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Linear Analysis of RCC High-Rise Structures with Multiple Combinations of Outrigger Systems under Seismic Loads

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Abstract - *It has been widely known that outrigger beams/truss are generally appropriate for resistance against eminent wind loads, but incorporating outriggers for earthquake resistance has been intriguing area for research. In the past many researchers have analyzed the effects of featuring outriggers with various configurations in the high-rise building in frames with different loading condition in order to reduce and control the deflections and stresses. However, the performance of various other possible outrigger systems under seismic loads has not been studied extensively for commercial high-rise structures. In this paper the feasibility of various Outrigger Structural Systems for Commercial High-rise structures under Seismic load is studied. This includes linear methods of analysis, namely Response Spectrum Analysis and Equivalent Static Load Method. It is concluded that the two outriggers with belt truss combination offers maximum reduction in deflection of 18%.*

Key Words: High-Rise Buildings, seismic loads, outrigger systems, belt truss systems, linear analysis

1. INTRODUCTION

In modern tall buildings, lateral loads induced by wind or earthquake are often resisted by a system of coupled shear walls. The design of skyscrapers is usually governed by the lateral loads imposed on the structure. More specifically the design of tall and slender structures is controlled by three governing factors, strength (material capacity), stiffness (drift) and serviceability (motion perception and accelerations), produced by the action of lateral loading, such as wind. The overall geometry of a building often dictates which factor governs the overall design. As a building becomes taller and slenderer, drift considerations become more significant. Proportioning member efficiency based on maximum lateral displacement supersedes design based on allowable stress criteria. Through the design of a high-rise structure, numerous problems appear such as the number of columns or size and shape of concrete core or even basic dimensions of the structure itself. Having constraints for the building immediately defines and solves part of the unknown variables but it is the geometry of the structural system inside these basic parameters that identifies an efficient design. Undoubtedly, the factor that governs the design for a tall and slender structure most of the times is not the fully stressed state but the drift of the building. There are numerous structural lateral systems used in high-rise building design such as: shear frames, shear trusses, frames with shear core, framed tubes, trussed tubes, super frames etc. However, the outriggers and belt trusses system is the one providing significant drift control for the building.

1.1 LITERATURE REVIEW

Many researchers have analysed the effects of featuring outriggers with various configurations in the high-rise building in frames with different loading conditions in order to reduce and control the deflections and stresses. **Akash Kala et. al.** studied the optimum position of outrigger with belt truss in tall building under horizontal load. The main aim of this study is to study the use of outrigger and belt truss placed at different location subjected to wind loads. The study concluded the optimum outrigger location of high-rise building under action of wind load is between 0.25-0.33times the height of building (from bottom of building) [1]. **Akshay Khanorkar et. al.** reviewed various parameters such as lateral displacement, storey drift, core moment and optimum position related to outrigger and belt truss for controlling deflections in tall buildings. The concluded Optimum position of structural system for deflection criteria is different than bending moment criteria [2]. **Suresh and Pradeep K.M.** analysed the effect and performance of outrigger in 30 storey building provided different levels along the building height by varying relative stiffness. They concluded the percentage reduction of lateral displacement and inner storey drift with respect to bare frame varies for different model configuration for different seismic zone and the maximum inner storey drift is observed at building height in range of 5-15m [3]. **Mohd Abdus Sattar et. al.** studied the effect of building displacements in lateral direction with shear core, outrigger and belt truss. They concluded that floor rigidity is not required to be increased beyond that required for the load carrying of Dead load and Live load on floors. Column forces and moments are minimum in case of "Building frame with Double Core arrangement of shear wall and Stringer beams" for which drift and displacement are also comparatively less. Moments in Corner column are less compared to the middle column. Moments in outer periphery columns are less compared to the moments in interior columns [4]. **Kiran Kamath et. al.**

studied the performance of multi-outrigger based on location of outrigger and also performance in term of lateral displacement in top, storey drift, shear force and bending moment in core wall based on relative axial rigidity. They found the maximum percentage of reduction in bending moment achieved when outriggers were placed between top and 67% of total height when compared with model without outrigger [5].

In this paper the feasibility of various Outrigger Structural Systems for Commercial High-rise structures under Seismic load is studied. This includes linear methods of analysis, namely Response Spectrum Analysis and Equivalent Static Load Method.

1.2 Outrigger systems

For design of tall structures, the use of core-wall system has been a very effective and efficient structural system used in reducing the drift due to lateral load. However, as and when the height of the building increases, the core does not have the adequate stiffness to keep the drift down to acceptable limits. For such high-rise structures, horizontal structural systems known as outriggers are introduced. The layout of an outrigger in a building is shown in figure 1.

