

# **Study of Outrigger Systems for High Rise Buildings**

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**ABSTRACT:** Today in modern tall buildings, lateral loads induced by both wind and earthquake were battled by an arrangement of coupled shear walls. When building height increases, the structure should have a lateral load resisting systems other than shear walls for avoiding the effect of these loads, since the shear walls when used alone are suitable only upto 20 stories high. Outrigger systems are one such prominent system and are considered to be the most popular and efficient because they are easier to build and provide good lateral stiffness. This paper presents the results of an investigation on displacement, drift and base shear reduction in steel building frame with rigid outriggers, through time history analysis using the software ETABS 2015. Results shows that double outrigger system can effectively reduce seismic response of the building and optimum location of outriggers was found to be 0.75 times its height along with cap truss.

**KEYWORDS:** Base shear, Displacement, Drift, Outriggers, Time history analysis etc.

## **I. INTRODUCTION**

Today's increased need for housing in metropolitan cities leads to the emergence of high rise buildings. Tall buildings are becoming more and more slender and this leads to more possible sway during the occurrence of lateral loads. When building height increases tremendously, the structure should have lateral load resisting system other than shear walls for avoiding the effect of these loads, since the shear walls when used alone are suitable only upto 20 stories high. Outrigger systems are one such prominent system and are now considered to be the most popular and efficient because they are easier to build, save on costs and provide good lateral stiffness. Outrigger braced structures is an efficient structural form in which the central core is connected to the outer columns. The structural concept of these systems is that when the central core tries to tilt, its rotation at the outrigger level induces a tension-compression couple in the outer columns acting in opposition to that movement. Most importantly, outrigger braced structures can strengthen a building without disturbing its aesthetic appearance and this is a significant advantage over other lateral load resisting systems.

## **II. RELATED WORK**

The purpose of this paper is to study the performance of outrigger systems during their service life. Several researches were conducted on this topic in the previous years but few of them are reviewed as follows. Shivacharan K, Chandrakala S, Karthik N.M [1] (2015) had studied about the optimum position of outrigger system for tall vertical irregularity structures.. It was concluded that there is 12.78% and 11.5% of the deflection and drift is controlled by comparing first position outrigger system and second position of outrigger system of the building. Abdul KarimMulla and Srinivas B. N [2] (2015) had conducted a comparative study on regular building with and without outrigger and irregular building with and without outrigger with centrally rigid shear wall and steel bracings as outrigger. The modeling was done using "ETABS" program and concluded that the usage of outrigger system in the building increases the efficiency of the building when compared to building without outrigger under the action of lateral loads. Krunal.Z.Mistry and Prof. Dhruithi.J.Dhyani [3] (2015) had studied about the outrigger location optimization and the efficiency of each outrigger when three outriggers are used in the structure. They concluded that the optimum position of outrigger is between 0.5 times its heights.P.M.B.RajKiranNanduri and B.Suresh [4] (2013)

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

conducted detailed study about outrigger systems and came to know that the use of outriggers and belt truss systems in high rise buildings increases the stiffness and makes the structural form efficient under lateral load. KiranKamath, N.Divya and AshaRao [5] (2012) had studied the static and dynamic behavior of outrigger structural systems and an investigation has been performed to examine the behavior of various alternative 3D models using ETABS software for reinforced concrete structure with central core wall with outrigger and without outrigger by varying relative flexural rigidity from 0.25 to 2.0 with step of 0.25. The optimum position is at mid height for both static and dynamic behavior for the structure considered. J.C.D. Hoenderkamp, M.C.M Bakker and H.H.Snijder [6] (2003) had presented a paper regarding a graphical method to optimize the position of outriggers on shear walls with flexible foundations. This method requires the calculation of six structural parameters. It is concluded that all these parameters need to be included in the preliminary analysis of a proposed tall building structure. Kian and Siahaan [7] (2002) has studied effectiveness of belt truss and outrigger in concrete high rise building. They have shown that deflections can be controlled effectively by the efficient use of this arrangement. R.Shankar Nair [8] (1998) conducted a detailed study of various types of outriggers and their relative behavior and performance subjected to lateral loading. It is clear from this example that belt trusses used as virtual outriggers are effective at coupling exterior columns to the core of a tall building.

