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Optimization of vertical position of Outrigger and Belt truss structural system

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Abstract*— High rise structures are subjected to various lateral loads like earthquake and wind loads. So that it is important in the design of these buildings. Various lateral load resisting structural systems were introduced for the analysis and design of these high-rise buildings which mainly include tubular structures, core supported outriggers with bracings, diagrid structures, etc. The outrigger and belt truss system is one of the most commonly used structural systems to control lateral displacement. The main aspect of the design of outriggers is to fix the position of outriggers. In the present study a comparative parametric study on outrigger and belt truss system by varying location along the height has been done. A 30, 45 and 60 storey building have been modelled and analysed. The modelling and analysing has been performed on Etabs. The dynamic analysis is performed by response spectrum method and wind dynamic analysis. From the analysis lateral displacement, drift ratio, base shear and fundamental time period are compared for all model and optimum position of outrigger and belt truss system is found out .

Keywords*— Belt-truss, Bracings, Deflection, Earthquake loads, High-rise, Lateral displacement, Lateral loads, lateral bracings, Outriggers, Storey drift, Wind dynamics

I. INTRODUCTION

The outrigger and belt truss system comprises of a main concrete core connected to exterior columns by relatively stiff horizontal members such as bracings termed as outriggers. The bracing can be of different shape. The core may be centrally located or it may be located on one side of the building with outriggers extending to the building columns on one side. The basic structural response of the system is based on very simple concept. When structure is subjected to lateral loads, the columns on which the outriggers rest combining the column restrained by outrigger resist the rotation of the core, causing the mitigation in magnitude of lateral deflections and moments in the core in comparison to the freestanding core alone resisted the loading. The external moment is now resisted by combined action of the bending of the core and the axial tension and compression of the exterior columns connected to the outriggers. As a result of this effect the strength of the structure for resisting bending is increased when the core acts as a vertical cantilever, by the development of tension in the windward columns and compression in the leeward columns. The column located at periphery also help in distributing the moments and reducing the rotation of outriggers, which can happen by combining the exterior columns with bracings commonly referred to as a “belt truss,” around the building. The belt truss is the bracing around the building at the same floor which are located between adjacent columns. The belt truss and the outrigger together combined stiffens the building and mitigate the rotation of the core, storey displacement and storey drift. This method is aimed to reduce obstructed space compared to the conventional method.

II. AIM AND OBJECTIVE

The objectives of the paper are as follow:

- To model three different structures each of 30,45, 60 storey in ETABS.
- To optimize the vertical location of outrigger and belt truss system by varying its location along the height of the structure
- To find out number of outrigger and belt truss system required for optimum result .
- To compare lateral displacement , drift ratio , time period and base shear of structure.

III. METHODOLOGY

Following steps are adopted in present study ,

1. In this present study , three different height of structures are considered i.e. 30 storey , 45 storey , 60 storey and three different arrangements/system of outriggers and belt truss are considered i.e. a) one outrigger system- one no. of outrigger and belt truss system is provided in whole structure is provided, b) two outrigger system- two no. of outrigger and belt truss system is provided in whole structure is provided, c) three outrigger system- three no. of outrigger and belt truss system is provided in whole structure is provided.
2. For 30 storey structure only one outrigger system is considered and for 45 storey and 60 storey structure all 3 outrigger systems are considered.
3. Selection of suitable modelling data and site conditions .
4. To perform a parametric study , modelling is done using ETABS for all 3 different arrangements/systems by varying position of outrigger and belt truss along height of structure .
5. Dynamic analyses is done for structure subjected to wind and seismic loads as per IS 875 (part 3) and IS 1893 (Part-1): 2002 respectively .
6. Determination of the best location of belt-truss and outriggers arrangement by comparison of results of lateral storey deflection ,storey shear, drift ratio and time period .