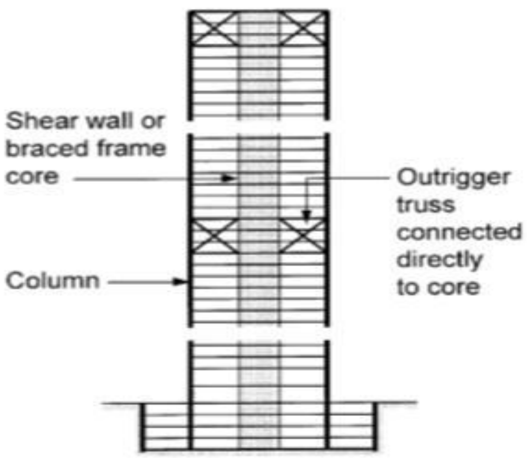


Fig - 1 Layout of conventional of outriggers in tall buildings [2]

1.3 Working principle of outriggers

Outriggers are primarily conceived to reduce the global deformation of the building, caused by the flexural behaviour of the resistant core. This is achieved by reducing the overturning moment of the cantilever scheme and by transferring the reduced moment to the outer members through extremely rigid horizontal beams connected to the core at specific levels. These horizontal beams are referred to as outriggers. The efficiency of the outrigger system depends upon the flexural stiffness of the girder and the axial stiffness of perimeter vertical columns. Additionally, by including deep spandrel girders, which work as belts surrounding the entire building, it is possible to mobilize also the other peripheral columns to assist in restraining the outriggers, providing an improvement up to 25-30 per cent in stiffness. In order to have the outrigger and belt girder adequately stiff in flexure and shear, they often present a vertical extension which covers at least one or two storey. Figure 2 shows the structural behaviour and mechanics of buildings with and without outriggers.

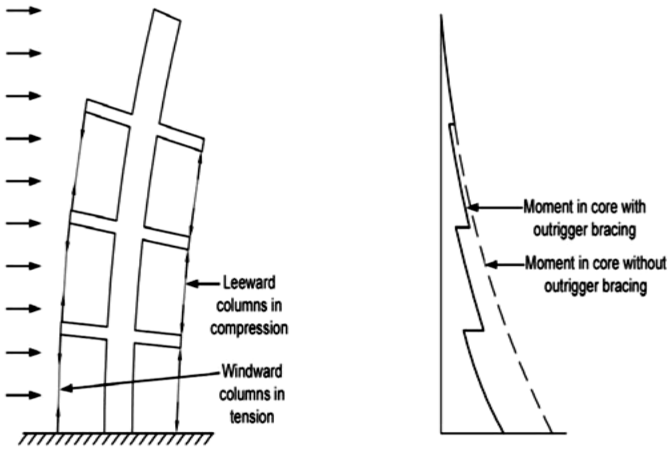


Fig - 2 Structural behaviour of an outrigger system and comparison of moment diagrams with and without outrigger bracings [6]

2. STRUCTURAL MODELING

In this study 3D models were prepared using Finite Element based software ETABS. The software is able to run, analysis and obtain results according to Indian Standard Code of practice. The following design criteria were considered for modeling purposes:

1. A 54 storey building with different outrigger configurations. The models shall be based on an actual plan of a commercial building.

2. Storey height shall be kept constant at 3.9meters for all stories

3. The plan of the structure shall be square in shape with size 49.7m. X 49.7m.

4. The structure shall be analyzed in Seismic Zone-IV and soil type selected shall be Type-1 (Rock and Hard soil) as per IS: 1893(part-I):2002.

2.1 Loading parameters

The various loading parameters for dead load, live load and seismic loads are shown in Tables 1-3

Table -1: Consideration of Dead Loads

Unit weight of Concrete	25kN/m3 (for calculating self weight of structure)
Unit weight of floor finish	24kN/m3
Unit weight of Brick masonry walls	20kN/m3

Table -2: Typical live loads for commercial buildings

Commercial area	4.0kN/m2
Staircases	3.0kN/m2
Terrace	2.0kN/m2
Lift machine room	10.0kN/m2 or as per Lift Vendor (whichever is higher)

Table -3: Seismic loads

Zone factor (Z)	0.36
Response reduction factor	5
Importance factor	1.5
Frame type	Special Moment Resisting Frame (SMRF)

