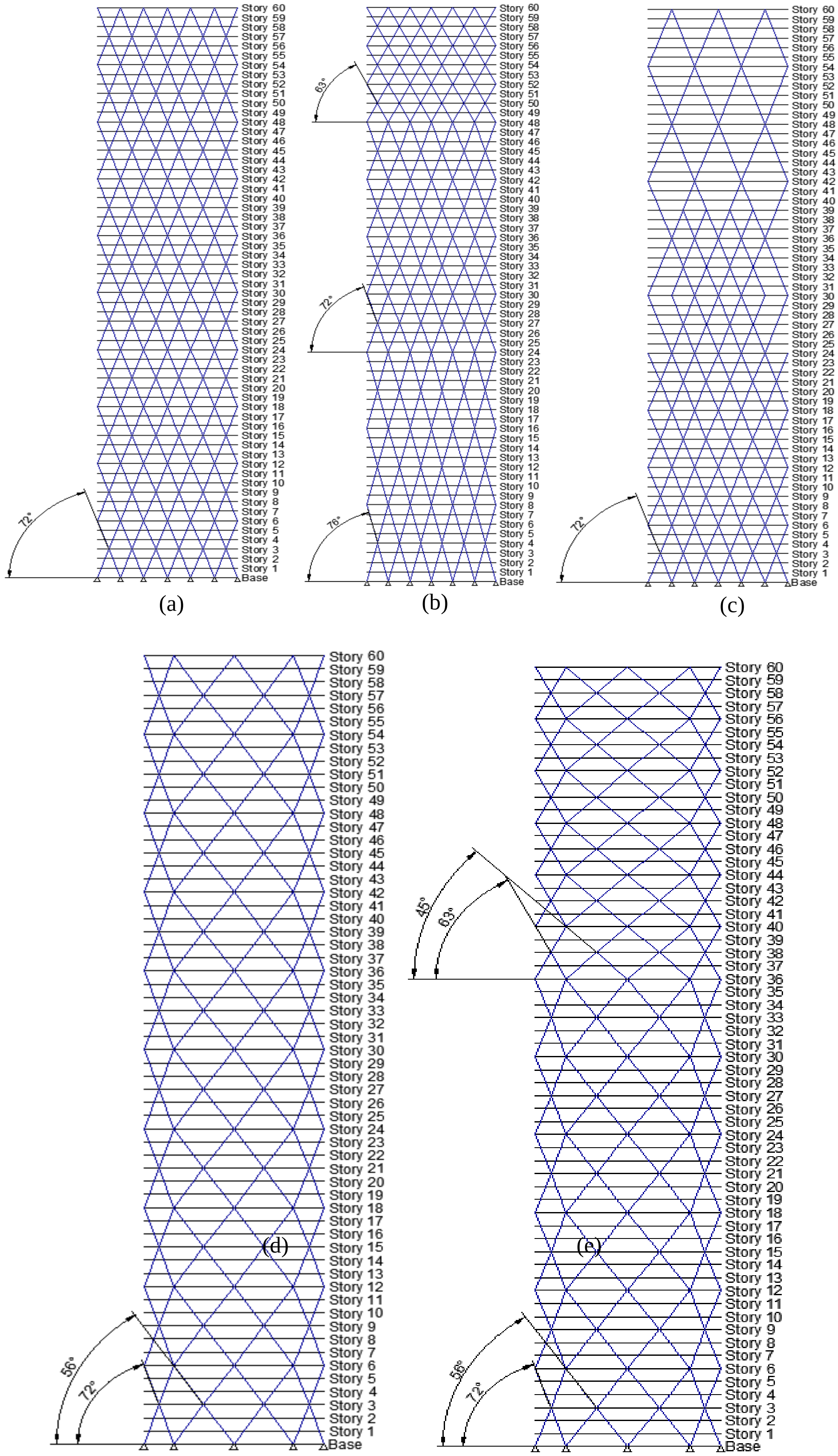

Fig. 6 Elevation View of Diagrid Structures (a) DC1A (b) DC1V (c) DC1d (d) DC1H (e) DC1HV