IV. MODELLING DATA

TABLE I
Modelling Parameters

Parameter	**Specification**
Type of Structure	Reinforced concrete structure
Location	Mumbai
Structure utility	Commercial
Number of storeys	30,45,60.
Floor to floor height	3 m.
Plan Dimensions	27.5m x 27.5m
Analysis method	• Dynamic analysis(RSM) • Wind dynamic analysis
Codes used	• IS 456-2000, • IS 800-2007. • IS 875-2015. • IS 1893 Part 1-2016

TABLE II
Loading Considerations

Type of Load	**Intensity of Load**
Live load	3 KN/m^2
Floor load (SIDL)	1.5 KN/m^2
Wall load	11.04 KN/m^2
Parapet wall load	6.25 KN/m^2

TABLE III
Section Properties

Description	Size
Slab thickness	150 mm
Shear wall thickness	300 mm
Beam	230 mm x 600 mm
Column	
a) For 30 Storey structure	600 mm x 600 mm
b) For 45 Storey structure	800 mm x 800 mm
c) For 60 Storey structure	800 mm x 800 mm 1000 mm x 1000 mm
Size of outrigger a) Breadth b) Depth	 230 mm 3000 mm

TABLE IV
Earthquake Load Parameters

Parameter	Specification
Seismic zone	3
Seismic coefficient	0.16
Response reduction factor (R)	5
Importance factor (I)	1

TABLE V
Wind Load Parameters

Parameter	Specification
Seismic zone	3
Seismic coefficient	0.16
Response reduction factor (R)	5
Importance factor (I)	1

In this present study , three different storey heights are considered i.e. 30 storey , 45 storey , 60 storey and three different arrangements of outriggers and belt truss are considered. For all 3 different arrangements position of outrigger and belt truss is varied along height and analyzed for best possible combination using ETABS software are:

1. Structural Model without Outrigger (SOM).

2. **S**tructural model with 1 outrigger and belt truss system (SM 1).

3. Structural model with 2 outrigger and belt truss system (SM 2).

4. Structural model with 3 outrigger and belt truss system (SM 3).

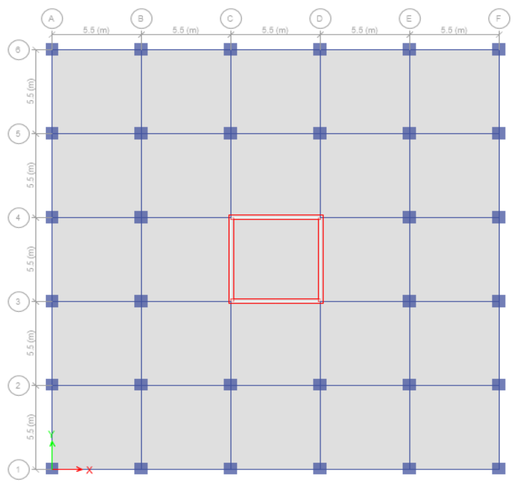

Fig. 2 Plan of Bare Frame structure

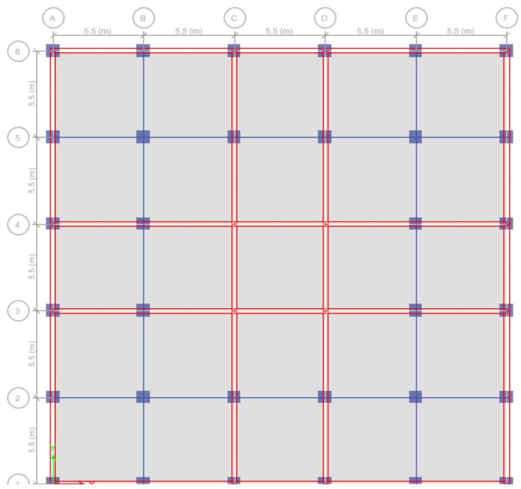

Fig. 1 Plan of storey with outrigger and belt truss system

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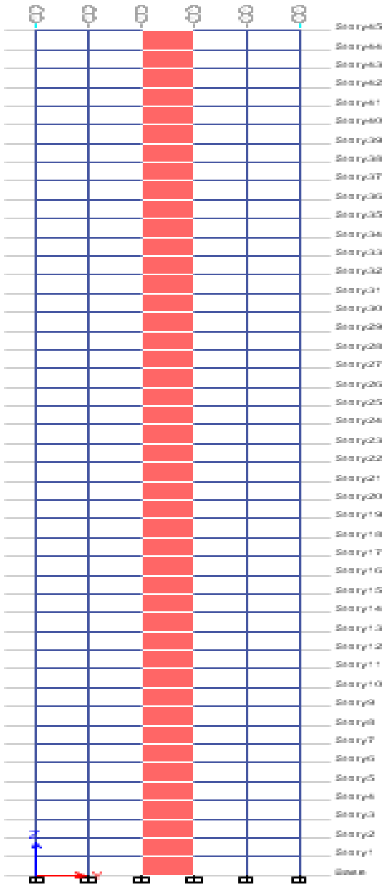

Fig. 4 Elevation of structural model without outrigger (SOM).

