Comparative Study of Analysis of High-Rise Building for Various Outrigger Systems

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Abstract— The outrigger system is one of the most efficient systems used to effectively control the excessive drift due to lateral load, so that, during small or medium lateral load due to either wind or earthquake load, the risk of structural and non-structural damage can be minimized. For high-rise buildings, particularly in seismic active zone or wind load dominant, this system can be chosen as an appropriate structure. This paper studies the efficient use of outrigger and belt truss system for high-rise concrete building subjected to wind or earthquake load. Seven 32 storey two dimensional models of outrigger and belt truss system is subjected to wind and earthquake load, analyzed and compared to find the lateral displacement reduction related to the types of outrigger and belt system. The analysis has been carried out to study the effect and performance of outrigger system in 32 storey building. The outrigger system is provided at different levels along the height of the building. The depth of the Outrigger and belt trusses is equal to the height of the typical story and maintained same in all the models. The key parameters discussed in this paper include lateral deflection, storey drifts and base shear. Loads are considered as per Indian Standards IS: IS: 875(Part3)-1987 and IS: 1893(Part-1) -2002. The modelling and analysis were performed using finite element software ETABS 2016.

Key words: Outrigger, Earthquake Analysis, Various Outriggers, Lateral Displacement

I. INTRODUCTION

Tall building development has been rapidly increasing worldwide introducing new challenges that need to be met through engineering judgment. In modern tall buildings, lateral loads induced by wind or earthquake are often resisted by a system of coupled shear walls. But when the building increases in height, the stiffness of the structure becomes more important and introduction of lateral load resisting system is used to provide sufficient lateral stiffness to the structure. The lateral load resisting system effectively control the excessive drift due to lateral load, so that, during small or medium lateral load due to either wind or earthquake load, the risk of structural and non-structural damage can be minimized. For high-rise buildings, particularly in seismic active zone or wind load dominant, these systems are chosen as an appropriate structure.

A. Outrigger and Belt Truss System

Outriggers are rigid horizontal structure i.e. truss or beam which connect core wall and outer column of building to improve building strength and overturning stiffness. Outriggers have been used in tall building for nearly half century, but innovative design principle has been improving its efficiency. Outrigger system is one type of structural system which is formed from a cantilever shaped horizontal member connected to structures inner core and outer columns. Through the connection, the moment arm of the core will be increased which lead to higher lateral stiffness of the system. Central core in a building act as cantilever, outriggers are provided to reduce overturning moment in core and to transfer moment from core to outer column by connecting the core and column. Wall frame outrigger trusses is one of the most efficient and economical structures in tall building, at outer end they connected to the foundation through exterior columns. When the structure is subjected to horizontal loading, the wall and outrigger trusses will rotate, causing compression in the downwind column and tension in column on the upwind side, these axial forces will resist the rotation in the wall. The outrigger systems can be produced in any combination of steel, concrete and composite construction. Normally in steel structure outrigger are in the form of trusses and in the form of wall or deep beam in concrete structure. Outrigger may be extended to both side of central core or core may be located at one side of building with outrigger extending to other side column. Outrigger connected to core and outer column act as stiff beam under action of lateral load inducing a tension compression couple in the outer columns, to distribute these tensile and compressive forces to a large number of exterior frame columns belt trusses are often provided. Belt truss connects outer perimeter column of a building and offer a wider perimeter to resist lateral deflection of building. This efficient structural form consists of a central core, comprising either Braced Frames or Shear Walls, with horizontal cantilever trusses or girders known as outrigger Trusses, connecting the core to the outer columns. The core may be centrally located with outriggers extending on both or it may be located on one side of the building with outriggers extending to the building columns on one side as shown in Fig.1 (a) & Fig.1 (b).