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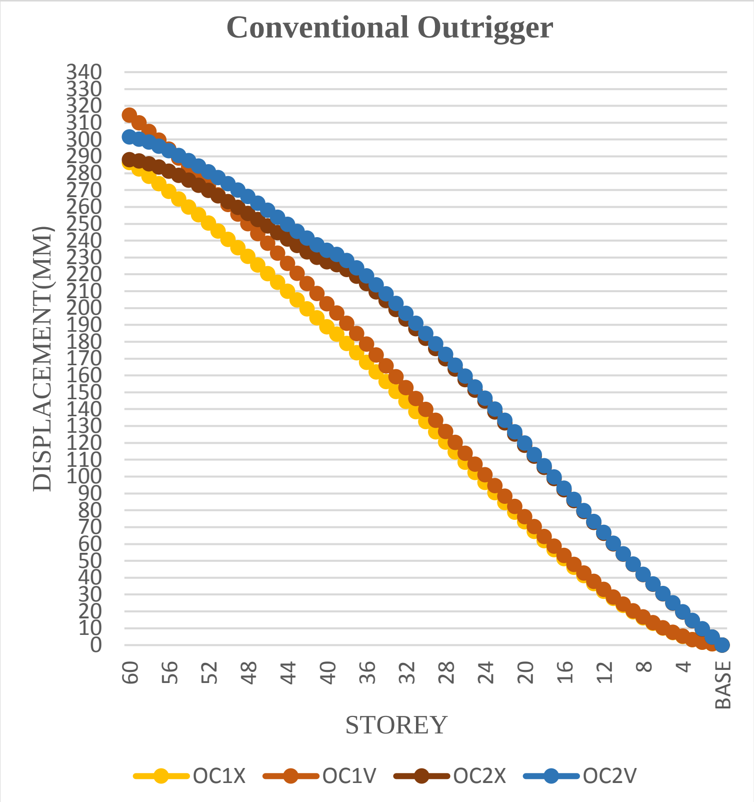
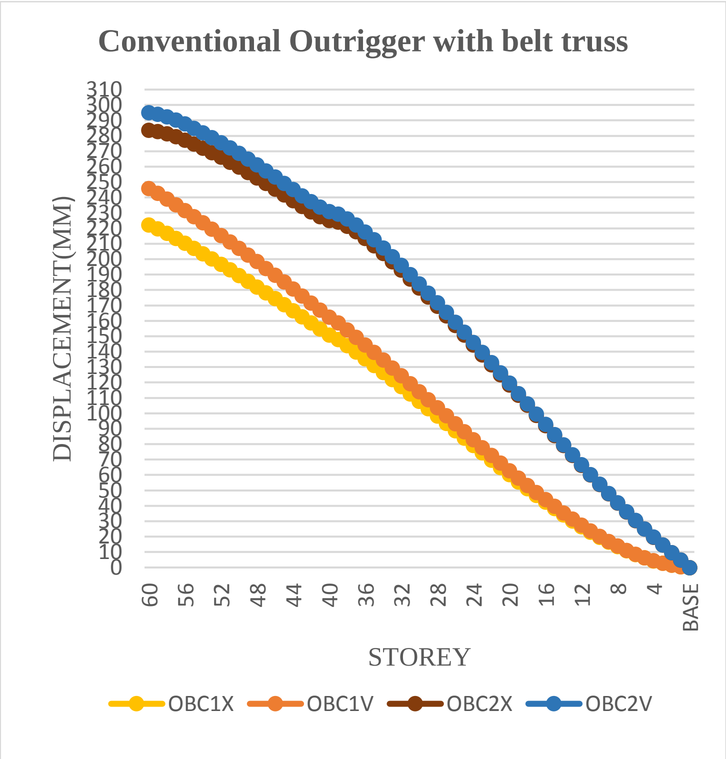
III. RESULT AND DISCUSSION

A. *Comparison of Analysis Results in terms of Displacement*

The various graph of displacement for different configurations of outrigger are compared in figure 7 (a), (b), (c).



(a)



(b)

