Analyzing Utility of Component Elements of Outrigger System

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Abstract - *Outriggers are rigid horizontal structures designed to improve the building overturning stiffness and strength by connecting the building core or spine to distant columns in the perimeter. In any tall building its structural efficiency depend upon its lateral stiffness and lateral load resistance capacity. There are various structural systems available to resist lateral loads in tall buildings. Outrigger system is one of the lateral load resisting systems which is widely used for tall buildings. Present work aims at understanding the fundamental functionality of this outrigger system, the utility of each component element involved viz. Belt Truss, Core and Outrigger Trusses and understanding the economic implications of using outrigger system. A comparative study between Virtual and Conventional outrigger is performed to understand their effect in resisting lateral load in a 30 m high building.*

Key Words**: Outrigger System, Structural Analysis, Static Analysis, Optimization, Utility, Economy, Structural Performance**

1. INTRODUCTION

Economic prosperity and population increase in the urban areas increases the necessity of judicial use of the land available, thus, points towards a future with increased number of high-rise structures of commercial and residential use. As a result of this tall building developments have been rapidly increasing worldwide. A number of structural systems have been evolved over the years depending upon various complex factors such as economics, aesthetics, technology, municipal regulations. Various studies show that the structural efficiency of tall buildings mainly depends on the lateral stiffness and resistance capacity of the structure. Out of all the systems Outrigger is one of the most efficient systems especially for buildings with regular floor plan. The use of outrigger in building structure can be traced back from the concept of deep beams. As the building height increases, deep beams become concrete walls or large steel truss type outrigger. This paper focuses on analysing the structural components of outrigger system viz. Outrigger truss, Belt truss, stiff core and the load transferring mechanism and in the pursuit of the same aims to understand the utility and contribution of each component elements by carrying out a comparative study on models simulated in STAAD. The paper also discusses the differences in virtual and conventional outriggers after performing comparative studies on models in STAAD.

2. LITERATURE REVIEW

Case Study: Taipei 101

In order to understand the practical application of outrigger system in a high-rise a case study was performed to identify the key areas influenced by the use of outriggers. At 101 stories and 508 m above ground, the Taipei 101 is one of the world's tallest buildings that adopted the outrigger system. It consists of a structural framing system of braced core and multiple outriggers along with a system of perimeter frames and connections to the core that resists lateral loads specially the seismic forces. The Structure has adopted a unique way of controlling the drift by using large box type columns of steel filled with high-strength concrete that were termed as Mega columns. A central braced core stiffened by providing connections (outrigger trusses) to the perimeter columns adds to the lateral load resisting system. The primary structural skeleton of a tall building can be visualized as a vertical cantilever beam with its base fixed in the ground. The structure has to carry the vertical gravity loads and the lateral wind and earthquake loads. Gravity loads are caused by dead and live loads. Lateral loads tend to snap the building or topple it. The building must therefore have adequate shear and bending resistance and must not lose its vertical load-carrying capability.

Takeaways of Study

Provision of outrigger system provided the required lateral stiffness to the building via transferring the forces from the core to the coupled mega columns. The component systems viz. the outrigger truss, stiff core and the mega columns when clubbed together behaved more efficiently. The outrigger system engaged the perimeter columns that otherwise would have meant only as gravity-only elements. Thus when the core tries to tilt, a tension-compression couple is induced in the outrigger in opposition that acts as a restoring moment. Outrigger system proves to be a solution, adopted for structures to be built in areas of high turbulence and seismicity. For a high-rise structure multiple outriggers can be provided at suitable locations by identifying their optimum locations. This system also provides a dampening effect in case of seismic force.

3. METHODOLOGY

3.1 Problem Formulation

A space frame model of a typical commercial / office type G + 9 building having each story of 3 meters and having 3 bays along X-axis and having 5 bays along Z-axis is considered. After the dimensions of the frame have been finalized 4 different frames having combinations of various component systems - Bracing of core, Belt Truss in periphery and Outrigger Truss connecting core to exterior of structure or a rigid diaphragm are modeled in the STAAD.PRO software. The structure considered is a steel frame provided with cladding of glass as curtain wall / façade.