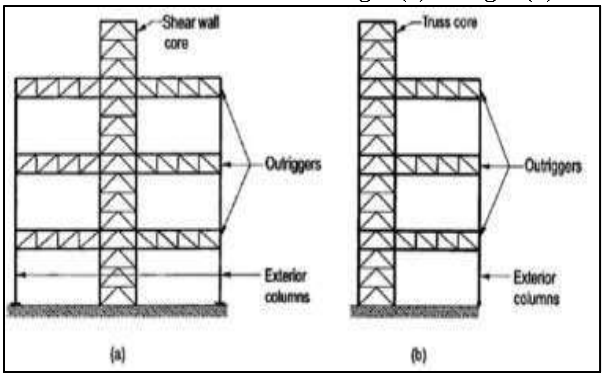

Fig. 1: (a) Outrigger System with a Central Core (b) Outrigger system with Offset Core.

B. Objectives of the Study

1) To study the effect of introduction of Outriggers in high rise building subjected to dynamic wind and seismic loading.

2) To study the reduction in storey drift, with and without application of various outriggers in high Rise buildings.
3) To compare results obtain from Earthquake Analysis using Response Spectrum Analysis and Dynamic Wind Analysis in ETABS 2016.
4) To study the effect of various Outrigger Systems
5) To study the influence of core wall with X braced outriggers.
6) To study the parameters with different types of Outriggers, i.e. X Bracings and V Bracings and Inverted V Bracings.

II. MODELING & ANALYSIS

In the present study the gravity load analysis and lateral load analysis for the RC frame building with the provision of introduction of outriggers as per seismic codes for zone II is carried out and an effort is made to study the effect of seismic loads on them and thus assess their seismic vulnerability by performing analysis.

A. *Method of Modeling*

The ETABS software is utilized to create 3D model and to carry out the analysis. The software is able to predict the behaviour of space frames under static or dynamic loadings, taking into account material in elasticity. The software accepts static loads as well as dynamic loads and has the ability to perform static and dynamic analysis.

B. *Model Description*

The model considered for this study is a 96m high rise reinforced concrete building frame. The building represents a 32 storeyed office building. The plan area of the structure is 38.5 X 38.5m with columns spaced at 5.5m and 5.5m center to center in longitudinal and transverse direction respectively. The plan layout for all the models is same as shown in Fig 2.

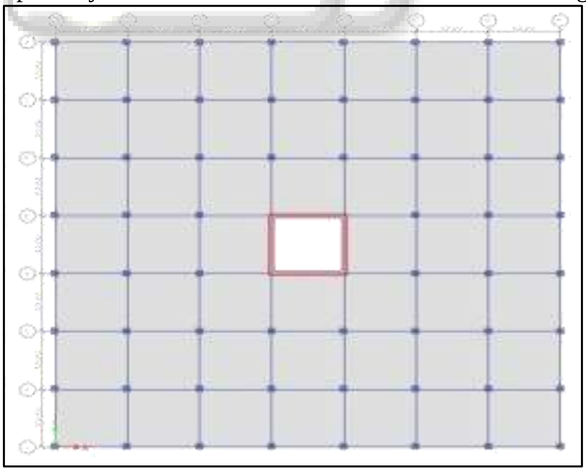

Fig. 2: Plan Layout

Model Geometry (mm)						
No of Storey	No. of bays in X Direction	Bay width in X direction	No. of bays in Y direction	Bay width in Y direction	Each Storey Height	Total Storey Height
32	7	5.5	7	5.5	3	96

Table 1: Models Geometry

The models that were selected for the study are listed as follows;
1) Model 1 – A Bare frame model
2) Model 2 – Model with Concrete Core wall and braced Outriggers (X Bracings).
3) Model 3 – Model with Concrete core wall and braced Outriggers (V Bracings).
4) Model 4 – Model with Concrete Core wall and Braced Outriggers (INVERTED V bracings)
5) Model 5 – Model with Braced Concrete Core wall and Braced Outriggers (X Bracings).
6) Model 6 – Model with Concrete Core wall and Steel Outriggers (X bracings).