### III. FINITE ELEMENT MODELLING AND ANALYSIS

The model considered for the present study is 120m high rise steel building frame and it represents a 40 storied building. Modelling and analysis were conducted by using the engineering software ETABS Nonlinear version 2015. The floors and roofs were modelled as rigid diaphragms. Wind loads and earthquake loads were given as per IS 875 (Part 3) and IS 1893-2002 (Part 1) respectively. Live loads were also assigned. Table 1 gives the details of the building.

Table 1: Details of the building

Particulars	Steel Structure	
No. of stories	40	
Total height of the building	120m	
Height of each story	3m	
Size of beam	Story 1-10	ISMB 550
	Story 11-20	ISMB 450
	Story 21-30	ISMB 350
	Story 31-40	ISMB 250
Size of column	Story 1-10	ISMB 600
	Story 11-20	ISMB 500
	Story 21-30	ISMB 400
	Story 31-40	ISMB 300
Location	Delhi	
Seismic zone	IV	
Seismic intensity	Severe	
Seismic zone factor ( Z )	0.24	
Basic wind speed (m/s)	47	
Response reduction factor ( R )	5.0	

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

Importance factor ( I )	1.0
Grade of concrete	M25
Grade of reinforcing steel	Fe415
Density of concrete	25kN/m <sup>2</sup>
Supports at base	Fixed
Diaphragm	Rigid

Here in this study, different arrangements of shear wall were considered and a best arrangement is determined by using time history analysis. In that arrangement, outriggers were provided in the structure at top, one fourth, three fourth and mid height. Cap trusses were provided in all these cases. Time history analysis was conducted to investigate the variations in displacement, drift and base shear thus the optimum position was determined. Fig.1 shows the different shear wall arrangements which were used in the study.

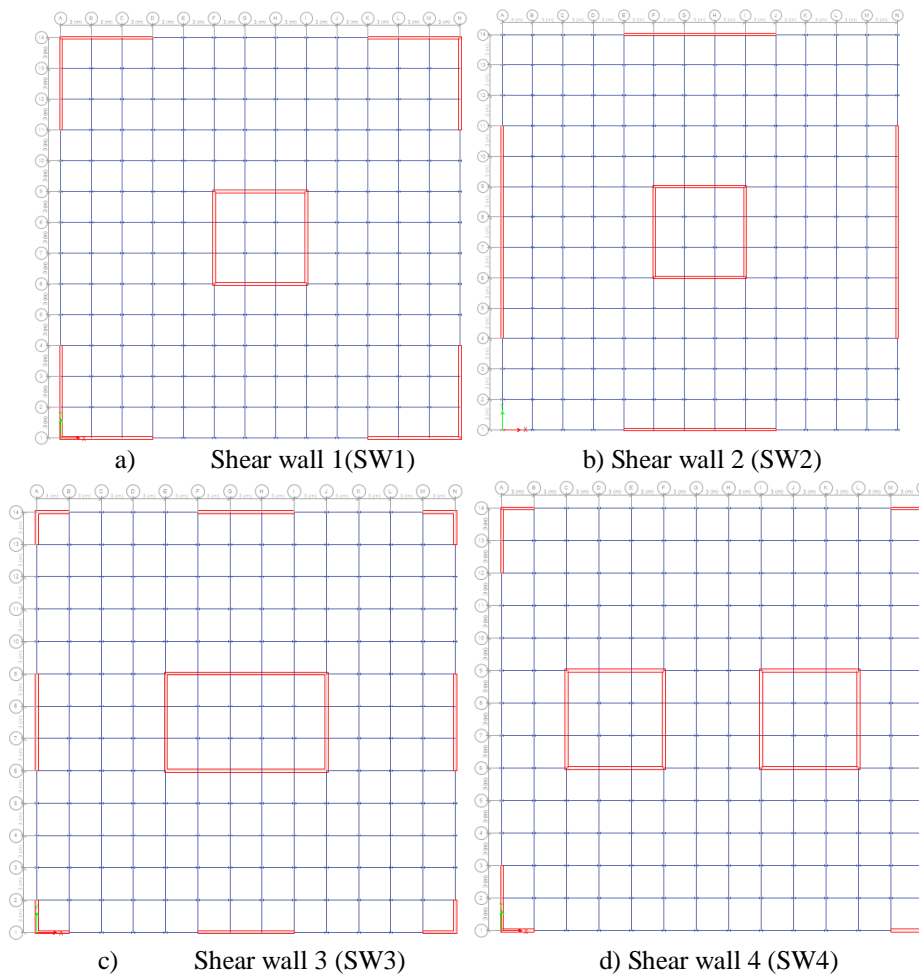


Fig 1: Different shear wall arrangements

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

From the analysis, by taking displacement as the parameter, the third arrangement shows the least value compared to others. Hence, for further studies, the third arrangement was chosen.