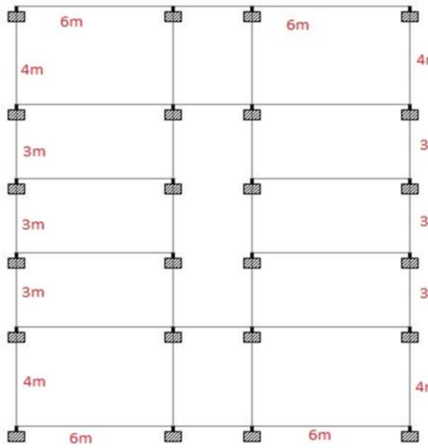
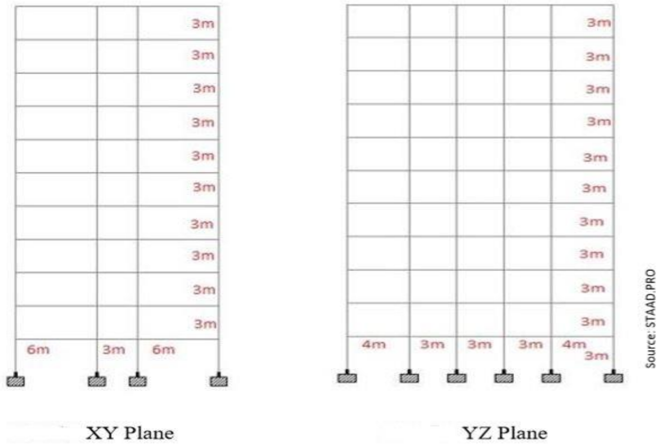


Fig. 1 Plan of Structure



Source: STAAD.PRO

Fig. 2 Elevation

3.2 Parameters of Models

Length along X- axis = 15 m
Length along Z- axis = 17 m
Height along y- axis = 3m per floor
Total Height = 30m

3.3 Load Calculation

DEAD LOAD

- Self-weight
- Floor Load – Thickness of Slab = 15 cm
  Unit Weight of Concrete = 25 KN/m^3
  Intensity of Floor Load = 3.75 KN/m^2
- Member load – Annealed Glass of Density 2520 kg/m^3. Intensity of member load = 1 KN/m (Applicable on peripheral beams)

LIVE LOADS

Imposed Loads - The imposed loads to be assumed in the design of buildings shall be the greatest loads that probably will be produced by the intended use or occupancy, but shall not be less than the equivalent minimum loads specified in Table 1 and clause 3.1 of IS 875 part II. Therefore, a floor load of 4 kN/m^2 is considered by considering the building as Office / Business type building.

SEISMIC LOAD

- Importance Factor, I = 1.5
- Zone Factor, Z = 0.24
- Response Reduction, R = 4
- Damping Ratio, D = 0.05

According to IS 1893-2002 Imposed Load to be considered in seismic weight calculation is 50%. The seismic load calculator of STAAD is used for load calculations.

3.4 Load Combinations

When earthquake forces are considered on a structure, these shall be combined as per guidelines mentioned in Clause 6.3.1.1 and 6.3.1.2 of IS 1893:2002 where the terms DL, IL and EL stand for the response quantities due to dead load, imposed load and designated earthquake load respectively. In the limit state design of the structures, the following load combinations are considered:

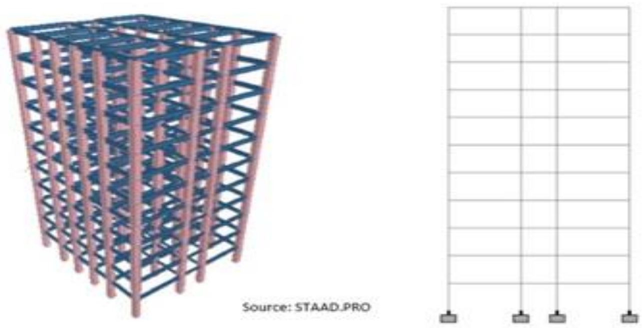
1) 1.5(DL+ IL)
2) 1.2(DL+IL+EL)
3) 1.5(DL+EL)
4) 0.9DL+ 1.5EL

3.5 Modeling Structures

Sections used for modeling were:

- Beams: ISMB 500
- Columns: User Defined Tube of Width = 600 mm, Depth = 600 mm and Thickness = 8 mm.
- Bracing: ISMC 300
- Belt Truss: ISMC 300
- Outrigger Truss: ISMC 300

Using these STAAD models are obtained shown in Fig 3 to Fig 6.



Source: STAAD.PRO

Fig. 3 Simple Steel Frame (Model 1)

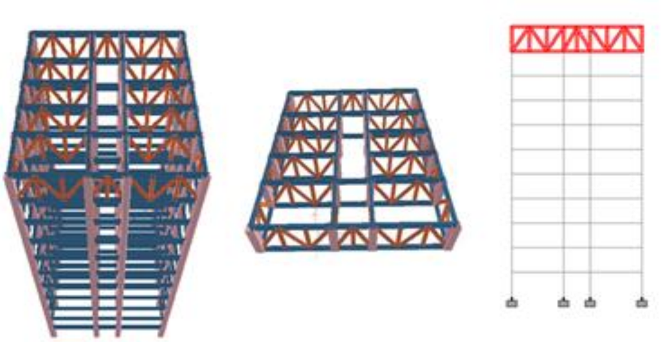


Fig.4 Steel Frame with Belt Truss and Outrigger Trusses (Model 2)

