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Optimum Position of Multi Outrigger Belt Truss in Tall Buildings Subjected to Earthquake and Wind Load

A S JAGADHEESWARI AND C FREEDA CHRISTY
School of Civil Engineering, Karunya University Coimbatore, Tamil Nadu, India
Email: *jagakec@gmail.com*

Abstract: This present study is focused on the performance of multi-outrigger structural system for a 40 storey building. Static and dynamic analysis of various models were examined using SAP2000 software for concrete outrigger with central shear wall, without outrigger and outrigger bracing with belt truss. The performance analysis of the tall building for different models are performed to find the optimum position of outrigger system and belt truss by using lateral loads. Time history analysis for ground motion data of the 40 storey building model are carried out. The analysis includes Lateral displacement; storey drift and base shear for static and dynamic loading. From the obtained results the effective performance of building with outriggers are evaluated.

Keywords: *Tall buildings, seismic load, and outrigger braced truss, Dynamic analysis*

1. Introduction

The development in tall buildings has rapidly increased in the recent years. Populations from rural areas are migrating in large numbers to metro cities in search of jobs and day today facilities. Due to this, metro cities are getting densely populated day by day in the recent years. As population is getting denser the availability of land is diminishing and cost is also increasing. Hence to overcome these problems multi-storey buildings is most prominent and efficient solution. In developing country like India and increased number of population, the multi-storey building is a suitable option. Many numbers of multi-storey buildings have come up in India. Conventionally tall buildings are built for the function of commercial office buildings, hotels, and shopping malls, suburban. Development in tall buildings involves various compound aspects for example money matters, requirements, technology, construction regularities etc. The challenges are more for the designer as the height of the building and building plan becomes complex. Tall buildings cannot be designed without taking into account the detailed tolerant of denoting factors that affect for the selection of structural system. Self-weight of the building, live load acting, and earthquake loads and along with wind forces are significant factors and play major role in the design. There will be adequate increase in stress, strain, deflection, lateral displacement and deformation of the building, which hence ultimately increases the cost of construction due to the size and structure of the elements used for the construction.

The development of tall building has always increased from the ancient times. From the past, tall structures have always seen as a symbolic example of power and development. The challenging task in the construction field is to assemble the tall building. The design of tall building is based on analysis of models with experience and fundamental mechanics. As the height of the building increases the risk of horizontal and vertical load forces also increases. The moment resisting frames and braced core at certain height becomes inefficient to provide stiffness against wind and seismic loads. The lateral deflections due this load should be prevented for both structural and non-structural damage to achieve the building strength and also stiffness against lateral loads in the analysis and design of tall building.

1.1 Structural Behaviour of Frames and Shear Walls

The moment resisting frames are constituted by beams and columns devised to absorb the loads coming from the slab [1]. The latter is usually outlined as a horizontal rigid diaphragm which transfers vertical and lateral loads to the structural skeleton. In the absence of specific bracings, all the horizontal stiffness is based on the flexural and shear resistance of the network of beams and columns, and the joints designed as perfectly rigid as shown in Figure 1.

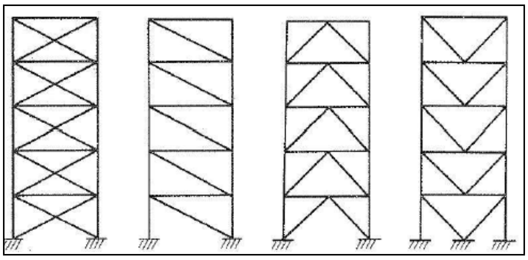

Figure 1 *Different types of Braced Frame*

1.2 Structural Behaviour of Outrigger

In modern tall buildings, lateral loads induced by wind or earthquake forces are often resisted by a system of outriggers. The outrigger structural system is one of the horizontal load resisting systems. An outrigger is a stiff beam that connects the shear walls to exterior columns. In outrigger structural system the belt truss ties all the external columns on the periphery of the structure and the outrigger connect these belt trusses to the central core of the structure thus restraining the exterior columns from rotation. When the structure is subjected to lateral forces, the outrigger and the columns resist the rotation of the core and thus significantly reduce the lateral deflection and base moment [2]. To increase stiffness action against wind and seismic load outriggers are provided by the shear core with exterior frames in tall buildings. The effective depth of the structure is increased, when the outriggers are placed. The primary purpose of the structural system is to effectively transfer the gravity loads without causing damage to the buildings. The gravity loads are mainly dead load, live load and snow load which affect the tall buildings [3]. Apart from these loads the building is also subjected to horizontal lateral loading caused by the action of wind and earthquake forces. These lateral loads leads to huge damage to tall building by producing high stresses by causing vibration or sway movement. Therefore it becomes important that the tall buildings should be provided by necessary strength by installing these structural systems. The system is very effective to resist the lateral loads. As the concept of outrigger and bracings are combined it decreases the bending moment in beams and shear forces in columns by increasing the column axial compression [4]. The structure consists of central core comprises shear wall with horizontal girders or cantilever type trusses called outriggers made up of steel bracing, connecting to the outer columns of building as shown in Figure 2.