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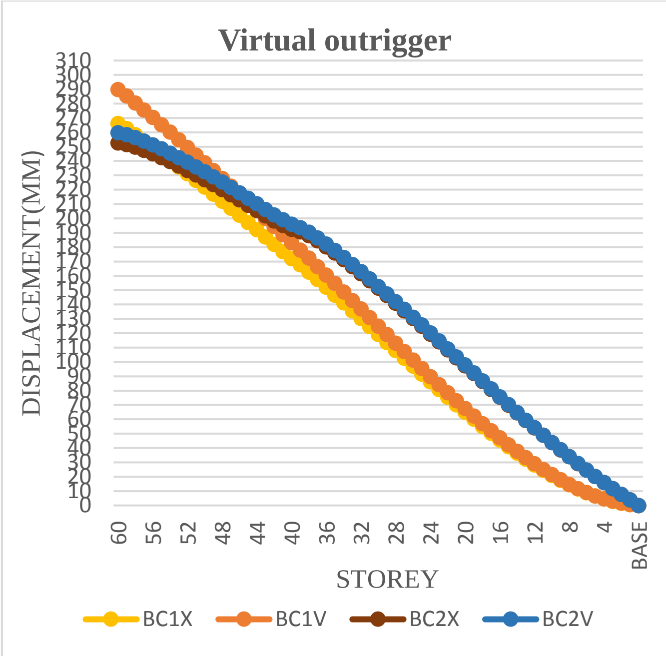
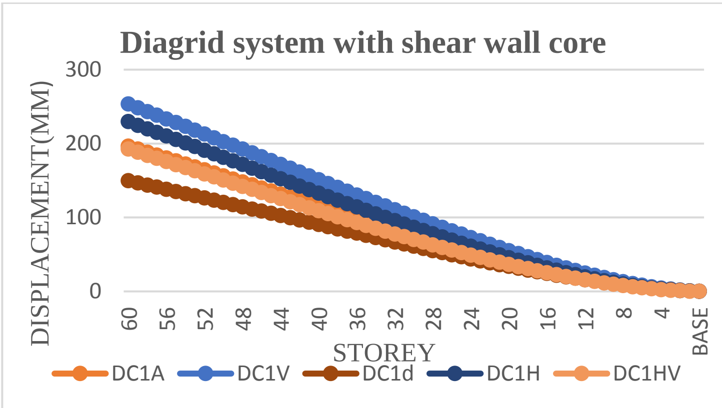


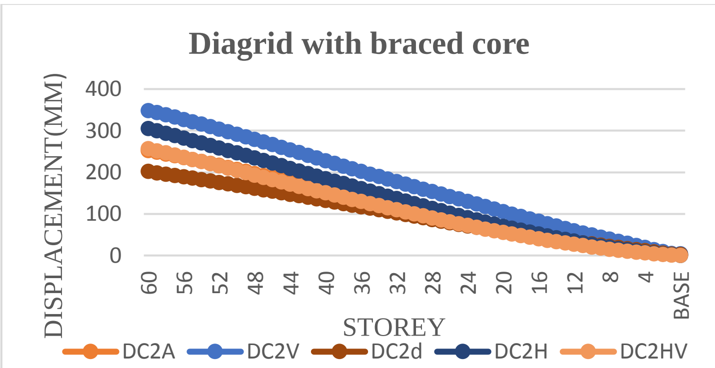
(c)

Fig. 7 Comparison of Displacement for Outrigger system (a) Conventional Outrigger (b) Conventional Outrigger with Belt-truss (c) Virtual Outrigger

The various graph of displacement for different configurations of diagrid are compared in figure 8 (a), (b).



(a)



(b)

Fig. 8 Comparison of Displacement for Diagrid System (a) Diagrid with Shear Wall Core (b) Diagrid with Braced Core

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B. *Comparison of Analysis Result in terms of Structural Steel Quantity*

Figure 9 and 10 shows the comparison of steel mass for different configurations of outrigger and diagrid system respectively.

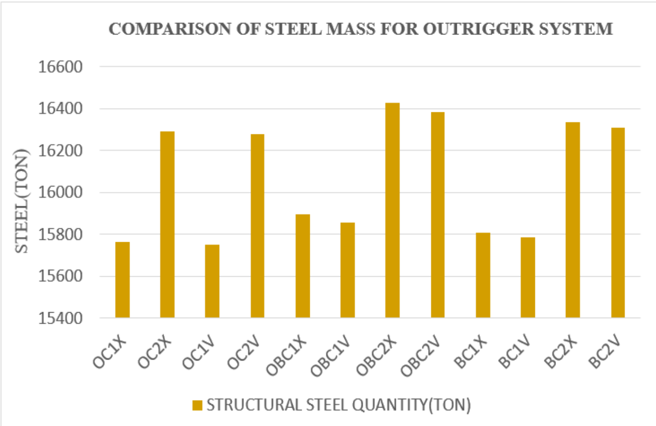

Fig. 9 Comparison of Structural Steel Quantity for Outrigger System

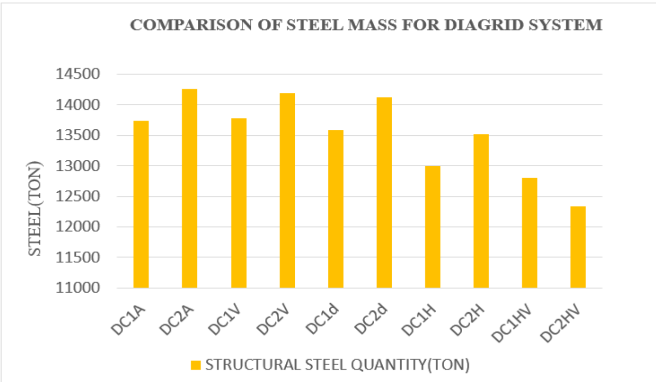

Fig. 10 Comparison of Structural Steel Quantity for Diagrid System

C. *Comparison of Analysis Result in terms of First Mode Time Period*

Figure 11 and 12 shows the comparison of first mode time period for different configurations of outrigger and diagrid system respectively