Table 2: Displacement

Shear wall arrangement	Displacement (mm)
SW1	735.3
SW2	740
SW3	638.7
SW4	705.1

Since the displacement value for the selected shear wall arrangement was found to be 638.7mm, it is beyond the limiting value so the structure should have another lateral load resisting system such as outriggers. Fig.2 shows the different outrigger arrangements which were used in the study.

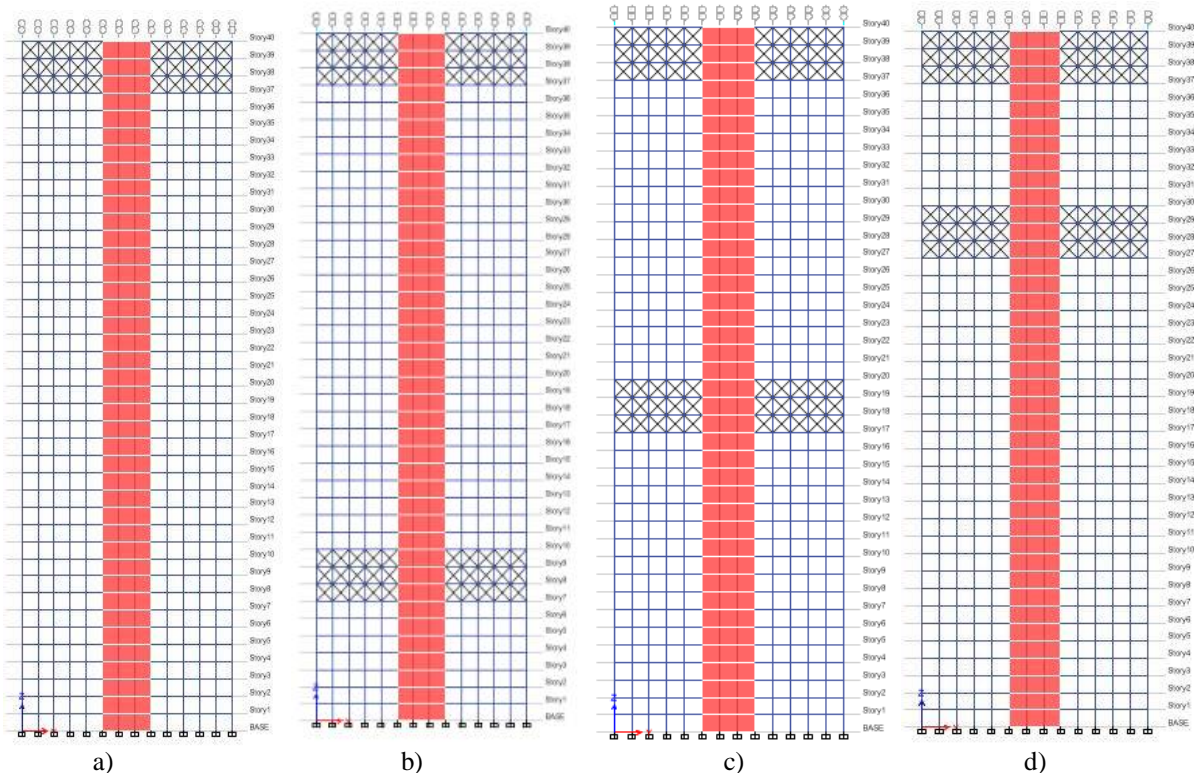


Fig 2: Outrigger arrangements a) at top, b) at top & one fourth height, c) at top & mid height  
d) at top & three fourth height

**IV. RESULTS AND DISCUSSIONS**

By conducting the time history analysis in different arrangements of outriggers, the following results were obtained.

❖ **Displacement**

It is the deviation of the whole structure from its neutral position under an applied load. Fig 5 shows the comparison of story displacement.

