ISSN: 2278-4632
Vol-10 Issue-5 No. 9 May 2020

Parametric Study on Different Outrigger Truss System for High Rise Structures

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Abstract:

When the height of the building increases, the building should have a good lateral load resisting capacity. There are many methods to incorporate lateral load resisting ability into a structure. One of these methods is an outrigger system. For high-rise buildings, particularly in seismic active zone or wind load dominant, this system can be chosen as an appropriate structure. An outrigger system has two distinct types - conventional and virtual. The conventional outrigger system has a direct connection between the wall and the perimeter columns by using a truss or any other structural member. This paper deals with the efficient use of various outrigger truss system for high-rise concrete building subjected to earthquake load and wind load. 50 storied structure of different outrigger truss configuration are subjected earthquake load and wind load have been analyzed and compared to find the lateral displacement reduction related to different outrigger truss system. In this paper the outrigger system will be provided at top level and top with middle storey height of the building. The parameters under this study are lateral deflection, storey drifts.

Keywords:

Outrigger System, High-rise Structure, Earthquake and Wind Load, Time History Analysis.

1. Introduction

The designing of tall storey structure is commonly regularized by the lateral loads levied on the structure. As structures have turned out to be taller and slenderer, the structural engineer has been progressively tested to satisfy the imposed drift requirements while decreasing the architectural influence of the structure. In reply to this issue, the designers have proposed a huge number of lateral systems that are these days utilized as a part of tall structures over the earth. The main three factors, strength, stiffness (drift) and serviceability (motion perception and accelerations) governs designing of skyscrapers which is developed by the action of lateral force, which includes wind load. The entire geometry of a structure generally determines which factor dominates the overall design. As a structure becomes taller and slenderer, drift considerations become more significant. For successful design for maximum lateral displacement based on permissible stress criteria effective proportioning of member should be done. In the designing of a tall storey structure, several problems emerge such as size and shape of concrete shear wall core or the number of column or even basic properties of the structure itself. So, by setting limits for the building directly defines and resolves unknown variables. However, the geometry of the building inside these basic parameters that distinguishes an efficient design. There are various structural lateral systems used in tall storey structure design such as: shear trusses, shear frames, framed tubes, frames with shear wall core, trussed tubes, super frames etc. Nevertheless, the outrigger system is the one providing significant drift control for the building. Structural design of high-rise structures with the purpose of limiting the drift because of the lateral loads to permissible limits without paying high premium in steel tonnage. The preservation in steel tonnage and cost can be spectacular if specific methods are employed to utilize the full capacities of the structural elements. Several wind bracing techniques have been developed in this regard; one such is an Outrigger System, in which the axial stiffness of the outer columns is utilized for improving the resistance to overturning moments [1]. In the conventional outrigger concept, the outrigger trusses or girders are connected directly to shear walls or braced frames at the core and to columns located outboard of the core.

Typically, (but not necessarily), the columns are at the outer edges of the building. Figure 1 is an idealized section through a tall building with two sets of outrigger trusses, including one at the top. The outrigger trusses in Figure 1 are shown three stories tall, with double diagonals in an "X" configuration. Shallower and deeper trusses have been used, with diagonals of various configurations. The number of outriggers over the height of the building can vary from one or more than one [21].