The time period calculations is shown in Table-4

Table -4: Time period calculations

With infill panel (with brick wall)	Without infill panel (without brick wall)
$T=0.09 \times H/D^{0.5}$	$T=0.075 \times H^{0.75}$
Where, **T**= time period in second, **H**=total building height from bottom to terrace level **D**=x & y Dimension of the building	

Wind loads are calculated as per IS: 875 (Part 3) using the following parameters:

Basic wind speed (Vb) = 44m/sec
Design Wind Speed (Vz) = Vb * k1 * k2 * k3
Where, k1 = Probability factor = 1
k2 = Terrain, height and structure size factor
k3 = Topography factor (Class: C)
(Terrain Category: 2)
Design wind pressure (Pz) = 2 6 .0z

2.2 Loading combinations

Following load combinations are considered for calculating the forces at ultimate limit states as per IS: 875-1987 (Part-V) and IS: 1893-2002 (Part-I)

- 1.5DL + 1.5LL
- 1.2DL + 1.2 LL ± 1.2EQX 1.2DL + 1.2 LL ± 1.2EQY
- 1.5DL ± 1.5EQX 1.5DL ± 1.5EQY
- 0.9DL ± 1.5EQX 0.9DL ± 1.5EQY
- 1.2DL + 1.2 LL ± 1.2WLX 1.2DL + 1.2 LL ± 1.2WLY
- 1.5DL ± 1.5WLX 1.5DL ± 1.5WLY
- 0.9DL ± 1.5WLX 0.9DL ± 1.5WLY

Where,
DL = Dead Load EQ = Earthquake Load
WL = Wind Load LL = Live Load

2.3 Combinations of structural models

Based on the literature review and the gaps found in the research, the combinations of model for different Outrigger systems are obtained. The various model combinations are as follows:

- RCC bare frame with shear core walls (base model for comparison)

- RCC bare frame with shear core and two outriggers (outrigger at top + outrigger at mid height)

- RCC bare frame with shear core, two outriggers and peripheral belt truss (outrigger at top + outrigger at 0.6th height)

- RCC bare frame with shear core and three outriggers (outrigger at top + two equally spaced throughout the height)

3. ANALYSIS METHODOLOGY

In this paper two linear analysis methods have been studied namely Equivalent Static Load Method and Response Spectrum method.

3.1 Equivalent static load method

As per IS-1893-2002, the mass of the structure multiplied by design Equivalent coefficient, acts statically in a horizontal direction. It is also assumed here that the magnitude of the coefficient is uniform for the entire members of the structure. Design shears at different levels in a building shall be computed from the assumption of linear distribution horizontal accelerations, varying from zero at the base of the structure to a maximum at the top. This method includes the following design components.

a) Design Seismic Base Shear
b) Seismic Weight of Building
c) Fundamental Natural Time Period
d) Distribution of Design Force
Detailed description and formulation for the above can be found in IS-1893(2002) and the same have been used in the ETABS software.

3.2 Response spectrum method

The response spectrum represents an envelope of upper bound responses, based on several different ground motion records. This method is an elastic dynamic analysis approach that relies on the assumption that dynamic response of the structure may be found by considering the independent response of each natural mode of vibration and then combining the response of each in same way.

This method includes following components:

a) Modal mass (Mk)
b) Modal Participation factor (Pk)
c) Design lateral force at each floor in each mode
d) Storey shear forces in each mode
e) Storey shear force due to all modes considered

Detailed description and formulation for the above can be found in IS-1893(2002) and the same have been used in the ETABS software

3.3 ETABS Models

As discussed in section 2, a generic commercial building having 54 storey and floor area of 49.7x49.7m has been assumed. The ETABS model for the building along with the outrigger combinations is shown in figures 3 to 5.