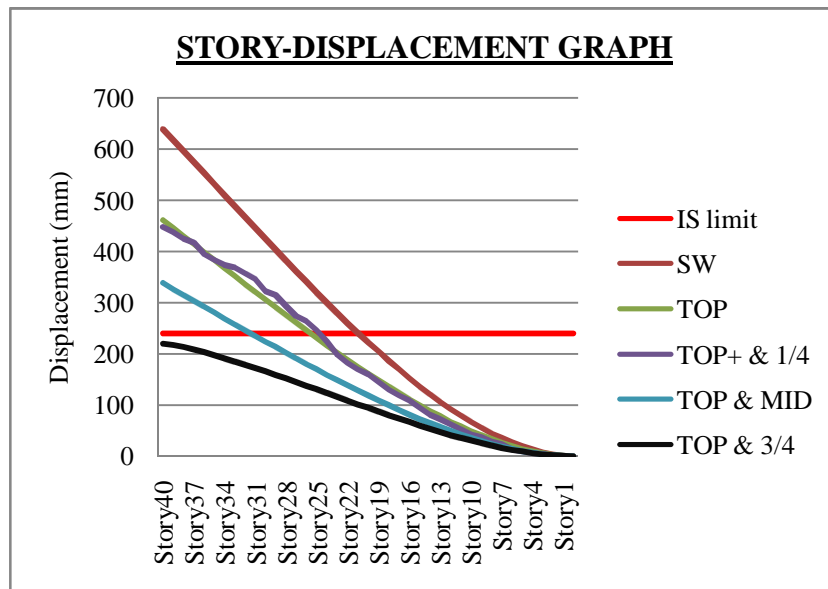


Fig 5: Comparison of story displacement

While evaluating the story displacement graphs from time history analysis, a notable reduction was observed by the introduction of double outriggers. It can be seen that by providing outriggers at top and 3/4<sup>th</sup> height, the displacement value will be in acceptable limits. In all other cases, the displacement was beyond the limiting value.

The table shows the percentage reduction of displacement from time history analysis.

Table 2: Percentage reduction of displacement

Position	Displacement- Maximumvalue (mm)	Percentage reduction (%)
Bare frame with shear wall	638.7	-
Cap truss	460.9	27.83%
Out @ top & 1/4 <sup>th</sup> H	447.5	29.93%
Out @ top & 1/2 <sup>th</sup> H	338.7	46.97%
Out @ top & 3/4 <sup>th</sup> H	220.4	65.49%

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

From the above results, it is clear that when the outriggers are provided at top and 3/4<sup>th</sup> height, the displacement value satisfies the limiting value specified in IS 1893-2002, i.e.; 0.002 times the building height and there will be a percentage reduction of about 65.49.

### ❖ Story drift

It is the lateral drift of a level relative to the level below in a multi-story structure. Fig 6 shows the comparison of story drift graphs of bare frame with shear wall and different arrangements of outriggers from time history analysis.

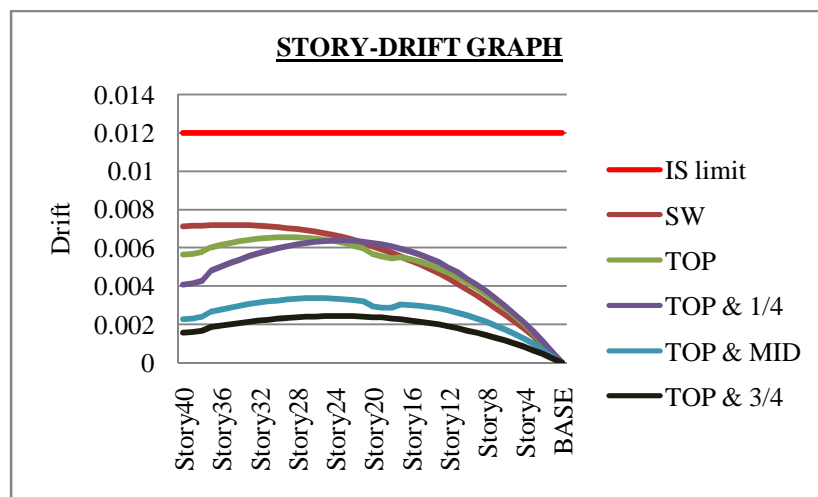


Fig 6: Comparison of story drift

From the analysis, when double outriggers are used, a significant reduction can be seen in the case of story drift.

The table shows the percentage reduction of drift from time history analysis.

