OPTIMUM POSITION OF OUTRIGGER WITH BELT TRUSS IN HIGH-RISE BUILDING UNDER HORIZONTAL LOADING

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Abstract - In this era, the quest for increasing the height of the building has been rising. With that comes the challenge to keep storey displacement and storey drift under limits. Outrigger with belt truss system helps keep the storey drift within limits. This paper gives insight into the use of outrigger with belt truss system for high-rise RC building subjected to wind and earthquake loading. In the present study, a 60-storey RC building has been analyzed in order to determine the maximum top storey displacement, maximum storey drift, time period and base shear. Triple outrigger with belt truss system of three-storey depth is incorporated in the structure and compared with regular and shear wall models to find the optimum location. For triple outrigger with belt truss system, the optimum location is found to be at 0.5H - 0.33H - 0.16H from the bottom of the building.

Keywords - High-rise Structure; Outrigger; Belt Truss; Multiple Outrigger; Optimum Location; Static Analysis; Wind Analysis.

1. INTRODUCTION

The concept of outrigger for buildings was derived from sailing boats of ancient times, which used to have outrigger booms connected to the float to obtain lateral stability. Outriggers have been in use for the past half century in buildings. Of all the positions of shear walls, the core shear wall presents itself as the best position[1]. This position holds best for relatively low height buildings. However, for high rise buildings, it does not perform to its potential due to inadequate stiffness. Wind load is the most critical loading for high rise buildings, so structural systems like outrigger with belt truss are used to reduce lateral displacements, drifts and time period significantly[2].

Outriggers are connected to the core shear wall and extended to the outermost column of the building in all directions. Belt truss connects all the exterior columns of a building and offers great resistance to lateral deflection of the building[3]. When the building is subjected to lateral loading, the core wall and outrigger trusses will rotate, causing compression in the leeward columns and tension in the windward columns. These axial forces in outriggers will resist the rotation in the core wall and lateral sway in columns thus significantly reducing overall deflections, unlike a free core wall[4]. Outrigger structural systems are not only efficient in governing the top displacements but also play a crucial role in minimizing the inter-storey drifts.

2. OBJECTIVES

Objectives of this study are as follows:
1. Study on static and wind analysis of a structure having outrigger and belt truss system.
2. Having as many different model combinations as possible to get accurate results.
3. Analyzing all buildings and listing of results.
4. Comparing the results (Top Storey displacement, Max storey drift, time period and base shear) with regular and shear wall models.
5. Choosing the best location among all the models.

3. METHODOLOGY

E-TABS[5] software has been used to develop the 3D model and analyze. The loads to be applied on the buildings comply to the Indian code. The methodology includes:
1. A 60 storey building is modeled in Etabs. The plan view is shown in fig. 1, triple outrigger with belt truss system at most effective location is shown in fig. 2 and outrigger with belt truss system connected to shear wall is shown in fig. 3.
2. Two kinds of resisting systems are used i.e., core shear wall and outrigger with belt truss system.
3. The position of triple outrigger system is varied i.e., at 60-50-40, 60-40-30, 60-30-20, 60-20-10, 50-40-30, 50-30-20, 50-20-10, 40-30-20, 40-20-10 and 30-20-10th storey. Fig. 2 came out to be the best location.
4. Wind load and static earthquake load are applied and results are acquired for worst load combinations i.e., 1.5 (D.L + W.L) and 1.5 (D.L + E.Q) and these results are compared with regular and core shear wall models.

The dimensions of various members, loads, geometry and other specifications are given in Tables 1, 2, 3 and 4.

Table 1. Geometry parameters

Contents	Description
Height	210m
No. of Storeys	60 (3.5 m each)

Length	42 m (6m each bay)
Breadth	20 m (4m each bay)
Location	Madurai
Column dimensions from	
0-20 floors	2743 x 600 mm
21-40 floors	2210 x 457 mm
41-60 floors	1524 x 381 mm
Shear wall thickness	300 mm
Beam dimensions	683 X 381 mm
Outrigger dimensions	683 X 300 mm

Table 2. Types of loads

Live load of Floor (kN/m^2)	**Live load on Roof (kN/m^2)**	**Floor Finishes (kN/m^2)**	**Wall load (kN/m)**
2	1.5	1	10

Table 3. Seismic parameters

Seismic Zone	**Soil Type**	**Damping in Percentage**	**Response reduction factor**	**Importance factor**
II	I	5	5	1

Table 4. Wind parameters

Wind Speed km/hr	**Windward coefficient**	**Leeward coefficient**	**Terrain**	**K1**	**K3**
39	0.45	0.35	3	1	1