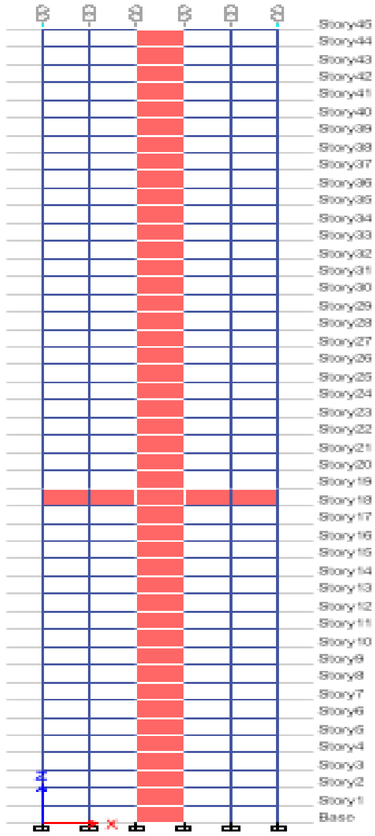

Fig. 3 Structural model with 1 outrigger and belt truss system (SM 1)

Fig. 6 Structural model with 2 outrigger and belt truss system (SM 2)

Fig. 5 Structural model with 3 outrigger and belt truss system (SM 3)

V. Results

A. Lateral Displacement :

TABLE VI
Lateral Displacement Comparison for one outrigger and belt truss system

Outrigger Location	**Displacement in mm**		
	30 storey	**45 storey**	**60 storey**
Bare Frame	48.024	100.064	242.024
0.2H	37.179	85.928	202.63
0.3H	35.08	85.64	199.03
0.4H	34.457	85.377	198.1
0.5H	35.019	86.628	202.95
0.6H	36.419	90.137	210.667
0.7H	38.605	92.09	218.981
0.8H	40.542	95.558	224.182
0.9H	42.938	97.832	229.131
1H	44.061	98.358	235.35

TABLE VII
Lateral Displacement Comparison for two outrigger and belt truss system

Outrigger Location	**Displacement in mm**	
	45 storey	**60 storey**
Bare Frame	100.064	242.024
0.2H & 0.3H	76.59	178.23
0.2H & 0.4H	77.48	176.15
0.2H & 0.5H	73.47	170.98
0.2H & 0.6H	75.17	174.26
0.2H & 0.7H	78.73	174.69
0.2H & 0.8H	80.11	176.16
0.3H & 0.4H	76.52	175.55
0.3H & 0.5H	74.26	170.48
0.3H & 0.6H	75.12	171.83
0.3H & 0.7H	76.11	173.33
0.4H & 0.5H	76.704	179.97
0.4H & 0.6H	73.307	170.15
0.4H & 0.7H	77.7	176.48
0.4H & 0.8H	80.116	182.83
0.5H & 0.6H	81.48	187.93
0.5H & 0.7H	83.38	189.71
0.5H & 0.8H	85.92	194.26
0.6H & 0.7H	87.39	199.45
0.6H & 0.8H	87.91	199.46

TABLE VIII
Lateral Displacement Comparison for one outrigger and belt truss system