1) *Locations of Outriggers*

According to Bryan Stafford Smith, for Optimum performance of an n-Outrigger Structure, the Outriggers are placed at 1/ (n+1), 2/ (n+1) up to the n/ (n+1) height locations. Therefore, positions of various Outriggers for all the models are as follows:
1) 1st Outrigger = 1/ (4+1) = 1/5= 0.2H
2) 2nd Outrigger = 2/ (4+1) = 0.4H
3) 3rd Outrigger = 3/ (4+1) = 0.6H
4) 4th Outrigger = 4/ (4+1) = 0.8H

Therefore, the outriggers are provided at every 7th storey.

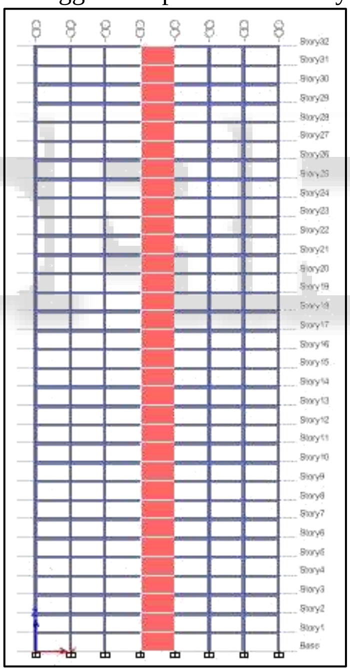

Fig. 3: Sectional Elevation of Building Model 1 (Without Outrigger)

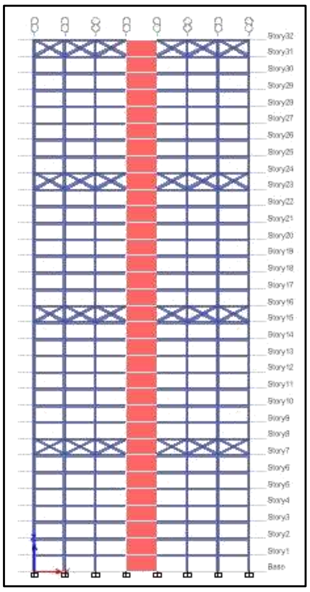

Fig. 4: Sectional Elevation of Building Model 2 (With X Outriggers)

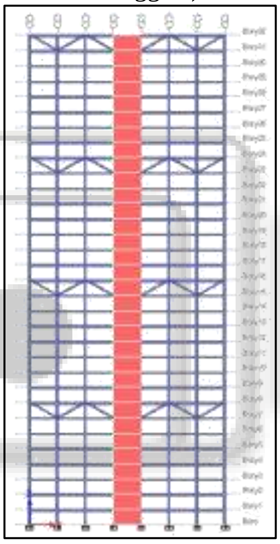

Fig. 5: Sectional Elevation of Building Model 3 (With V Outriggers)

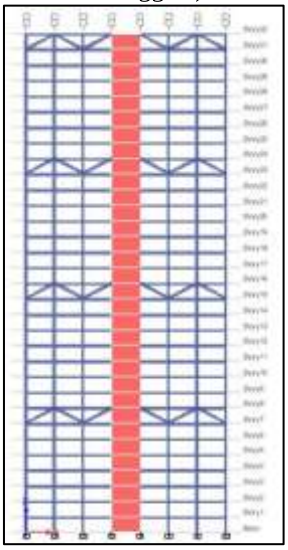

Fig. 6: Sectional Elevation of Building Model 4 (With Inv. V Outriggers)

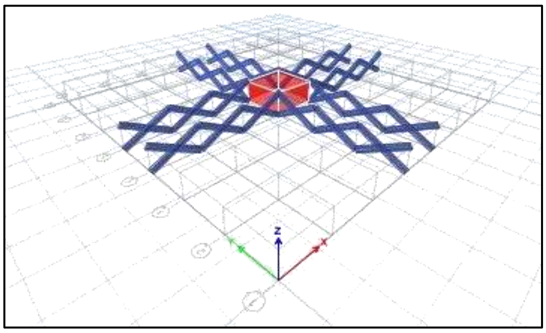

Fig. 7: Perspective view of a storey of Building Model 2(With X Outriggers)

