Comparative Study by Varying the Number of Outriggers for High Rise Building

Saif Azhar[1], Amit Pratap Singh[2]

[1,2]*Civil Engineering and Applied Mechanics Department, Shri G.S. Institute of Technology and Science, Indore, India*

***Abstract* - The demand for the high-rise buildings has increased in the modern era. The taller and slender buildings are the most vulnerable to lateral loads due to wind and earthquake. Outrigger system proves to be very efficient solution for controlling excessive drift and displacement by increasing stiffness of the high-rise building. The location and number of outriggers provided in a structure must be such that the maximum benefit is achieved in the minimum cost. In this paper, a comparative study is presented by changing the number of outriggers along with the belt trusses at the top and mid height levels of 20, 40 and 60 storey structural models. Since from the previous researches it is evident that the optimal location of outrigger system in tall building is at the top and mid height, therefore this location is chosen to increase the number of outriggers along with the belt trusses and the variation in the results in terms of maximum top storey displacement, storey drift and time period are studied by Equivalent Static Method and Response Spectrum Method.**

***Index Terms* - Outrigger System, Equivalent Static Method, Response Spectrum Method, Lateral Displacement, Storey Drift, Time Period**

I.INTRODUCTION

The demand for the taller and slender buildings has risen in the modern era. High rise buildings are the most vulnerable to the lateral loads due to wind and seismic forces. Thus, a suitable lateral load resisting system is required to counter the effect of lateral loadings on the structure. Outrigger is an efficient lateral load resisting system in which the central core of the structure is connected with the peripheral columns through stiff beams or trusses known as the outriggers. The peripheral columns in turn are connected with each other through the beams or trusses known as the belt beams or the belt trusses. Outriggers engage the peripheral columns more efficiently in the lateral load resisting system. Columns in the windward side experiences the tensile forces and columns in the leeward side experiences the compressive forces and a tension - compression couple is mutated at each outrigger level. This couple counters the overturning moment due to lateral loads and thus helps in reducing the lateral displacement and drift by strengthening the structure.

Several research have been conducted in increasing the stiffness of the high-rise building by providing outrigger system at different locations of the structure. B.S. Taranath [1] suggested the mid height as the optimum location of single outrigger for high rise building subjected to wind load. Kian and Siahaan [2] analysed the structural models subjected to wind loads and seismic loads and found that the optimum location of a single outrigger is at the mid height and for two outriggers, the least drift is observed when one outrigger is provided at the top and the other at the mid height level of the structure. N. Herath et al [3] also worked on optimizing the location of outrigger and suggested 0.44 – 0.48 times the height (nearly mid height) of building as the suitable location for single outrigger. P.M.B. Raj Kiran Nanduri et al [4] worked on increasing the stiffness of the high-rise building with outrigger system at different locations using ETABS software. They found the most optimum location of outriggers as the top and mid height.

It is evident from the previous researches that the least displacement and drift is observed when the outriggers are provided at the top and 0.5H where H is the height of building. Therefore, this location of outriggers is selected for the present study. The purpose of this paper is to determine the effect of increasing the outrigger numbers in high rise building on the basis of parameters like lateral displacement, storey drift and fundamental time period. The basic aim is to increase the stiffness of the structural models by increasing number of outriggers one by one and investigate the subsequent change in values of parameters under consideration.

II. METHODOLOGY

The modelling and analysis of the various structural models for this study is done in ETABS 2017 software package.

A. Details of Structural Models

For the present study, the structural models of three different storey heights i.e. 20 storey, 40 storey and 60 storey are prepared for the comparative study based on various parameters. Table 1 shows the geometric details of the structural models.

Table 1 Geometric detail of the structural models

Parameter	20 Storey	40 Storey	60 Storey
Bay Width	3m	4m	5m
No. of Bays	5	5	5
Plan Dimensions	15m x 15m	20m x 20m	25m x 25m
Storey Height	3m	3m	3m
Height of structure	60m	120m	180m
Slenderness Ratio	4	6	7.2

The maximum allowable slenderness ratio in seismic zone IV for structural walls + moment frame configuration as per IS 16700-2017 is 8. The slenderness ratios of 20, 40 and 60 storey models prepared for this study are 4, 6 and 7.2 respectively which are under the allowable limit.