Table 3: Percentage reduction of drift

Position	Drift- Maximum value	Percentage reduction (%)
Bare frame with shear wall	0.0071	-
Cap truss	0.0056	21.12%
Out @ top & 1/4 <sup>th</sup> H	0.0040	43.66%
Out @ top & 1/2 <sup>th</sup> H	0.0022	69.01%
Out @ top & 3/4 <sup>th</sup> H	0.0015	78.87%

When outriggers are provided at top and 1/4<sup>th</sup> height of the building, there will be a percentage reduction of about 43.66% and at top and mid height it is about 69.01%. It is to be noted that when outriggers are provided at top and 3/4<sup>th</sup> height, the percentage reduction will be 78.87%.



# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

## ❖ Base shear

It is an estimate of maximum expected lateral that will occur due to seismic ground motion at the base of a structure. Fig.7 shows the comparison of base shear-time graphs of bare frame with shear wall and different arrangements of outriggers from time history analysis.

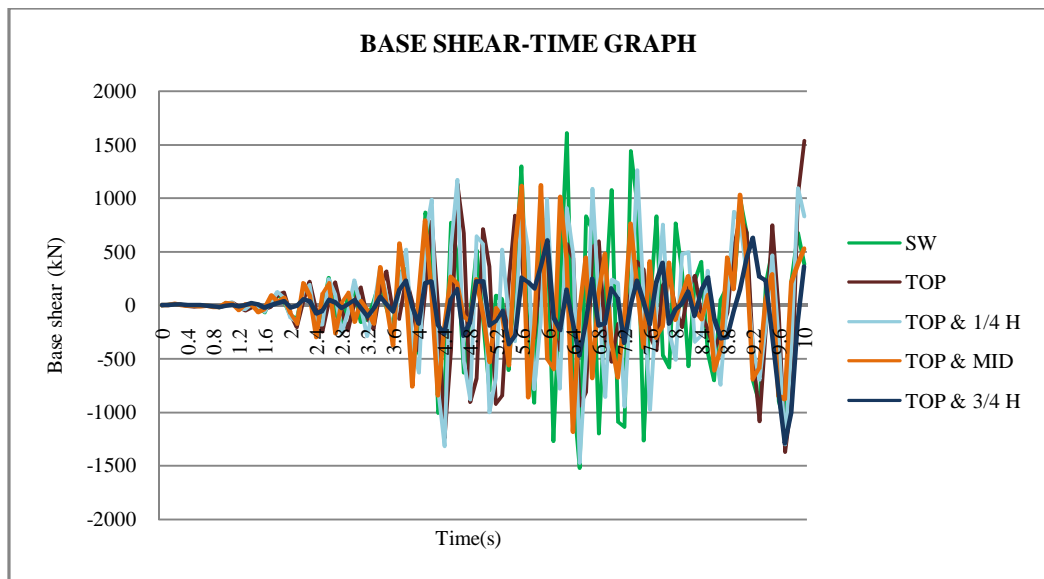


Fig 7: Comparison of base shear-time graph  
The table shows the percentage reduction of base shear.

Table 4: Percentage reduction of base shear

Position	Base shear- Maximum value	Percentage reduction (%)
Bare frame with shear wall	1605	-
Cap truss	1534	4.3%
Out @ top & 1/4 <sup>th</sup> H	1257	21.58%
Out @ top & 1/2 <sup>th</sup> H	1117	30.31%
Out @ top & 3/4 <sup>th</sup> H	626.9	60.94%

From time history analysis, the introduction of double outriggers results in about 65.49% and 78.87% displacement and drift reduction respectively. Also there is 60.94% base shear reduction. It may be noted that the obtained values are within the acceptable limits.

## IV. CONCLUSION

This study assessed the overall behaviour of outrigger braced building under lateral loads from which the following conclusions can be drawn based on the above results.

- Outrigger braced tall building is considered as one of the most popular and efficient tall building design because they are easier to build, save on costs, and provide massive lateral stiffness.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 5, Issue 8, August 2016

- With the implementation of outrigger systems, factors such as base shear, displacement and story drift of the structure during an earthquake are lowered and hence building is to be designed only for wind and gravity loads. Hence reducing the size of structural elements, results in an economic construction.
- The location of outrigger beam has a critical influence on the lateral behaviour of the structure under lateral loads and the optimum outrigger locations is found to be 0.75 times the building height along with cap truss when provided at three stories depth.
- Numerical study was conducted on a 40 storied steel structure providing outriggers at top, one fourth, middle and three fourth height of the building, and outrigger at three fourth along with cap truss was found superior among the three in terms of story drift, displacement and base shear since it confirmed to the safety limits described in IS 1893-2002.
- A notable reduction was observed while evaluating story displacement, drift and base shear from time history analysis.

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