4. MODELING

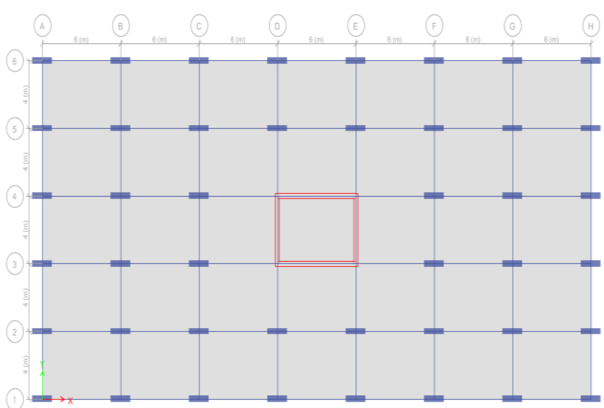

Fig. 1: Plan view

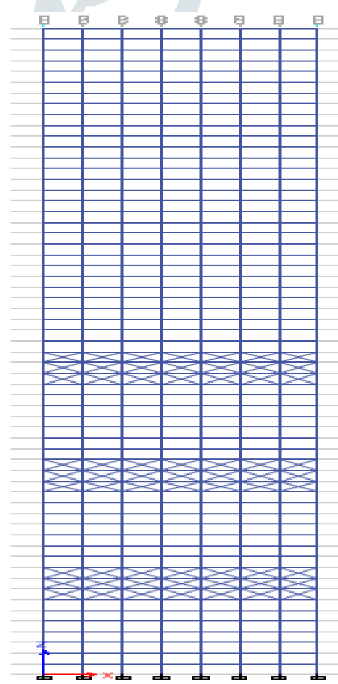

Fig. 2: Triple outrigger with belt truss system at most effective location

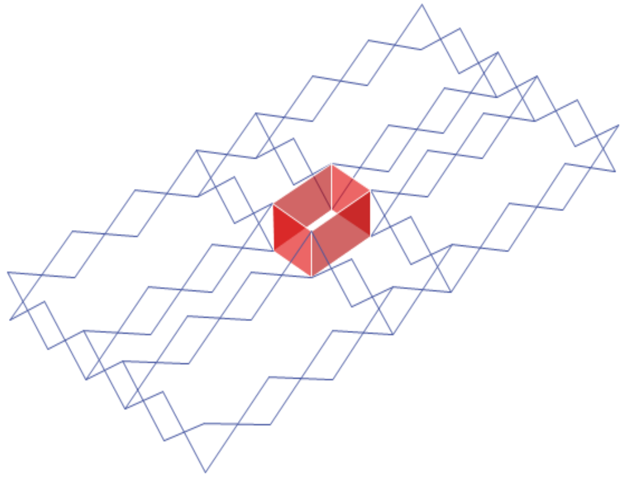

Fig. 3 : Shear wall and outrigger with belt truss system connected to core shear wall

5. RESULTS AND DISCUSSIONS

Parameters such as top storey displacement, maximum storey drift, time period and base shear are evaluated and a comparative study has been done.

5.1 Top storey displacement:

The Top storey displacements for worst load cases are listed in Table 5.

In 1.5(D.L + W.L) load case:

a) Introducing core shear wall to the regular building reduces top storey displacement by 8.75%.

b) Introducing outrigger with belt truss at 30-20-10th storeys, to the core shear wall reduces top storey displacement by 25.2%.

In 1.5(D.L + E.Q) load case:

a) Introducing core shear wall to the regular building reduces top storey displacement by 6.29%.

b) Introducing outrigger with belt truss at 30-20-10th storeys, to the core shear wall reduces top storey displacement by 19.58%.

Table 5. Top storey Displacements and % reduction of outrigger with belt truss system building with regular and shear wall building

Model id	Top Storey displacement					
	1.5(D.L + W.L) (mm)	% Reduction	% Reduction	1.5(D.L + E.Q) (mm)	% Reduction	% Reduction
R	377	-----	-----	143	-----	-----
R+SW	344	8.75	-----	134	6.29	-----
R+SW+ O@ 60-50-40	316	16.18	8.14	124	13.29	7.46
R+SW+ O@ 60-40-30	307	18.57	10.76	122	14.69	8.96
R+SW+ O@ 60-30-20	301	20.16	12.50	122	14.69	8.96
R+SW+ O@ 60-20-10	298	20.95	13.37	123	13.99	8.21
R+SW+ O@ 50-40-30	299	20.69	13.08	116	18.88	13.43
R+SW+ O@ 50-30-20	292	22.55	15.12	116	18.88	13.43
R+SW+ O@ 50-20-10	289	23.34	15.99	117	18.18	12.69
R+SW+ O@ 40-30-20	289	23.34	15.99	115	19.58	14.18
R+SW+ O@ 40-20-10	285	24.40	17.15	116	18.88	13.43
R+SW+ O@ 30-20-10	**282**	**25.20**	**18.02**	**115**	**19.58**	**14.18**

5.2 Maximum story drift:

The Maximum story drift for worst load cases are listed in Table 6.

i) In 1.5(D.L + W.L) load case:

a) Introducing core shear wall to the regular building reduces maximum story drift by 10.39%.

b) Introducing outrigger with belt truss at 30-20-10th storeys, to the core shear wall reduces maximum story drift by 21.49%.

ii) In 1.5(D.L + E.Q) load case:

a) Introducing core shear wall to the regular building reduces maximum story drift by 11.68%.

b) Introducing outrigger with belt truss at 30-20-10th storeys, to the core shear wall reduces maximum story drift by 23.47%.