A conventional model of 20, 40 and 60 storey height is modelled having the central shear wall core and the models with outrigger structural system are modelled with varying outrigger numbers at the top and mid height level of the structure. The shear walls and beam-column framing systems are provided of the reinforced concrete sections in all the models and the outriggers and belt trusses are provided of the structural steel sections.

Figure 1 shows the four different types of models prepared by increasing the outriggers in the top and mid height region of the 20 storey building. The outriggers are increased from one at the top and 0.5H to four each at the top and 0.5H locations. Similarly the 40 storey and 60 storey models are shown in Figure 2 and Figure 3 respectively. The models of 40 storey are prepared by increasing the number of outriggers from one to four at the top and mid height levels and the models of 60 storey are prepared by increasing the outriggers from one to six at the top and mid height levels. The conventional models of 20, 40 and 60 storey heights consist of the central core only and no outrigger is provided. The sections are kept uniform throughout the comparative study.

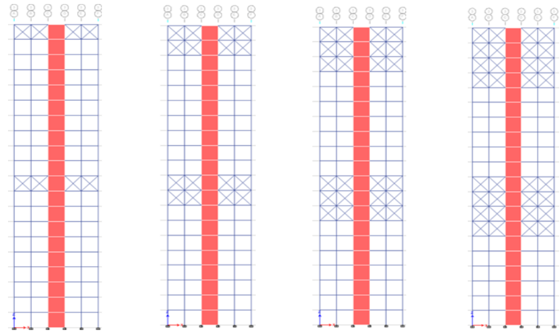

Figure 1 Variation in number of outriggers in structural models of 20 storey

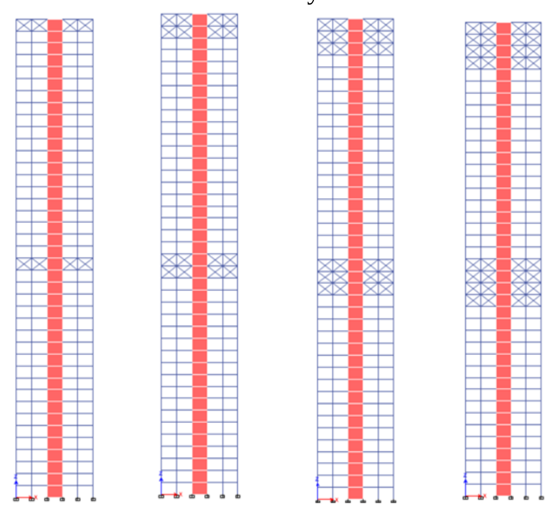

Figure 2 Variation in number of outriggers in structural models of 40 storey

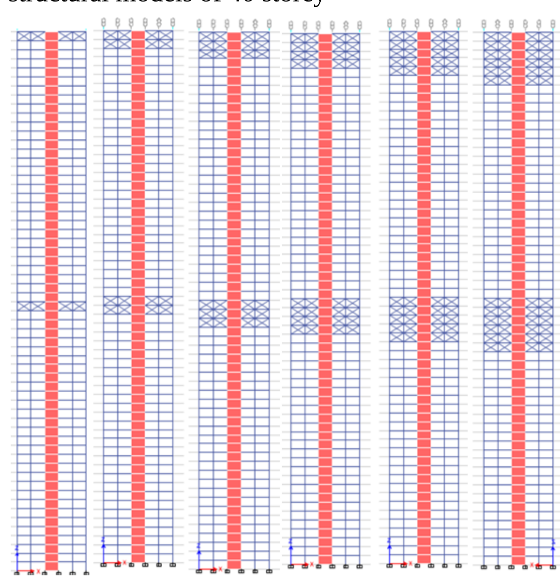

Figure 3 Variation in number of outriggers in structural models of 60 storey

B. Loadings and Analysis:

The various loads are applied as per the relevant IS codes. Live load is applied as per the IS 875 (Part 2) – 1987 considering the mercantile building and seismic load is applied as per the IS 1893 (Part 1) – 2016. The loading details are mentioned below:

Live Load	3.5kN/m^2 on all the floors and 1.5kN/m^2 on the roof
Dead Load	Self-weight of structural members is automatically calculated by ETABS 2017 software according to the section dimensions
Floor Finish Load	1.5kN/m^2 on all the floors including roof
Wall Load	9kN/m
Seismic Zone	Zone IV
Seismic Zone Factor (Z)	0.24
Response Reduction Factor (R)	5 (SMRF)
Importance Factor (I)	1
Type of Soil	Type II – Medium soil

