Performance Study for Optimum Location of Multi-Outrigger and Belt Truss System in Tall Structures

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Abstract— In the present study, one such structural system known as Outrigger and Belt Truss system are studied. The behavior of 45 storey structure for lateral loads is evaluated with Core wall, 3 Outrigger and Belt Truss systems by placing them at different storey levels using ETABS structural software. The parameters like Displacements, Inter-storey drifts and Bending Moments in Core wall are plotted and compared with the structure having only Core wall. Using these parameters, optimum location of 3 Outriggers and Belt Truss is obtained. Outriggers and Belt Truss placed at four equal parts of the structure is observed to be more efficient for lateral loads.

Key words: Outrigger, Belt Truss, Core Wall, Inter-story drift, Bending Moment, Displacement

I. Introduction

A. General

The fascination of constructing tall buildings were started by the mankind from the early stage of Civilization. Initially they were constructed for defence purposes, however now a days it is been largely used for commercial, residential and mixed purposes also.

Consequent development of urban population, constrained availability of space, cost of plots, urge to preserve agricultural lands, significance of pride, advanced technologies has contributed to construct tall buildings.

Once the height of the structure increases, its stiffness and strength decreases. Therefore an engineer will be having a tedious job of taking due concern about the various parameters such as strength, stability, displacements, storey drifts etc. The major loads acting will be vertical like gravity load (Dead Load and Live Load), lateral like Earthquake Load and Wind Load. The main function of the structural elements is to withstand all these forces

Tall structures can basically be simplified into a cantilever which is restrained at the base and free at the top. Even though gravity loads are the prominent loads on the structure, lateral loads like earthquake and wind loads are dominant as they are unpredictable and has the tendency to tilt and overturn the whole structure.

To tackle the forces various structural forms has been evolved over the years. In the current world, structural forms are chosen based on the materials and construction technique, outer architectural appearance, extent of height and building proportion. Weight of the structure is depending on span and load on column is directly proportional to the height of structure. Structure with 10 floors may be designed for vertical loads. Whereas structures above 10 floors require appropriate extra structural form to resist wind loadings which is expected to be nonlinear with respect to elevation.

The significant step in RCC structural form is improved with the help of implementing shear walls to resist lateral loadings. This structural form aided the structure to elevate them from previously 20 to 25 storey.

B. Background for Research

Outriggers are horizontally rigid structures designed to overcome overturning stiffness and strength by coupling the structure core and the distant mega-column which are capable of resisting upward and downward forces, thus improving structural stability. Even though outriggers are utilized in narrow structures recently for about half a century, the principle concepts were used way beyond. One or more horizontal beam fastening to main narrow canoe shaped hulls on one side or both the sides of hulls to exterior stabilizing floats or amas are classic examples of outriggers. A narrow hull will topple along with the unexpected waves. But ama flotation or weight acting through outriggers provide a lever arm to restrain overturning. The same concept is adopted in building where outriggers are connected to peripheral mega-columns capable to resist upward and downward forces improving structures overturning resistance. The hull can also be controlled by ballasting to restrain overturning but still uncomfortable. Outrigger connected amas reduce these uncomfortable feeling. In a similar manner, outriggers in a building can greatly reduce overall lateral deflection, inter-storey drifts and time period of building.

C. Structural Behaviour of Outrigger System

Whenever a lateral load is acting on an outrigger structure, column-restrained outrigger offers resistance to the core from rotation. This leads to lateral deflection and moments in the central core lesser than that generated by a free standing shear wall. It induces tensile force and compressive force in windward and leeward mega-columns resulting in an increased effective depth of the whole structure.

II. Objectives of Work

- Study of the behaviour of the multi-outrigger and belt truss system for lateral loads in a 45storey structure.
- Comparison of structural parameters such as deflection, inter-storey drift, and moments.
- To arrive at the optimum location of three outrigger and belt truss in the structure.