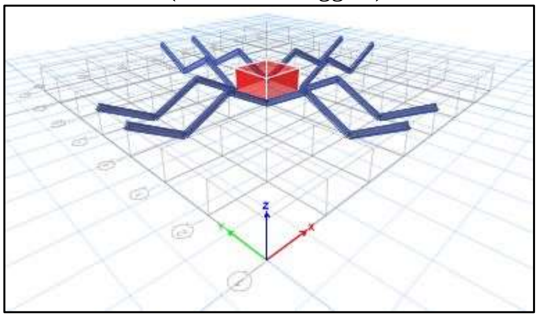

Fig. 8: Perspective view of a storey of Building Model 3 (With V Outriggers)

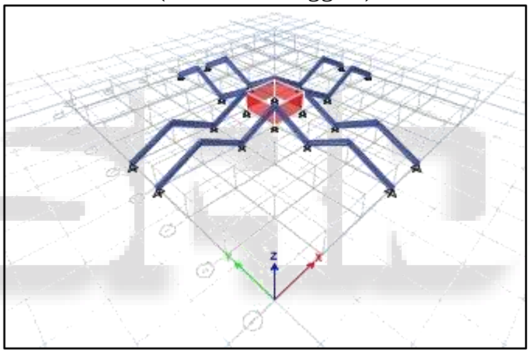

Fig. 9: Perspective view of a storey of Building Model 4 (With Inv. V Outriggers)

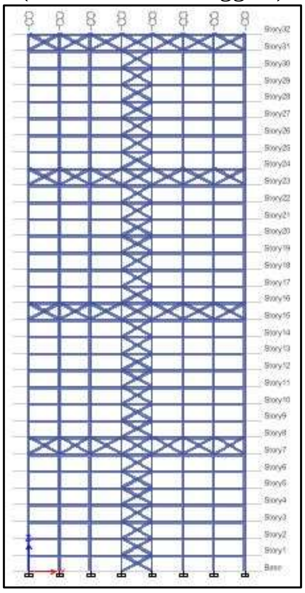

Fig. 10: Sectional Elevation of Building Model 5 (Braced core wall with X Outriggers)

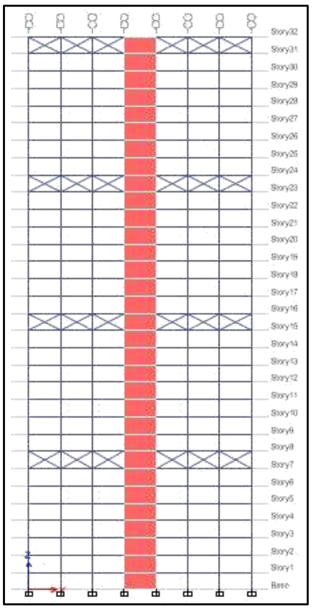

Fig. 11: Sectional Elevation of Building Model 6 (With Steel X Outriggers)

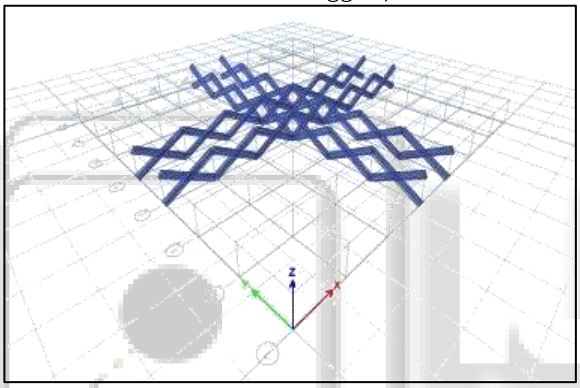

Fig. 12: Perspective view of a storey of Building Model 5 (Braced core wall with X Outriggers)