All the models are analysed by the linear static method i.e. Equivalent Static Method (ESM) and the linear dynamic method i.e. Response Spectrum Method (RSM). The parameters considered for this comparative study are lateral displacement, storey drift and fundamental time period. The load combinations for ESM are considered as follows:

1. 1.5 (D.L + L.L)
2. 1.2 (D.L + L.L + EQx)
3. 1.2 (D.L + L.L – EQx)
4. 1.2 (D.L + L.L + EQy)
5. 1.2 (D.L + L.L – EQy)
6. 1.5 (D.L + EQx)
7. 1.5 (D.L – EQx)
8. 1.5 (D.L + EQy)
9. 1.5 (D.L – EQy)
10. 0.9 D.L + 1.5 EQx
11. 0.9 D.L – 1.5 EQx
12. 0.9 D.L + 1.5 EQy
13. 0.9 D.L – 1.5 EQy

The response spectrum function is defined in ETABS 2017 as per IS 1893 (Part 1) – 2016. The response spectrum curve is selected for Zone IV and Type II Medium Soil for the damping of 5%. An eccentricity of 0.05 is taken for all the diaphragms to account for any accidental eccentricity arising in the structure. CQC method is implemented for combining the responses of various modes. The following load combinations are considered for response spectrum analysis:

1. 1.2 (D.L + L.L + RSx)
2. 1.2 (D.L + L.L + RSy)
3. 1.5 (D.L + RSx)
4. 1.5 (D.L + RSy)
5. 0.9 D.L + 1.5 RSx
6. 0.9 D.L + 1.5 RSy

C. Section Details

The details of the reinforced concrete and steel sections provided for various structural members in the structural models of 20, 40 and 60 storeys under consideration are shown in Table 2. The sections are designed and checked as per the relevant IS codes using the ETABS 2017 software package.

Table 2 Section Properties of the Structural Members

20 Storey models	40 Storey models	60 Storey models
Beams – 300mm x 400mm (M30)	Beams – 300mm x 450mm (M30)	Beams – 300mm x 550mm (M30)
Columns – 400mm x 400mm (M40)	Columns – 750mm x 750mm (M40)	Columns– 1000mm x 1000mm (M50)
Slabs – 125mm thick (M25)	Slabs – 125mm thick (M25)	Slabs – 125mm thick (M25)
Shear walls – 200mm thickness (M30)	Shear walls – 250mm thickness (M30)	Shear walls - 300mm thickness (M30)
Outrigger Beams – ISHB450 (Fe250)	Outrigger Beams – ISHB450 (Fe250)	Outrigger Beams – ISHB450 (Fe345)
Outrigger Bracings – ISHB300 (Fe250)	Outrigger Bracings – ISHB350 (Fe250)	Outrigger Bracings – ISHB400 (Fe345) with 300mm x 40mm cover plates

III. RESULTS AND DISCUSSIONS

A. Lateral Displacement

The results of 20 storey models in terms of maximum roof displacement by ESM and RSM are shown in Table 3. The introduction of single outrigger at top and

0.5H reduced top storey displacement by 22.29% in ESM and 18.5% in RSM. However, as we go on increasing the number of outriggers, the subsequent reduction in displacement goes on decreasing. The introduction of second outrigger at top and mid height further reduced the displacement merely by 3.88% in ESM and 3.81% in RSM analysis and this percentage reduction is further reduced by incorporating more number of outriggers. When four outriggers are used at the top as well as the 0.5H locations, the subsequent percentage change in displacement is only 2.41% by ESM and 2.25% by the RSM and hence leading to the uneconomical solutions to control the displacement and drift. This means increasing number of outriggers beyond a certain limit is uneconomical as compared to the benefits in drift control. Similarly, the comparison is done for the 40 and 60 storey models also and the results are shown Table 4 and Table 5 for 40 and 60 storeys respectively.