III. Methodology

A. Model Data

No of storey	45
Bottom storey height	4m
Typical storey height	3.5m
Grade of concrete(fck)	M20 (Slabs and Wall) and M30 (Columns)
Grade of steel(fy)	Fe 500

Column size Base to 14th floor 15th to 30th floor 31st to 45th floor	 0.9m X 0.9m 0.75m X 0.75m 0.6m X 0.6m
Slab thickness	150mm
Drop thickness	300mm
Drop size	4m X 3m
Core wall thickness	250mm
Outrigger and Belt Truss Hollow Box section	500 X 500 X 50mm
Zone	V
Soil type	II
Importance factor	1.5
Response reduction factor	5
Wind speed	50m/s
Terrain category	2
Structure class	B
Floor finish	$1.5KN/m^2$
Live load	$3KN/m^2$

Table 1:

B. *Set of models*

- 1st set of model: Model with only core wall.
- 2nd set of models: Model with 3 outrigger and belt truss out of which one is cap truss at the top of structure.
- 3rd set of models: Model with 3 outrigger and belt truss, all the three outriggers locations are varied.

C. *Grid System*

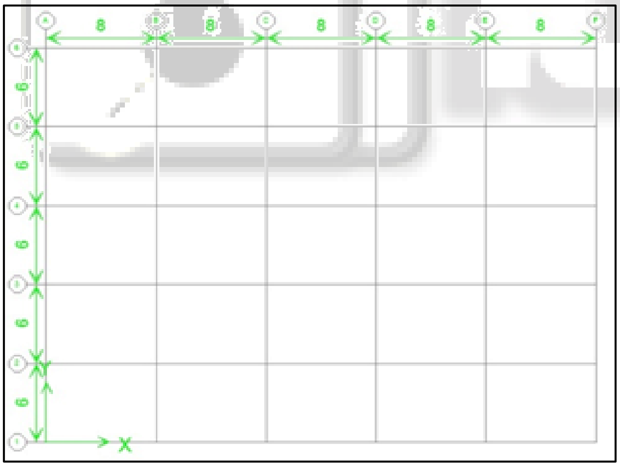

Fig. 1: Grid System of Structure

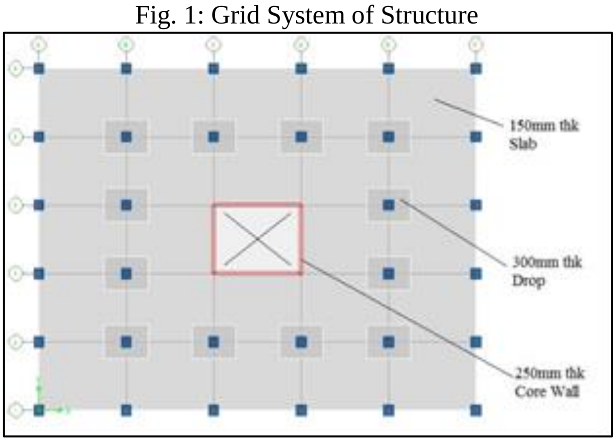

Fig. 2: Typical Floor plan

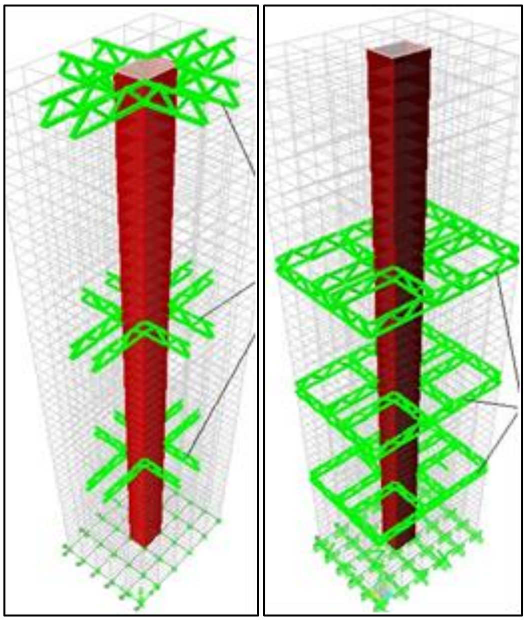

Fig. 3: 3D View of Outrigger and Belt Truss System

A base model with only core wall is modelled to verify various other models

FSCW

Structure with core wall, one outrigger and belt truss fixed at top and other two locations are varied as mentioned below

FSCW+O45-30-15

FSCW+O+BT45-30-15

FSCW+O+BT45-37-22

FSCW+O+BT45-22-7

Structure with all the three outrigger location varied along the height of building