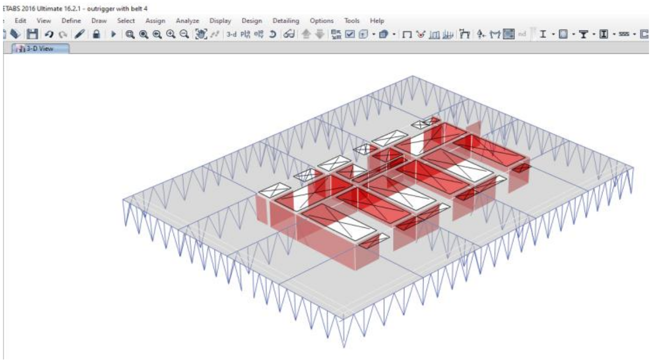


Fig - 3 Floor View of Shear Core and Two Outriggers with Belt Truss Model

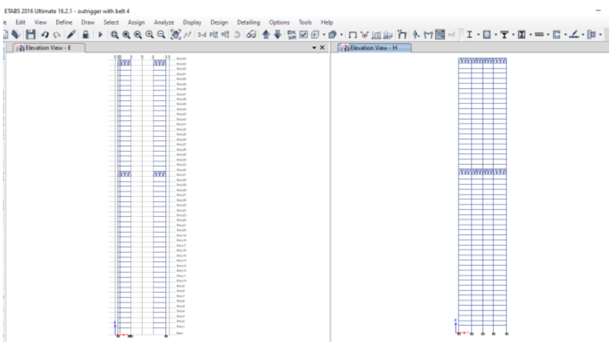


Fig - 4 Elevation of Shear Core and Two Outriggers with Belt Truss Model

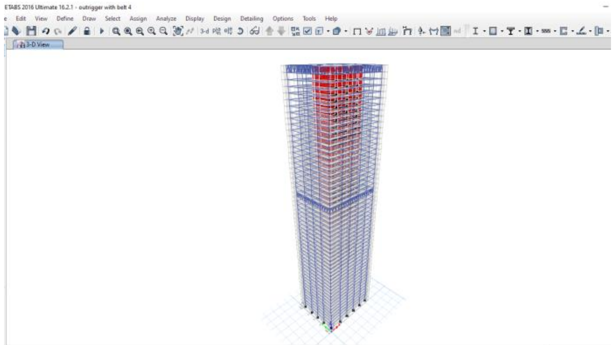


Fig - 5 3D View of Shear Core and Two Outriggers with Belt Truss Model

4. RESULTS AND DISCUSSIONS

The above analysis for the various structural model combination listed in section 2.2 were performed on basis of the two performance evaluations parameters namely Top storey displacement and storey drift ratios.

4.1 Top storey displacement

The top storey displacement represents the maximum deflection that a tall building experiences. In this study this displacement is compared for various structural models along the x and y directions as shown in Chart 1.

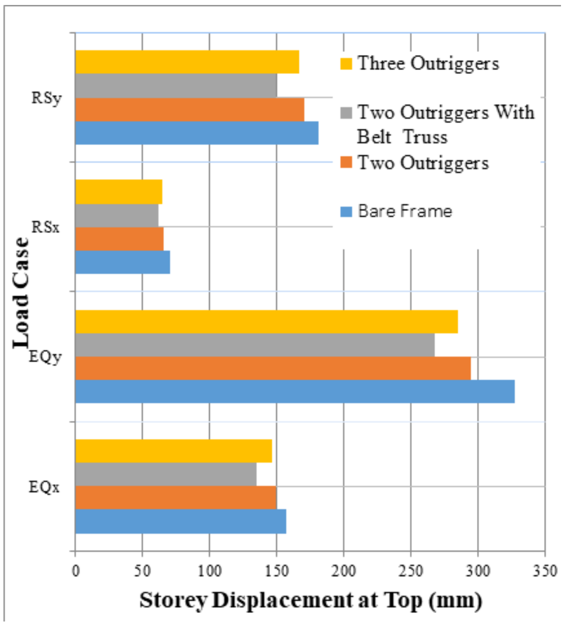
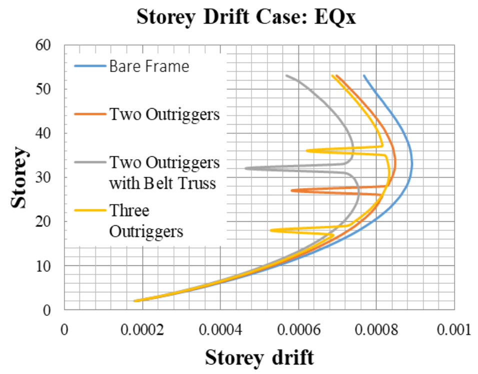


Chart - 1 Top Story Displacement using Response Spectrum method (RS) and Equivalent static method (EQ)

It is seen that the equivalent static method shows greater displacement as compared to the response spectrum along both the direction. Furthermore, it is seen that deflection along the y direction is greater than x direction despite being symmetrical building this difference in the directional displacement because the outriggers in X direction are aligned on either side of the Shear wall core whereas; it is slightly staggered in Y direction. Additionally, it is seen that the maximum top displacement reduction of 18% compared to the bare frame occurs in the case of two outriggers with peripheral belt truss.