Table 3 Maximum displacement at the top of 20 storey models

Type of model	Equivalent Static Method			Response Spectrum Method		
	Displacement (mm)	Change in Displacement (mm)	% Change in Displacement	Displacement (mm)	Change in Displacement (mm)	% Change in Displacement
Conventional (No outrigger)	60.561	-	-	43.20	-	-
One outrigger	47.059	13.502	22.29%	35.20	8.00	18.5%
Two outriggers	44.713	2.346	3.88%	33.56	1.64	3.81%
Three outriggers	42.740	1.973	3.26%	31.96	1.60	3.71%
Four outriggers	41.278	1.462	2.41%	30.99	0.97	2.25%

Table 4 Maximum displacement at the top of 40 storey models

Type of model	Equivalent Static Method			Response Spectrum Method		
	Displacement (mm)	Change in Displacement (mm)	% Change in Displacement	Displacement (mm)	Change in Displacement (mm)	% Change in Displacement
Conventional (No outrigger)	170.617	-	-	125.282	-	-
One outrigger	125.332	45.285	26.54%	87.124	38.158	30.46%
Two outriggers	111.873	13.459	7.89%	78.283	8.841	7.06%
Three outriggers	105.792	6.081	3.56%	74.238	4.045	3.23%
Four outriggers	102.990	2.802	1.64%	72.520	1.718	1.37%

Table 5 Maximum displacement at the top of 60 storey models

Type of model	Equivalent Static Method			Response Spectrum Method		
	Displacement (mm)	Change in Displacement (mm)	% Change in Displacement	Displacement (mm)	Change in Displacement (mm)	% Change in Displacement
Conventional (No outrigger)	434.623	-	-	347.997	-	-
One outrigger	320.316	114.307	26.30%	248.015	99.982	28.73%
Two outriggers	300.230	20.086	4.62%	233.550	14.465	4.16%
Three outriggers	287.658	12.572	2.89%	224.331	9.219	2.65%
Four outriggers	277.340	10.318	2.37%	216.650	7.681	2.21%
Five outriggers	271.615	5.725	1.32%	212.690	3.96	1.14%
Six outriggers	266.199	5.416	1.25%	208.930	3.76	1.08%

From Table 4 and Table 5, it is evident that introduction of one outrigger at top and 0.5H reduced the displacement by a large amount (as much as 26.54% and 26.3% for 40 and 60 storeys respectively by ESM) but increasing the number of outriggers does not give much favorable results in terms of further reduction in displacement. The order of percentage reduction reduces from near about 26 to 30 percent with single outrigger to nearly 1 percent with four outriggers in 40 storey and six outriggers in 60 storey models. This can be concluded that incorporating single stiff outrigger system is very much effective in terms of drift control and economy but increasing the number of outriggers leads to higher expenses on steel and provides marginal further decrease in lateral displacement and drift. Although the displacement reduces with increasing the number of outriggers, but the magnitude of reduction is not very large and hence other measures must be resorted to for further decrease in lateral displacement if needed.

B. Storey Drift

The maximum storey drift ratios and subsequent change in it on increasing the number of outriggers at top and 0.5H levels of various 20, 40 and 60 storey models under consideration are shown in Table 6 to Table 8.

Table 6 Maximum storey drift ratio of 20 storey models

Type of model	Equivalent Static Method			Response Spectrum Method		
	Storey Drift	Change in Storey Drift	% Change in Storey Drift	Storey Drift	Change in Storey Drift	% Change in Storey Drift
Conventional (No outrigger)	0.001266	-	-	0.000924	-	-
One outrigger	0.000960	0.000306	24.17	0.000770	0.000154	16.67
Two outriggers	0.000921	0.000039	3.08	0.000709	0.000061	6.60
Three outriggers	0.000902	0.000019	1.50	0.000689	0.000020	2.16
Four outriggers	0.000888	0.000014	1.11	0.000679	0.000010	1.10

Table 7 Maximum storey drift ratio of 40 storey models

Type of model	Equivalent Static Method			Response Spectrum Method		
	Storey Drift	Change in Storey Drift	% Change in Storey Drift	Storey Drift	Change in Storey Drift	% Change in Storey Drift
Conventional (No outrigger)	0.00181	-	-	0.001390	-	-
One outrigger	0.00134	0.000470	25.97	0.001000	0.000390	28.06
Two outriggers	0.00122	0.000120	6.63	0.000929	0.000071	5.11
Three outriggers	0.00116	0.000060	3.31	0.000896	0.000033	2.37
Four outriggers	0.00113	0.000030	1.66	0.000883	0.000013	0.94