FSCW+O40-30-15

FSCW+O+BT40-30-15

FSCW+O33-22-11

FSCW+O+BT33-22-11

(Note: FS-Flat Slab, CW-Core Wall, O-Outrigger, BT-Belt Truss and numbers refers to the position of outrigger and belt truss)

IV. RESULTS AND DISCUSSION

A. *Comparison of 1st and 2nd Set of Models*

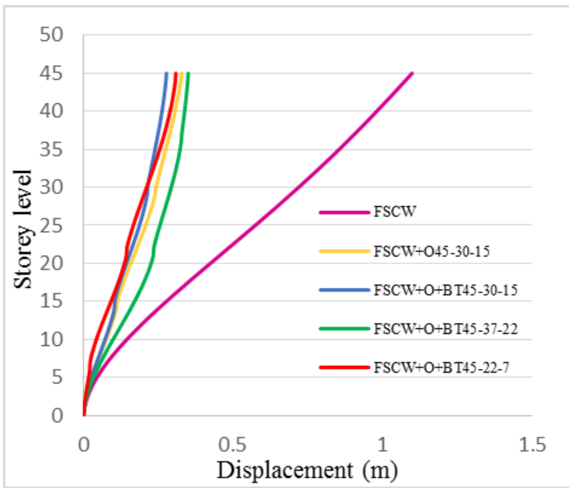

Fig. 4: Displacements of 1st and 2nd set of models due to WLX

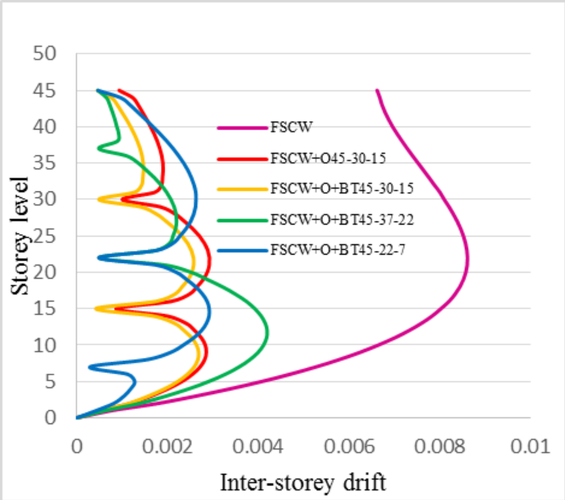

Fig. 5: Inter-storey drifts of 1st and 2nd set of models due to WLX

From Fig 4 it is clear that FSCW exceeds h/500. From Fig 5 we can understand that FSCW+O+BT45-37-22 in which the Inter-storey drift is exceeding the limit of 0.004 between 10th and 14th storey level since the structure is slender below the 22nd storey level. Therefore it cannot be considered in the list of optimum location of outrigger and belt truss. It can be noticed that the model with both outrigger and belt truss as a cap truss at the top can reduce the inter-storey drift by 93% when compared with FSCW. The location of 2nd and 3rd outrigger and belt truss has barely influenced in the drift at top.