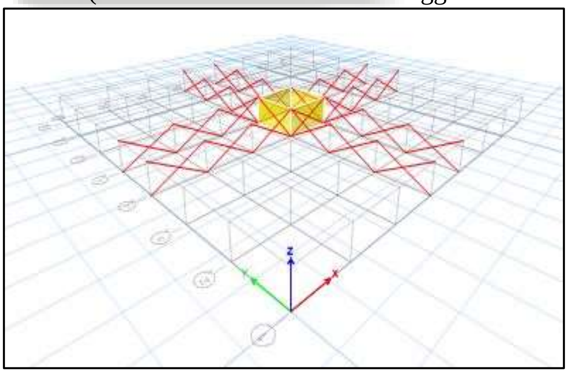

Fig. 13: Perspective view of a storey of Building Model 6 (With Steel X Outriggers)

III. Properties

A. Material Properties

- Grade of concrete = M40 for all members
- Grade of Steel = Fe 250 for steel outriggers
- Density of Reinforced Concrete = 25 KN/m3
- Poissons's ratio of concrete = 0.2
- Modulus of elasticity of brick masonry = 3500x103 KN/m2
- Density of brick masonry = 20 KN/m3
- Poissons's ratio of masonry = 0.15

B. Member Properties

- Thickness of RC slab = 115mm
- Column size = 600mmX600mm
- Beam size = 230mmX600mm
- Thickness of brick masonry wall = 230mm
- Thickness of RC shear wall = 350mm
- Concrete Outriggers = 230mmX600mm
- Steel Outriggers = ISA 130X130X12mm

C. Load Calculation

- Floor finishes = 1.5 KN/m2
- Live load on floors = 3 KN/m2
- Live load on roof = 1.5 KN/m2
- Wall load on roof level = 1x0.15x20 = 3 KN/m
- Wall load on all other levels = (3.2-0.6)x0.23x20 = 12 KN/m
- Earthquake live load on slab as per clause 7.3.1 and 7.3.2 of IS 1893 (Part-1) - 2002 is calculated as:
- Roof (clause 7.3.2) = 0
- Floor (clause 7.3.1) = 0.5x3 =1.5 KN/m2

D. Seismic Data

- Zone factor = 0.10 (Zone II)
- Importance factor = 1.5 (Important office building)
- Response reduction factor = 5 (SMRF)
- Soil type = Type II (Medium soil)
- Earthquake load and Dynamic Wind load is applied on the RC frame structure. Equivalent static method and Response spectrum
- Method are used in the analysis as per IS-1893 (Part 1). The structure is subjected to wind load as per IS-875 (Part 3).

IV. Results & Discussion

A. Lateral Displacements

Top Storey Displacement (mm)			
Model	Type of Outriggers	Response Spectrum Analysis	Dynamic Wind Analysis
		RSA-X	WIND_X
1	Without Outrigger	142.488	280.328
2	X	109.714	198.421
3	V	115.186	217.751
4	Inverted V	110.857	201.488
5	X with Braced Core wall	116.617	216.202
6	X steel outriggers	120.772	225.68

Table 2: Maximum Displacement by Response Spectrum Analysis and Dynamic Wind Analysis along Longitudinal and Transverse direction

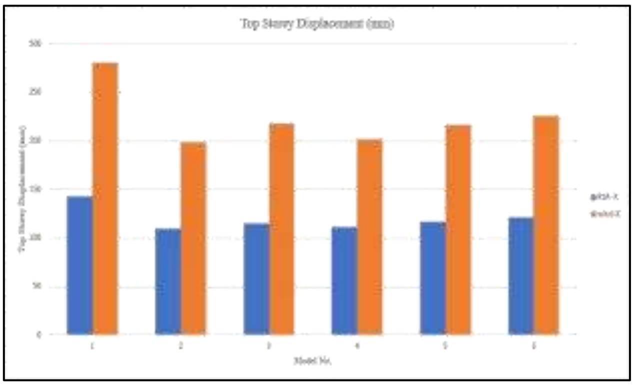

Fig. 16: Comparison of Top Storey Displacement by Response Spectrum Analysis and Dynamic Wind Analysis along Longitudinal and Transverse direction