dimensions had vital impacts on structural heights. Increase of height while keeping the plan dimensions same, leads to the reduction in the lateral rigidity. To achieve required stiffness increase of bracings sizes as well as introduction of additional lateral resisting system such as belt truss and outriggers is required. P.M.B. Raj Kiran Nanduri et al. [5] studied earthquake and wind analysis on 30−storey 3D models of RC building with outrigger and belt truss to find the lateral displacement reduction. Maximum drift at top is 50.6mm, 48.20mm and 47.6mm for core without any outrigger, outrigger with belt truss and outrigger without belt truss. Using second outrigger with cap truss gives the reduction of 18.55% and 23.01% with and without belt truss. The optimum location of second outrigger is at mid height of the building. Tae-Sung Eom et al. [8] derived a new lateral force-resisting structural system for concrete high-rise buildings, distributed belt wall system. Unlike conventional belt structures, the belt walls infilling the space between perimeter columns are distributed separately along the overall building height. In this study, the force transfer mechanism and performance of the distributed belt walls, acting as virtual outriggers under lateral load, are investigated. Osama Ahmed Mohamed et al. [9] studied the outrigger system to mitigate disproportionate collapse in building structures. This paper advocates the use of outrigger system to control lateral drift in a wider class of structures to benefit from the additional advantage of reducing the potential for collapse associated with the loss of one or more perimeter columns. Outcome of this paper is, outrigger system use also be designed to mitigate the disproportionate collapse due to the failure of a primarily load carrying column by redistribute the gravity load. Dongkyu Lee et al. [11] derive the method to decide optimal angle and position of outrigger truss members with respect to general-