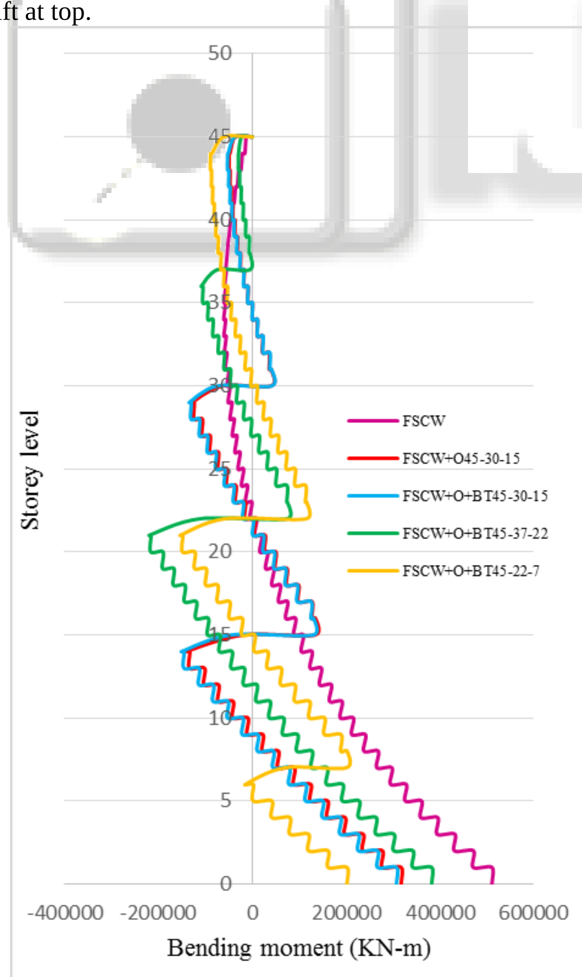

Fig. 6: Bending Moments in Core wall of 1st and 2nd set of models due to WLX

From Fig 6 it is clear that when the outrigger and belt truss are placed near to the base, there is maximum reduction of bending moments in core wall. On comparing FSCW+O45-30-15 and FSCW+O+BT45-30-15, the reduction of bending moments is just 3.13%.

B. Comparison of 1st and 3rd Set of Models

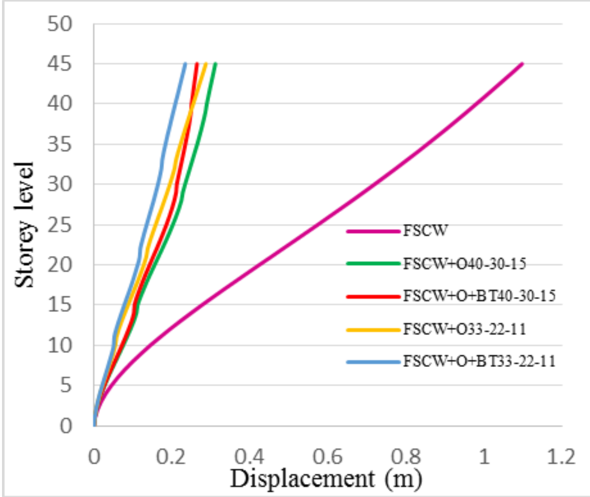

Fig. 7: Displacements of 1st and 3rd set of models due to WLX

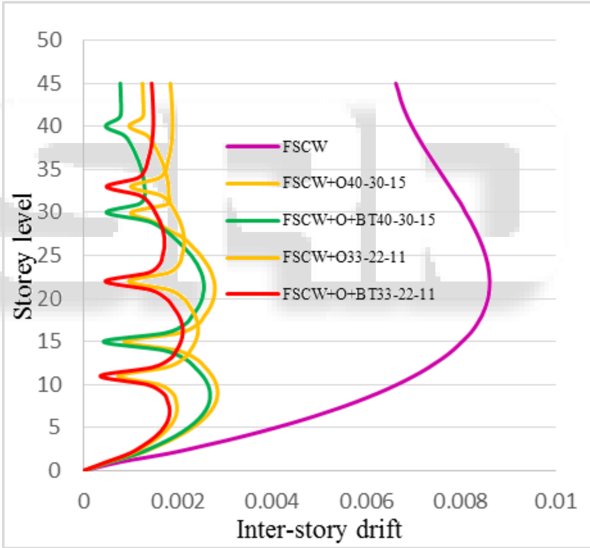

Fig. 8: Inter-storey drifts of 1st and 3rd set of models due to WLX

Fig 7 represents the displacements of 1st and 3rd set of models from which we can make out that FSCW+O+BT33-22-11 has the least deflection value of 234.2mm at the top. All the four model satisfies h/500 criteria. FSCW+O+BT40-30-15 and FSCW+O+BT33-22-11 are more efficient in restraining the displacements by 15% and 18% than that of FSCW+O40-30-15 and FSCW+O33-22-11 respectively. Therefore it can be said that the structure with outrigger as well as belt truss is 15% to 18% efficient in restraining the displacement than in structure with only outrigger. From Fig 8 it is observed that at the location of outrigger and belt truss there is 51% reduction of Inter-storey drift value.