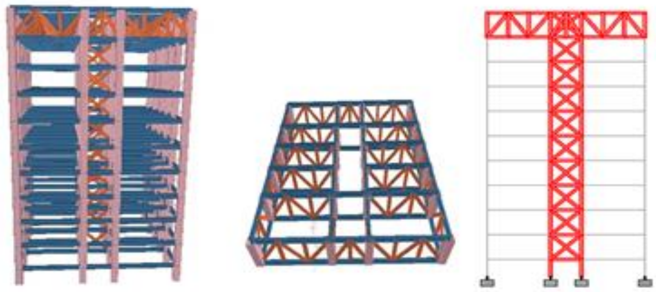


Fig. 5 Steel Frame with Braced core, Belt Truss and Outrigger trusses (Model 3)

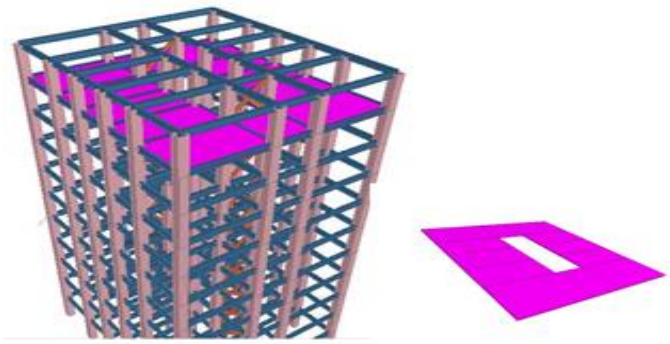


Fig.6 Steel Frame with Virtual Outrigger and Floor diaphragm (Model 4)

3.6 Parameter of Analysis

In order to compare the structures in this study, lateral displacement is considered as a parameter. This lateral displacement is indicative of the stiffness of the structure as for tall buildings, the higher we go the more influence lateral drift has on the analysis and design of the structure. Analysis of the structure that is particularly elastic analysis is carried out in STAAD. From Post- Processing results of analysis, Maximum Lateral Displacement values are observed for all the models for various load combinations and a comparative study is performed.

4. RESULTS AND DISCUSSION

The results of linear elastic analysis are made available by the software and are shown in table 1. To analyze the utility of each component element a comparative study is carried out. To establish the utility of stiffening of core a comparison is done between Model 2, Model 3 as the only distinguishing parameter between the two structures is the bracing that stiffens the core. The comparison is illustrated graphically in fig 7. Similarly, to establish the utility of outrigger a similar comparison between Model 1 and Model 3 is done. To determine the effect of using a complete outrigger on the lateral load resisting capacity of the structure a comparison between Model 1 and Model 3 is shown graphically in fig 6.

4.1 Utility of Component Elements

- **Utility of Stiff Core (Bracings)**: Models 2 and 3 differ with one another in terms of stiffness of core. It is understood that the stiffness of the structure is directly proportional to its lateral load resisting capacity. The bracings in the core provides additional stiffness to resist the lateral force thereby reducing the lateral drift in Model 3 by 24.56% in the direction in which the bracing is provided (X axis).

- **Utility of Belt Truss**: On comparing results of Model 1 and 2 it can be seen that belt truss and outrigger trusses together reduce the displacement values by 20.33mm which is approximately 39.47% that of Model 1. From these results a comment can be made on the interaction between the Belt truss and the outrigger trusses. The Belt truss when used with the outrigger trusses provides a suitable load transferring mechanism from the core to the perimeter columns. It distributes the tensile and compressive forces to a large number of exterior columns and also helps in minimizing their differential elongation and shortening.

- **Utility of Outrigger System**: Reduction in lateral displacements can be seen in results of Model 3 from those of Model 1. The difference between the two models is the outrigger trusses spanning between core and perimeter columns together with the belt truss and braced core. On comparing it is seen that the system reduced the lateral displacements by a significant 47.67%. From this we can infer that Outriggers along with the belt truss act as a backbone of the braced core system which help in force relaxation. If a link of appropriate stiffness that connects the braced core to the exterior column is absent then the braced core deforms without transferring the forces to the perimeter column and thus results in larger displacements.