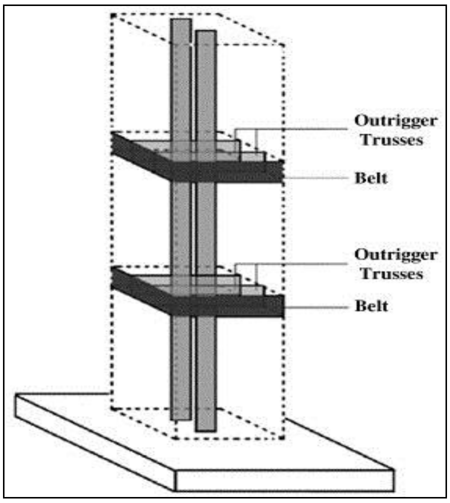

Figure 2 *Outrigger Braced Structure with central core*

2. Modelling and Analysis

In the present study a three-dimensional 40 storey building with 3 bays along x direction and 3 bays along y direction. The typical storey height is 3.5m and total height of 140m. The beams, columns, shear walls are assumed as concrete structure. The Column and beam sizes considered in the analysis are 0.7m x0.7m and 0.45m x 0.7m respectively. Core shear wall thickness is 0.35m which is modeled as shell thin and slab thickness is 0.2m, which is modeled as membrane. The height of the one storey is the depth for the outrigger beam. The size of outrigger is 0.45m x 3.5m. For belt truss and outrigger bracing ISLB250 structural steel is considered. The shape of outrigger bracing and belt truss is X-shaped .A total of 9 different arrangements of outriggers by varying H_s/H ratio has been modeled and analyzed using SAP2000 software.

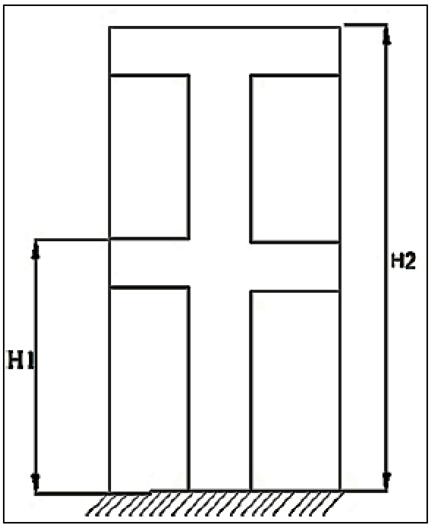

Figure 3 *Outrigger with central core wall*

2.1 Different Arrangements of Outrigger

The Following 9 models are modelled and studied at different location of outrigger is given below.

1) Structural Model without Outrigger
   I. By keeping H2=H constant that is one outrigger at 40th storey is fixed and H1 is varied.
2) Structural Model with 1st Outrigger at 6th storey and 2nd outrigger at 40th storey.
3) Structural Model with 1st Outrigger at 10th storey and 2nd outrigger at 40th storey.
4) Structural Model with 1st Outrigger at 16th storey and 2nd outrigger at 40th storey.
5) Structural Model with 1st Outrigger at 20th storey and 2nd outrigger at 40th storey.
   II. By keeping H1=H/2 constant that is one outrigger at 20th storey is fixed and H2 is varied.
6) Structural Model with 1st Outrigger at 20th storey and 2nd outrigger at 20th storey.
7) Structural Model with 1st Outrigger at 26th storey and 2nd outrigger at 20th storey.
8) Structural Model with 1st Outrigger at 30th storey and 2nd outrigger at 20th storey.
9) Structural Model with 1st Outrigger at 36th storey and 2nd outrigger at 20th storey.

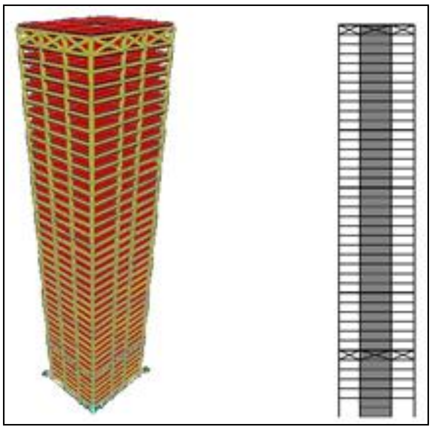

Figure 4 *Structural Model with Outrigger at H/H1=6.67*

2.2 Load Consideration and Analysis

For static behavior purpose, the live load of the building is considered as 3 KN/m^2 and Floor finish load as 1.5 KN/m^2,the analysis has been carried out for lateral wind load was considered conforming to IS-875-Part 3 (1987) and equivalent static analysis for seismic in accordance with IS 1893 (Part-I) 2002.