Table 8 Maximum storey drift ratio of 60 storey models

Type of model	Equivalent Static Method			Response Spectrum Method		
	Storey Drift	Change in Storey Drift	% Change in Storey Drift	Storey Drift	Change in Storey Drift	% Change in Storey Drift
Conventional (No outrigger)	0.00307	-	-	0.00258	-	-
One outrigger	0.00237	0.000700	22.80	0.00196	0.000620	24.03
Two outriggers	0.00227	0.000100	3.26	0.00185	0.000110	4.26
Three outriggers	0.00220	0.000070	2.28	0.00175	0.000100	3.88
Four outriggers	0.00213	0.000070	2.28	0.00168	0.000070	2.71
Five outriggers	0.00207	0.000060	1.95	0.00162	0.000060	2.33
Six outriggers	0.00202	0.000050	1.63	0.00156	0.000060	2.33

Similar to the lateral displacement parameter, storey drift also reduces by a considerable magnitude by employing single outrigger at the top and 0.5H levels of the structure but as we go on increasing the number of outriggers at these locations the storey drift decreases but by a very marginal value. In 20 storey models, the storey drift reduces by 24.17% by ESM and 16.67% by RSM when single outrigger at the top and mid height levels is incorporated. This reduction in storey drift is reduced to 1.11% and 1.10% by ESM and RSM respectively when four outriggers are used at the top and mid height levels. In 40 storey models, the storey drift reduces by 25.97% by ESM and 28.06% by RSM when single outrigger at the top and mid height levels is incorporated. This reduction in storey drift is reduced to 1.66% and 0.94% by ESM and RSM respectively when four outriggers are used at the top and mid height levels. Similarly in 60 storey models, the storey drift reduces by 22.80% by ESM and 24.03% by RSM when single outrigger at the top and mid height levels is incorporated. This reduction in storey drift is reduced to 1.63% and 2.33% by ESM and RSM respectively when six outriggers are used at the top and mid height levels.

C. Fundamental Time Period

Table 9 to Table 11 shows the fundamental time period of various 20, 40 and 60 storey models. The nature of variation of fundamental time period in different models by changing the number of outriggers is same as lateral displacement and storey drift. The introduction of outriggers at the top and mid height levels leads to a stiffer structural configuration thereby reducing the time period of the structure considerably but increasing the number of outriggers at these locations does not reduce the time period with the same rate. This means although the structure becomes stiffer as we increase the number of outriggers at top and mid height levels but the increase in stiffness or the reduction in fundamental time period is not very large.

Table 9 Fundamental Time Period of 20 storey models

Type of Model	Time Period (s)	Change in Time Period (s)	% Change in Time Period
Conventional (No outrigger)	2.314	-	-
One outrigger	1.769	0.545	23.55
Two outriggers	1.667	0.102	4.41
Three outriggers	1.596	0.071	3.07
Four outriggers	1.537	0.059	2.55

Table 10 Fundamental Time Period of 40 storey models

Type of Model	Time Period (s)	Change in Time Period (s)	% Change in Time Period
Conventional (No outrigger)	5.139	-	-
One outrigger	4.342	0.797	15.51
Two outriggers	4.104	0.238	4.63
Three outriggers	3.979	0.125	2.43
Four outriggers	3.867	0.112	2.18

Table 11 Fundamental Time Period of 60 storey models

Type of Model	Time Period (s)	Change in Time Period (s)	% Change in Time Period
Conventional (No outrigger)	8.221	-	-
One outrigger	6.995	1.226	14.91
Two outriggers	6.780	0.215	2.62
Three outriggers	6.609	0.171	2.08
Four outriggers	6.459	0.150	1.82
Five outriggers	6.331	0.128	1.56
Six outriggers	6.220	0.111	1.35

IV. CONCLUSIONS

The following conclusions can be drawn on the basis of the results obtained from this comparative study by linear static and linear dynamic methods of analysis:

1. Incorporating single stiff outrigger system is very much effective in terms of drift control and economy but increasing the number of outriggers leads to higher expenses on steel and provides marginal further decrease in lateral displacement and storey drift.
2. Although the displacement and storey drift reduce with increasing the number of outriggers, but the subsequent magnitude of reduction is not very large.
3. The structure becomes stiffer on increasing the number of outriggers at top and mid height levels and fundamental time period reduces but the subsequent reduction in time period is insignificant as we increase the outriggers.
4. Increasing the number of outriggers beyond a certain limit proves to be ineffective in increasing stiffness of the structure and controlling lateral displacement. Hence some other structural system must be incorporated in addition to outriggers in order to achieve further reduction in storey drift and displacement considerably.

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