4.2 Storey drift

Storey drift is the difference between the lateral displacement of a floor to the floor below and the storey drift ratio is the storey drift divided by the storey height. Chart 2 show the storey drift ratios for various structural combination using the equivalent static method along the x and y directions. Similarly, Chart 3 shows storey drift ratios using the response spectrum method.



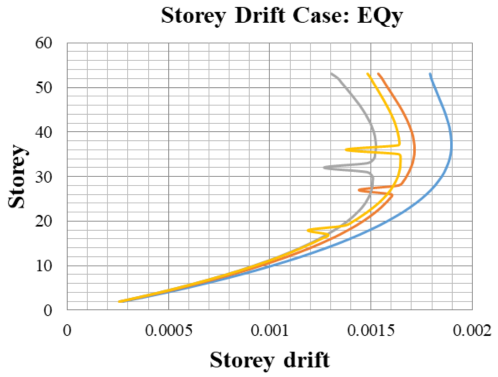
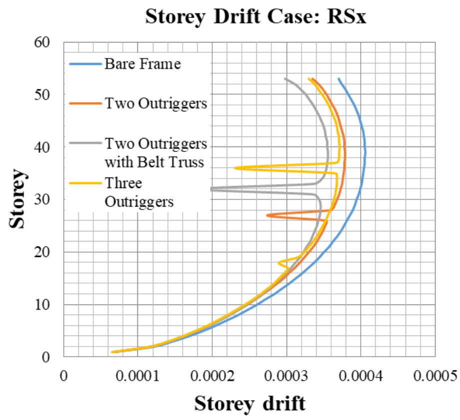


Chart - 2 Storey drift variation using Equivalent Static method (EQ) along X and Y directions



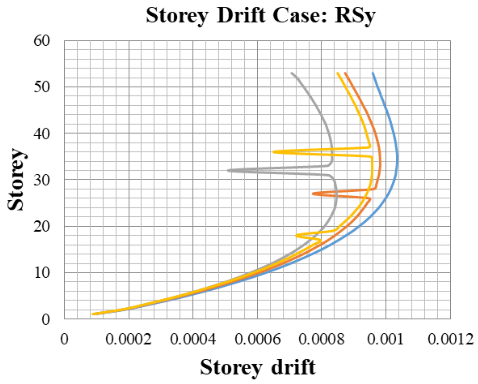


Chart - 3 Storey drift variation using Response Spectrum method (RS) along X and Y directions

5. CONCLUSION

The work in this research has analyzed the effect of outriggers in various configurations on the displacement and drift of tall buildings in particular the linear analysis was done using the equivalent static method and response spectrum method in ETABS software. It is seen that outriggers significantly reduce the maximum displacement and storey drift in the structure. In particular, the two outrigger with belt truss combination performed the best offering maximum of 18% reduction in top storey displacement and 27% reduction of top storey drift compared to bare frame model.

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REFERENCES

[1] Akash Kala, MadhuriMangulkar, Indrajeet Jain, “Optimum Position of Outrigger with belt truss in tall building under horizontal load” International Conference on Advances in Civil Engineering, February 2016.

[2] AkshayKhanorkar, ShrutiSukhdeve, S.V. Denge, S.P. Raut, “Outrigger and Belt Truss System for Tall Building to Control Deflection: A Review” GRD Journals- Global Research and Development Journal for Engineering, May 2016.

[3] M.R. Suresh, Pradeep K.M., “Influence Of Outrigger System in RC Structures for Different Seismic Zones”, IJSRD - International Journal for Scientific Research & Development, May 2015.

[4] MohdAbdusSattar, SanjeevRao, Madan Mohan, DR. Sreenatha Reddy,“Deflection Control in High Rise Building Using Belt Truss and Outrigger Systems”, International Journal of Applied Sciences, Engineering and Management, November 2014.

[5] Kiran Kamath, Avinash A. R., SandeshUpadhyaya K., “A Study on the performance of multi-outrigger structure subjected to Seismic loads”, IOSR Journal of Mechanical and Civil Engineering, 2014.

[6] Dr. K. S. Sathyanarayanan, A. Vijay and S. Balachandar, “Feasibility Studies on the Use of Outrigger System for RC Core Frames” IJAITI,May 2012.

[7] IS 1893 (Part-1) - 2002,"criteria for earthquake resistant design of structures"

[8] IS 875 (Part-3) - 1987,"criteria for wind resistant design of structures"

[9] IS 456-2000,"Plain and Reinforced concrete"