For dynamic behavior purpose Time History analysis is carried out for historical earthquake time histories. The acceleration time histories were obtained from records of past historical earthquakes occurred in the Nepal region [5].

The structure is assumed to be fixed at the ground level. Analysis is done for different arrangement of outrigger and belt truss and braced outrigger. The depth of the belt-truss is maintained same in outrigger braced structures i.e. height of one storey level [6].

Equivalent static method and Time History method are used in the analysis. The structure is subjected to earthquake and wind load. The design of wind load was calculated as per IS 875 (Part 3) and the lateral seismic load obtained using as per IS 1893 (Part-I) 2002 [7, 8].

3. Results and Discussion

3.1 Maximum Lateral Displacement for Earthquake Load

From the below Figure 5, the maximum lateral displacement for the building without outrigger and with outrigger beam is gradually reduced for H2/H1=1.3 that is first outrigger at 20th and second outrigger at 26th storey. The maximum percentage reduction for the building without outrigger is 15.17% and the maximum lateral displacement is found to be 107.4 mm.Totally 9 different arrangements of models are considered for this analysis. When compared to building without outrigger, the maximum lateral displacement is found to be 126.6 mm for the building subjected to earthquake load at the outrigger position of H1=H/2.

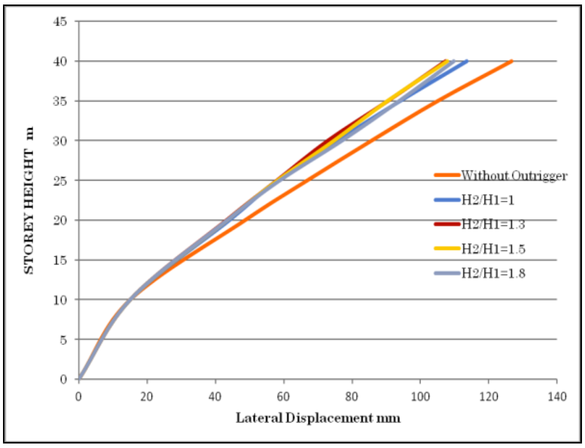

Figure 5 *Lateral displacement of the building for Earthquake load at H1 = H/2*

3.2 For Wind Load

From the Figure 6, it is observed that the maximum lateral displacement due to wind load is found to be 193.5 mm and the maximum percentage reduction is observed to be 15.73 %.The maximum lateral displacement is effectively reduced at outrigger position of H2/H1=1.3 that is one outrigger at 20th and other outrigger at 26th storey. When compared to the building without outrigger, the maximum lateral displacement was observed to be 229.6 mm. The lateral displacement of the building subjected to wind load is at outrigger location of H1=H/2.

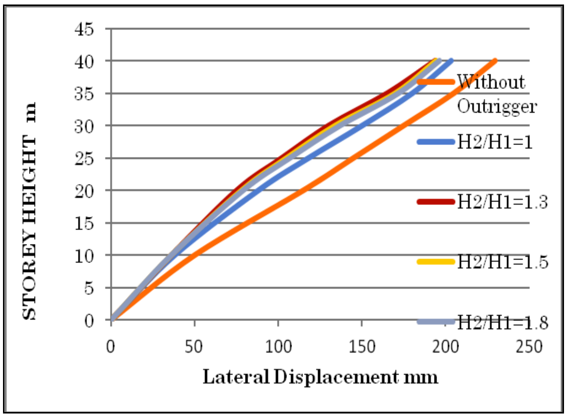

Figure 6 *Lateral displacement of the building for Wind load at H1 = H/2*

3.3 Maximum Storey Drift for the Building Model

From the Figure 7, it is observed that the maximum storey drift for outrigger bracing and belt truss was observed to be 0.00103 and the maximum percentage reduction was observed to be 9.20 %.The maximum storey drift is effectively reduced at outrigger position of H2/H1=1.3 that is one outrigger at 20th and other outrigger at 26th storey. When compared to the building without outrigger, the maximum storey drift was observed to be 0.00113.The maximum storey drift for outrigger bracing and belt truss for the building model at outrigger location of H1=H/2.