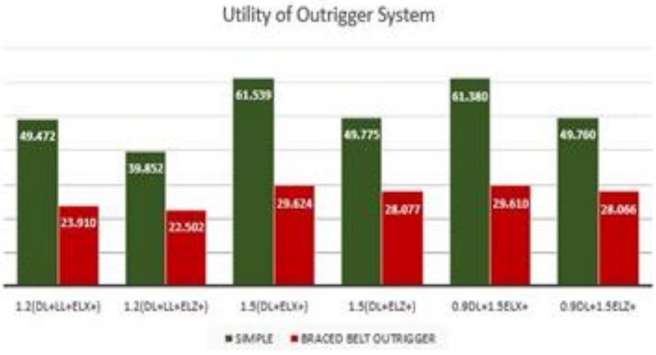
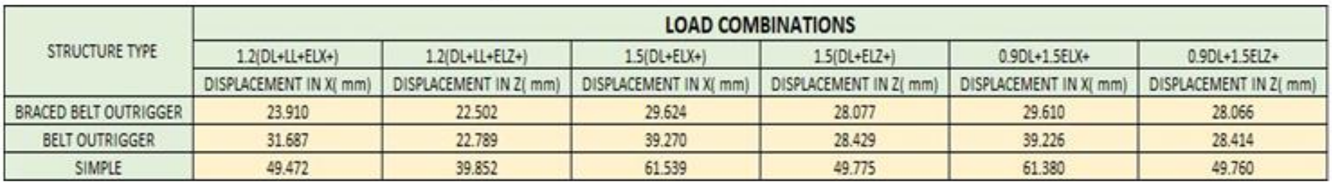


Fig. 7 Comparison of lateral displacements of Model 1 & 3

Table 1 Maximum Lateral Displacements for different models under different load combinations



STRUCTURE TYPE	LOAD COMBINATIONS					
	1.2(DL+LL+ELX+)	1.2(DL+LL+ELZ+)	1.5(DL+ELX+)	1.5(DL+ELZ+)	0.9DL+1.5ELX+	0.9DL+1.5ELZ+
	DISPLACEMENT IN X(mm)	DISPLACEMENT IN Z(mm)	DISPLACEMENT IN X(mm)	DISPLACEMENT IN Z(mm)	DISPLACEMENT IN X(mm)	DISPLACEMENT IN Z(mm)
BRACED BELT OUTRIGGER	23.910	22.502	29.624	28.077	29.610	28.066
BELT OUTRIGGER	31.687	22.789	39.270	28.429	39.226	28.414
SIMPLE	49.472	39.852	61.539	49.775	61.380	49.760

4.2 Comparing Conventional and Virtual Outrigger

In virtual outrigger the transfer of overturning moment from the core to elements is achieved by a stiff floor diaphragm. In the study the virtual outrigger system is modelled by providing a rigid floor diaphragm at the top story, the diaphragm provides the necessary stiffness that is otherwise offered by the trusses.

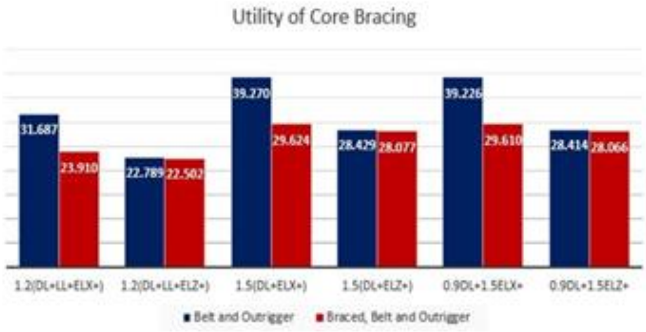


Fig. 8 Comparison of lateral displacements of Model 2 & 3

On comparing the displacements of the two structures from Table 2 it can be seen that virtual outrigger shows an improved efficiency of 36.42% in the X direction and 52.37% in the Z direction than the conventional outrigger system.

Table -2: Comparison of Optimized model 1 & model 4

System	Displacements	
	X (mm)	Z (mm)
Conventional Outrigger	38.52	46.68
Virtual Outrigger	24.49	22.23

5. CONCLUSION

The present work compares the difference in the behavior of the building in presence and absence of an outrigger system. The following conclusions were drawn based on the study:

- Use of outrigger system in the building improves the efficiency of the building in comparison to the one without outrigger system.
- Outriggers increase the flexural stiffness by reducing base shear. Provision of stiff core along with the outriggers in the building decreases the forces in the core.
- The outrigger trusses improve the building overturning stiffness and strength by connecting the building core to the columns.
- The Belt truss engages multiple columns and improves the efficiency of the system by providing a load distribution mechanism between the outrigger truss and the columns.
- Belt truss also provides more gravity load to the columns that minimizes the net uplift, thereby minimizing the reinforcement needed to resist tension.
- Distribution of forces between the component elements of the outrigger system depends on the relative stiffness of each element. Stiffness of the component elements can significantly affect the outcome as visible from the comparison between the concrete outrigger and the steel truss outrigger.

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