Table 6. Maximum storey drifts and % reduction of outrigger with belt truss system building with regular and shear wall building

Model id	**Maximum storey drift**					
	1.5(D.L + W.L)	**% Reduction**	**% Reduction**	**1.5(D.L + E.Q)**	**% Reduction**	**% Reduction**
R	0.002127	-----	-----	0.000916	-----	-----
R+SW	0.001906	10.39	-----	0.000809	11.68	-----
R+SW+ O@ 60-50-40	0.001894	10.95	0.63	0.000761	16.92	5.93
R+SW+ O@ 60-40-30	0.001799	15.42	5.61	0.000779	14.96	3.71
R+SW+ O@ 60-30-20	0.001822	14.34	4.41	0.00077	15.94	4.82
R+SW+ O@ 60-20-10	0.00186	12.55	2.41	0.000768	16.16	5.07
R+SW+ O@ 50-40-30	0.001799	15.42	5.61	0.000708	22.71	12.48
R+SW+ O@ 50-30-20	0.001786	16.03	6.30	0.000793	13.43	1.98
R+SW+ O@ 50-20-10	0.001858	12.65	2.52	0.000804	12.23	0.62
R+SW+ O@ 40-30-20	0.001676	21.20	12.07	0.000762	16.81	5.81
R+SW+ O@ 40-20-10	0.001838	13.59	3.57	0.000767	16.27	5.19
R+SW+ O@ 30-20-10	**0.00167**	**21.49**	**12.38**	**0.000701**	**23.47**	**13.35**

5.3 Time period:

The time period for modal load case is listed in Table 7.

i) In modal load case:

a) Introducing core shear wall to the regular building reduces time period by 3.74%.

b) Introducing outrigger with belt truss at 30-20-10th storeys, to the core shear wall reduces time period by 14.49%.

Table 7. Time period and % reduction of outrigger with belt truss system building with regular and shear wall building

Model id	**Time period**		
	Modal load case (Sec)	**% Reduction**	**% Reduction**
R	7.81	-----	-----
R+SW	7.518	3.74	-----
R+SW+ O@ 60-50-40	7.487	4.14	0.41

R+SW+ O@ 60-40-30	7.249	7.18	3.58
R+SW+ O@ 60-30-20	7.084	9.30	5.77
R+SW+ O@ 60-20-10	7.037	9.90	6.40
R+SW+ O@ 50-40-30	7.149	8.46	4.91
R+SW+ O@ 50-30-20	6.965	10.82	7.36
R+SW+ O@ 50-20-10	6.911	11.51	8.07
R+SW+ O@ 40-30-20	6.851	12.28	8.87
R+SW+ O@ 40-20-10	6.778	13.21	9.84
R+SW+ O@ 30-20-10	**6.678**	**14.49**	**11.17**

5.4 Base Shear.
The base shear for worst load cases are listed in Table 8.
i) In 1.5(D.L + W.L) load case:
a) Introducing core shear wall to the regular building has no effect in base shear.
b) Introducing outrigger with belt truss at 30-20-10th storeys, to the core shear wall has no effect in base shear.
ii) In 1.5(D.L + E.Q) load case:
a) Introducing core shear wall to the regular building increases base shear by 1.46%.
b) Introducing outrigger with belt truss at 30-20-10th storeys, to the core shear wall increases base shear by 4.28%.

Table 8. Base Shear and % increase of outrigger with belt truss system building with regular building

Model id	**Base Shear**			
	1.5(D.L + W.L) kN	**% Increase**	**1.5(D.L + E.Q) kN**	**% Increase**
R	13215	-----	3367	-----
R+SW	13215	0	3416	1.46
R+SW+ O@ 60-50-40	13215	0	3511	4.28
R+SW+ O@ 60-40-30	13215	0	3511	4.28
R+SW+ O@ 60-30-20	13215	0	3511	4.28
R+SW+ O@ 60-20-10	13215	0	3511	4.28
R+SW+ O@ 50-40-30	13215	0	3511	4.28
R+SW+ O@ 50-30-20	13215	0	3511	4.28
R+SW+ O@ 50-20-10	13215	0	3511	4.28
R+SW+ O@ 40-30-20	13215	0	3511	4.28
R+SW+ O@ 40-20-10	13215	0	3511	4.28
R+SW+ O@ 30-20-10	**13215**	**0**	**3511**	**4.28**

6. CONCLUSIONS:
1. Shear wall is most effective when provided at the central periphery of the building.
2. Outrigger with belt truss is most effective when it is placed at bottom half of the building.

3. A notable reduction was observed while comparing top story displacement and maximum storey drift of buildings with outrigger and belt truss system from seismic and wind analysis with regular and shear wall buildings.
4. As time period decreases, the stiffness of the building increases when outrigger with belt truss system is used.
5. As responses of the building decrease, using outrigger with belt truss system proves to be economical by reducing the sizes of columns and beams.
6. There is a marginable increase in base shear by introducing outrigger with belt truss system compared to regular and shear wall buildings.

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