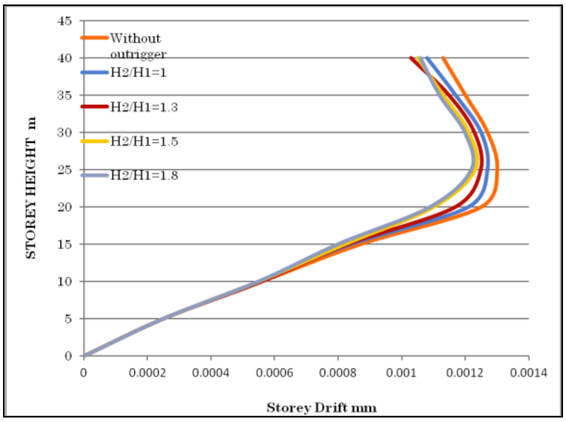

***Figure 7** Maximum storey drift of the building model H2 = H*

Building Model

From the Figure 8, it is observed that the maximum lateral displacement due to time history analysis was observed to be 0.01342 and the results of maximum percentage reduction was observed to be 2.76 %.The maximum lateral displacement is effectively reduced at outrigger position of H2/H1=1.3 that is one outrigger at 20th and other outrigger at 26th storey. When compared to the building without outrigger, the maximum lateral displacement due to time history analysis was found to be 0.0138.The maximum lateral displacement due to time history analysis at outrigger location of H1=H/2.

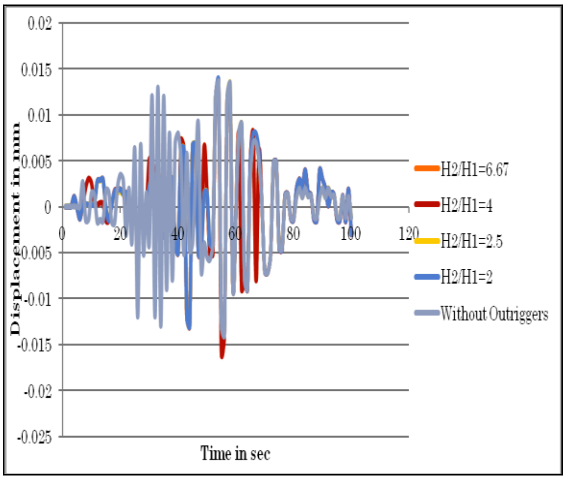

***Figure 9**: Variation in max displacement due to time history*

***Table 1**: Base shear for different outrigger*

SL No	No. of Outrigger	Weight of Building (kN)	Base Shear (kN)
1	Without Outrigger	258899.5	2112.61
2	One Braced Outrigger	258971.5	2113.12
3	Two Braced Outrigger	259043.8	2113.79

3.4 Base Shear of the Building

When compared to one braced outrigger the two braced outrigger gives the maximum base shear 2113.79 kN as shown in Table 1. So using two braced outrigger is more efficient compared to one brace outrigger.

4. Conclusion

Performance of the various models of outrigger position on a tall building is analyzed using SAP2000 software for outrigger with central shear wall, without outrigger and outrigger bracing with belt truss. Time history analysis for ground motion data of the 40 storey building model has been carried out. The analysis includes Lateral displacement; storey drift and base shear for static and dynamic loading. From the obtained results the effective performance of building with outriggers are evaluated and from the obtained results the following conclusions are derived.

The stiffness and stability is increased on using outrigger structural system against lateral load acting such as wind and earthquake loads for the magnitude of 7.8 in zone III, there is reduction in lateral displacement on wind and earthquake loads in both the direction.

On considering lateral displacement for earthquake load there is a reduction about 15.17% in 20th and 26th storey of the building in that location on using outrigger.

On considering lateral displacement for wind load there is a reduction about 15.73% in 20th and 26th storey of the building in that location on using outrigger.

When compared to without outrigger on outrigger bracing with the belt truss there is a reduction of 9.2 % in maximum storey drift on 20th and 26th storey of the building (H2/H1= 1.3).

On considering the time history analysis for the building model, the maximum lateral displacement is at the outrigger position at H2/H1=1.3. The Percentage Reduction is found to be around 2.76.

For the maximum lateral displacement criteria considered so that the optimum location of the outriggers is at mid height i.e. (H1=H/2) for both static and dynamic analysis for the structure.

There is considerable reduction in the lateral deflection, storey drift while adding a multi outrigger system in the structure. The multi outrigger structural systems not only controlling the top displacements but also helps in reducing the inter storey drift.

It is concluded that the 20th and 26th storey (H2/H1=1.3) of the building is considered as the optimum location of the building because overall the maximum displacement is effectively reduced in this location.

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