Outrigger Location	Displacement in mm	
	45 storey	60 storey
Bare Frame	100.064	242.024
0.2H,0.3H & 0.4H	67.97	158.19
0.2H,0.3H & 0.5H	66.07	152.21
0.2H,0.3H & 0.6H	68.43	154.99
0.2H,0.3H & 0.7H	71.01	156.48
0.2H,0.4H & 0.5H	66.79	153.02
0.2H,0.4H & 0.6H	65.22	149.86
0.2H,0.4H & 0.7H	67.56	152.68
0.2H,0.4H & 0.8H	68.05	154.98
0.2H,0.5H & 0.6H	67.63	155.09
0.2H,0.5H & 0.7H	69.28	157.04
0.3H,0.4H & 0.5H	69.51	159.4
0.3H,0.4H & 0.6H	67.32	155.22
0.3H,0.4H & 0.7H	70.93	157.83
0.3H,0.4H & 0.8H	73.62	160.58
0.3H,0.5H & 0.6H	68.45	156.41
0.3H,0.5H & 0.7H	70.59	161.62
0.3H,0.5H & 0.8H	74.77	165.39
0.4H,0.5H & 0.6H	69.38	166.69
0.4H,0.5H & 0.7H	71.27	168.57
0.4H,0.5H & 0.8H	74.39	169.89
0.4H,0.6H & 0.7H	71.95	160.76
0.4H,0.6H & 0.8H	73.427	166.048

B. Drift Ratio :

TABLE IX
Drift Ratio Comparison

Outrigger Location	Drift Ratio		
	30 Storey	45 Storey	60 Storey
SMO	0.000687	0.00096	0.001736
SM 30-1	0.000473	0.000857	0.001412
SM 30-2	-	0.000716	0.001282
SM 30-3	-	0.0006	0.000994

C. Base Shear :

TABLE X
Base Shear Comparison

Outrigger Location	Base Shear (KN)		
	30 Storey	45 Storey	60 Storey
SMO	1998.53	2514.83	3829.92
SM 30-1	2211.57	2534.34	3886.604
SM 30-2	-	2553.09	3957.61
SM 30-3	-	2883.57	3976.43

D. Time Period :

TABLE XI
Time Period Comparison

Outrigger Location	Time Period (Sec.)		
	30 Storey	45 Storey	60 Storey
SMO	3.231	4.774	8.039
SM 30-1	2.666	4.356	7.15
SM 30-2	-	4.162	6.779
SM 30-3	-	3.742	6.089

VI. CONCLUSION

It is observed that,

1. Maximum lareral displacement is reduced by 28.29% in 30 storey structure, 14.59% in 45 storey structure and 18.15% in 60 storey structure when single outrigger and belt truss system is provideded at $2/5^{th}$ of the the total height of building.
2. In the case of two outrigger and belt truss system , providing first outrigger at the $2/5^{th}$ of height of structure and second at $3/5^{th}$ of height of structure shows maximum reduction in lateral displacement by 26.59% in 45 storey structure and by 29.54% in 60 storey structure.
3. In three outrigger and belt truss system , when outrigger and belt truss system is at $1/5^{th}$, $2/5^{th}$ and $3/5^{th}$ of the total height of structure shows maximum reduction in lateral displacement by 34.61% in 45 storey structure and by 38.29% 60 storey structure.
4. Outrigger and belt truss system also helps in reducing drift ratio as compared with bare frame.
5. When outrigger and belt truss system is at $2/5^{th}$ height of structure drift ratio is reduced by 31.15% in 30 storey structure, 11.01% in 45 storey structure and 18.66% in 60 storey structure.
6. When one outrigger and belt truss system at the 2/5th of height of structure and second at $3/5^{th}$ of height of structure shows maximum reduction in drift ratio by 25.65% in 45 storey structure and by 26.15% in 60 storey structure.
7. In three outrigger and belt truss system , when outrigger and belt truss system is provided at $1/5^{th}$, $2/5^{th}$ and $3/5^{th}$ of the total height of structure drift ratio is reduced by 37.49% in 45 storey structure and by 42.74% 60 storey structure.
8. It is observed that as the number of outrigger and belt truss along the height of building increases base shear of structure increases.
9. As number of outrigger and belt truss system increases time period of structure decreases.
10. In single outrigger and belt truss system provided at $2/5^{th}$ of the total height of structure time period is reduced by 17.48% in 30 storey structure, 8.75% in 45 storey structure and 11.05% in 60 storey structure.
11. In two outrigger and belt truss system, one at $2/5^{th}$ of height of structure and second at $3/5^{th}$ of height of structure time period reduced by 12.81% in 45 storey structure and by 15.67% in 60 storey structure.
12. In three outrigger and belt truss system , when outrigger and belt truss system is provided at $1/5^{th}$, $2/5^{th}$ and $3/5^{th}$ of the total height of structure time period of structure is reduced by 22.91% in 45 storey structure and by 24.25% 60 storey structure.

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