B. Storey Drifts

Maximum Storey Drifts			
Model	Type of Outriggers	Response Spectrum Analysis	Dynamic Wind Analysis
		RSA-X	WIND_X
1	Without Outrigger	0.001205	0.002348
2	X	0.000999	0.001715
3	V	0.001025	0.001882
4	Inverted V	0.001004	0.0017435
5	X with Braced Core wall	0.001062	0.001898
6	X steel outriggers	0.001063	0.001934

Table 3: Maximum Storey Drifts by Response Spectrum Analysis and Dynamic Wind Analysis along Longitudinal and Transverse direction

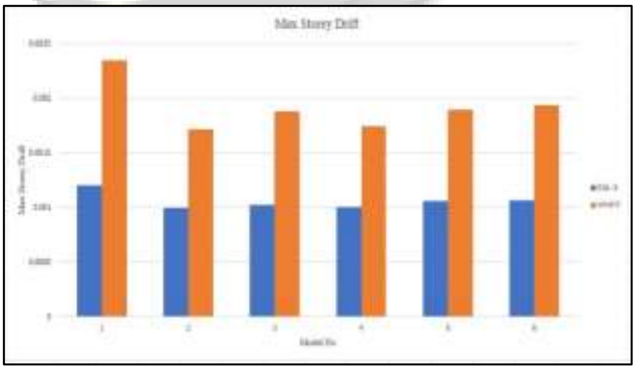

Fig. 17: Comparison of Maximum Storey Drifts by Response Spectrum Analysis and Dynamic Wind Analysis along Longitudinal and Transverse direction

C. Base Shear

Base Shear (KN)			
Model	Type of Outriggers	Response Spectrum Analysis	Dynamic Wind Analysis
		RSA-X	WIND_X
1	Without Outrigger	5907.3745	11978.2
2	X	6577.124	11149.6
3	V	6367.4337	11489.2
4	Inverted V	6506.5167	11149.6
5	X with Braced Core wall	6352.9902	11450.8
6	X steel outriggers	6227.4961	11338.1

Table 4: Base Shear by Response Spectrum Analysis and Dynamic Wind Analysis along Longitudinal and Transverse direction

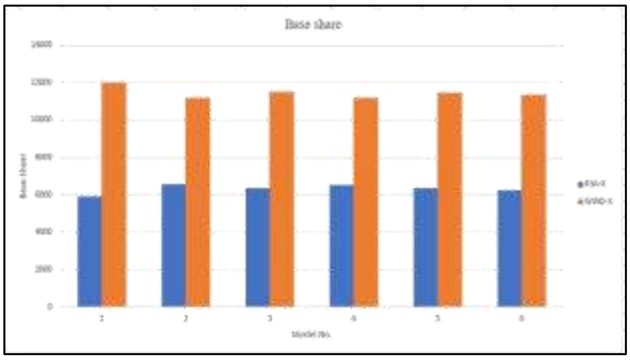

Fig. 18: Comparison of Base shear for different models by Response Spectrum Analysis & Dynamic Wind Analysis in longitudinal and in transverse direction

V. CONCLUSIONS

1) The maximum displacement at the top of structure when only core is employed is around 142.5 mm and this is reduced to 104.6 mm by placing of outrigger at top storey and 116.6 mm with and at mid truss respectively.
2) From the results it is found that there is (17%) reduction in storey drift after application of outrigger systems.
3) The steel outriggers are found least effective compared to Concrete one. Although Steel outriggers can be employed as the light weight substitute for concrete.
4) From lateral displacement result of table no 4.1.1 it is said that concrete core wall is more advantageous than core with braced core wall.
5) After studying different types of outrigger it is found that x outrigger found more effective.
6) The X-Outriggers are very much effective; as it shows minimum lateral displacement followed by V-braced Outriggers and V- Inverted braced Outriggers.
7) The use of outrigger system in high-rise buildings increase the stiffness and makes the structural form efficient under lateral load.

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