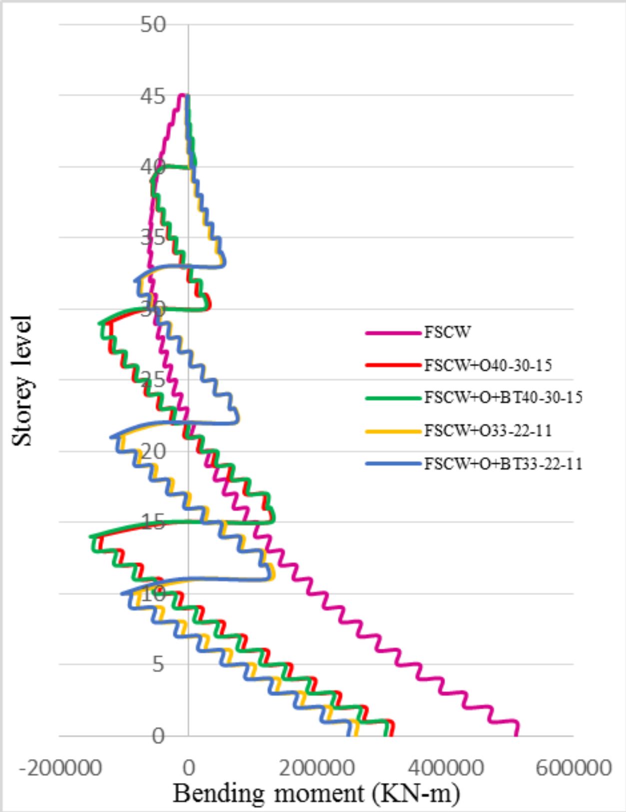

Fig. 9: Bending Moments in Core wall of 1st and 3rd set of models due to WLX

When we compare structure with only outrigger (FSCW+O33-22-11) and structure with outrigger as well as belt truss (FSCW+O+BT33-22-11), the percentage reduction in the latter model was found to be 4.5% only, which clearly indicates that providing belt truss does not influence much in reducing the core wall bending moments.

V. Conclusion

In this paper, the technique of using Multi-Outrigger and Belt truss and its locations has been proposed based on its behaviour due to the applied lateral loads. Analysis has been carried out using ETABS structural software for various models discussed earlier.

Based on the outcomes obtained following are the conclusions made:

- Models FSCW, FSCW+O45-30-15 and FSCW+O+BT45-37-22 does not satisfy deflection criteria of h/500. Even though the latter two models are efficient in reducing the deflection, the position of outriggers and belt trusses are unable to control the deflections.
- Providing Belt truss at the locations of Outriggers reduces the Inter-storey drift by 51% and deflection at the top by 15% to 18% as compared to models with Outriggers alone. Whereas only 4.5% reduction is found in Core wall bending moments.
- Even though when Outriggers and Belt truss placed at the top of the structure as a cap truss is not efficient, maximum reduction of Inter-storey drift was found.
- Maximum reduction of bending moment is observed in FSCW+O+BT45-22-7 when the Outrigger and Belt truss is placed near to the base of the structure. Hence leading to the economical section of the Core wall.
- For the structure considered in this study, based on the behavior due to lateral loads FSCW+O+BT33-22-11 is found to be efficient in all the criteria. From this model we can conclude that whenever the plan of the structure is symmetrical and when 3 Outrigger and Belt truss system are used, the optimal location of the outrigger can be obtained by subdividing the structure into 4 equal parts
- Similarly if 4 Outriggers are to be used in a symmetrical structure, optimal locations can be found by subdividing the structure into 5 equal parts.

VI. Scope for Future Works

- Study can be carried out with more number of Outrigger systems and more number of stories.
- Instead of RCC core wall, behavior of Steel Braced core wall along with Outrigger system may be studied.
- Behavior of Damped Outrigger and Belt truss system can be checked for lateral loads.
- Performance of the combination of Outriggers and other structural system can be carried out for further studies.
- In the current study, Effective depth and number of Outrigger is assumed to be one-storey height and 3 respectively and locations of optimal Outrigger is found out. Similarly effective depth of Outrigger can be found by keeping number of Outriggers and locations constant.
- Outrigger structural system for Tilted and Twisted High-rise structures and comparing the same with other structural system can be studied.
- Progressive collapse study can be carried out for Outrigger and Belt truss systems.

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