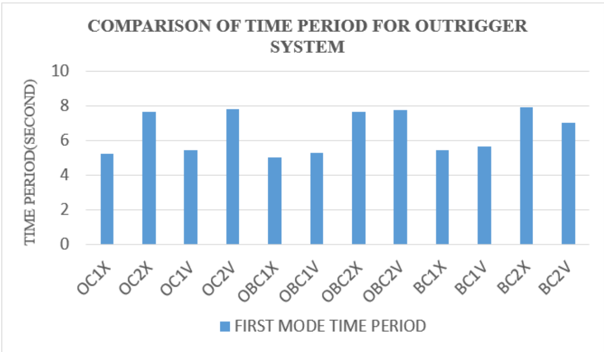

Fig. 11 Comparison of Time Period for Outrigger System

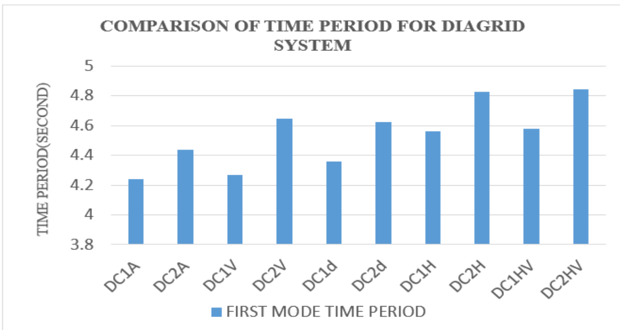

Fig. 12 Comparison of Time Period for Diagrid System

IV. CONCLUSION

The following conclusions are drawn based on the analytical results of 12 configurations of 60 storey outrigger system:

- For outrigger with shear wall core, the configuration, conventional outrigger with belt truss having X topology (OBC1X) performs better in terms of top storey displacement and inter-storey drift.

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- For outrigger with braced core, the virtual outrigger having X topology (BC2X) performs better in terms of top storey displacement and inter-storey drift.
- The configuration, shear wall core with conventional outrigger having V topology is economical in terms of steel mass.
- The time period for conventional outrigger with belt truss having X topology and shear wall core (OBC1X) is least. So it is concluded that it is much stiffer than other configuration.
- It can be concluded that the optimal configuration for outrigger system is obtained by using shear wall core and conventional outrigger with belt truss having X topology.

The following conclusions are drawn based on the analytical results of 10 configurations of 60 storey diagrid system:

- For both, diagrid with shear wall core and diagrid with braced core, the configuration, diagrid column having variable density (more numbers of diagrids upto 20 storey and less numbers of diagrids at higher storey) performs better in terms of top storey displacement and inter-storey drift.
- The top storey displacement for diagrid with shear wall core having variable density (DC1d) is reduces of about 25.7% as compared to the diagrid with braced core having variable density (DC2d).
- The inter-storey drift for diagrid with shear wall core having variable density (DC1d) is reduces of about 27.7% as compared to diagrid with braced core having variable density (DC2d).
- The configuration having combination of horizontal and vertical angle variation (DC1HV & DC2HV) is economical in terms of steel mass for both braced and shear wall core.
- The time period for diagrid with shear wall core having constant angle (DC1A) is least. So it is concluded that it is much stiffer than other configuration.
- It can be concluded that the optimal configuration for diagrid system is obtained by using shear wall core with peripheral diagrid column having variable density.

By comparison of optimal configured models amongst 10 models of diagrid and 12 models of outrigger structural system, following observation are made:

- There is 32.6% and 37.7% reduction is observed in displacement and inter-storey drift for diagrid system having variable density(DC1d) as compared to conventional outrigger with belt truss having X topology(OBC1X).
- The time period of the diagrid structural system having variable density is 4.36 sec and outrigger structural system with belt truss having X topology is 5.041 sec. Thus 13.5% reduction in time period of diagrid structural system.
- The consumption of steel material for diagrid structural system is less than the outrigger structural system. Hence it can be conclude that for tall steel buildings, provision of diagrid structural system will be economical.

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