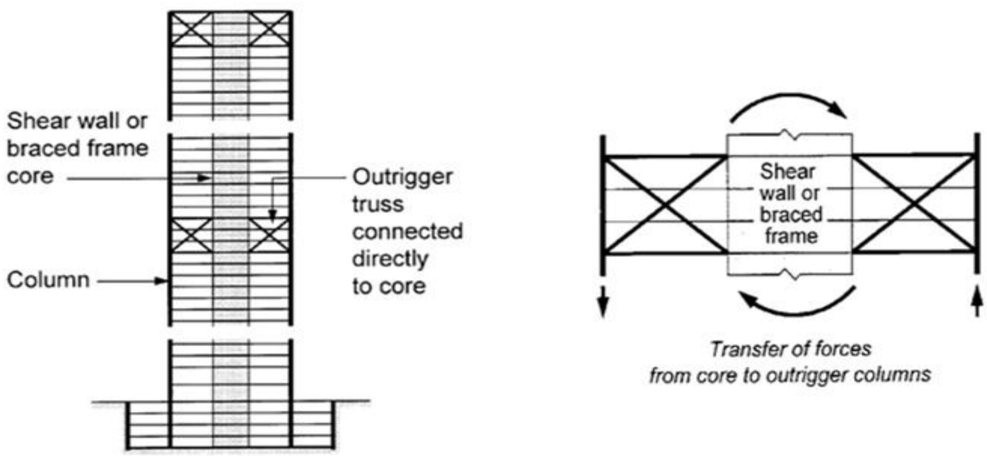

Figure 1 Conventional outrigger concept

M. Samadi et al. [2] determined the effective level of outrigger in preventing collapse of tall buildings by incremental dynamic analysis with an alternative damage measure. This study presents the results of an analytical study on the capability and effective level of outrigger in preventing collapse of tall buildings with braced core system during two sets of far and near field earthquakes. They observed that the strong braces result in collapse of tall building under near-field earthquakes. For the study on outrigger building vertical displacement is a better index for seismic collapse then drift ratio. Two outriggers used one at 2^{nd} story and other at 0.14 height of structure can prevent collapse. Kiran Kamath et al. [3] studied three-dimensional 40 storey RCC building with total height of 140m.They concluded that Lateral displacement is reduced by 37% by providing the outriggers at the top and 61% by providing the outriggers at mid height. there is 34% reduction in displacement at the top due to earthquake loads when the outrigger is placed at the top and 64% when outriggers are placed at the mid height. Shear force variation is negligible due to introduction of outrigger at any level. Peak acceleration is reduced up to 30% by providing the outrigger at top level. S. Fawzia et al. [4] examined the effects of cyclonic wind and provision of outriggers on 28- storey, 42-storey and 57-storey composite building. The results showed that Plan purpose prototype. Optimal connectivity of outrigger members under structural safety is evaluated using Maxwell-Mohr method. S. Fawzia et al. [12] investigates deflection control by effective utilization of belt truss and outrigger system on a 60-storey composite building subjected to wind loads. The analysis is performed with one, two and three outrigger level. The reductions in lateral deflection are 34%, 42% and 51% respectively as compared to a model without any outrigger system. Author showed that the best location for one outrigger option is at level 0.6 times the height of the structure. The best location for second outrigger of two outrigger system is 0.5 times the structure height while one is fixed at the top level. M.R Suresh et al. [13] analyzed 30 storey building with equivalent static method for different seismic zones using finite element software. They researched with provision of the outrigger system at different levels along the height of the building with varying the relative stiffness and represented that the percentage reduction of lateral displacement and inter- Storey drift with respect to base frame varied for different model configuration. Maximum inter-Storey drift was observed at building height in the range of 5 to 15m. Po Seng Kian et al. [14] studied the Use of outrigger and belt truss system for high-rise concrete buildings. In this paper they analyze two dimensional and three-dimensional model of outrigger system under wind load and earthquake load. For the two dimensional 40−storey models, 65% maximum displacement reduction can be achieved by providing first outrigger at the top and second outrigger at the middle of the structure height. For the three dimensional 60−storey structural models subjected to the earthquake load, about 18 % reduction in maximum displacement can be achieved with optimum location of the outrigger truss placed at the top and the 33rd level. Mohsen malekinejad et al. [15] deals with a new and simple mathematical model that may be used to determine natural frequencies and mode shapes of a multistory building that consists of a framed tube, a shear core and multi-outrigger–belt trusses. The effect of outrigger–belt truss and shear core on a framed tube was modeled as a concentrated moment placed at outrigger–belt truss location, which acted in opposite direction of the rotation created by lateral loads. Rabeekafina et al. [16] carried out the approximate analysis of reinforced concrete outriggers which are commonly used in the design and construction of super tall buildings subject to distributed horizontal loads. Two system namely, core-supported-with-outrigger (CSOR) system and less frequent tube-in-tube-with-outrigger (TTOR) system are analyze by Existing global formulae. To verify accuracy of above method compare the results with results of ETABS software of same models. Mehdi babaei [17] studied multi-objective optimization of tall steel frames with belt trusses is investigated to minimize displacement and weight of the structure. Structures with 20, 30, 40, and 50 stories are considered as models. The location and number of trusses and cross section of all structural elements are considered as design variables. After sizing of the structure for a specific topology and shape, weight and displacement of the structure are obtained and plotted in a diagram to illustrate trade-off between two objective functions. Sabrina fawzia et al. [18]are determine the optimum location of steel belt and outrigger systems by using different arrangement of single and double level outrigger for different size, shape and height of composite building. In this study a comprehensive finite element modeling of composite building prototypes is carried out, with three different layouts (Rectangular, Octagonal and L shaped) and for three different storey (28, 42 and 57-storey). Models are analyzed for dynamic cyclonic wind loads with various combinations of steel belt and outrigger bracings. It is concluded that the effectiveness of the single and double level steel belt and outrigger bracing are varied based on their positions for different size, shape and height of composite building. D.H. Lee et al. [19] are studied the seismic performance of twisted outrigger system with 60 stories. The seismic responses of the complex-shaped tall buildings are compared as the twisted angle varies (0°,1.5°,3°). Three prototypes are assumed to be located in high seismicity zone, and in low seismicity zone for other three buildings. In a high seismicity area, it is found that the angle of twist is an important factor that affects story drifts. Y. Zhou et al. [20] are carried out Analysis of high-rise building with energy dissipation story system. Nonlinear time history analyses were performed on a 252m high-rise building model, while displacement, inter-story drift, additional damping ratio and base shears of the building were analyzed in detail. The results show that: Seismic performance of the building with energy-dissipation stories is better than the building with outriggers. The inter-storey drifts of the building with energy-dissipation stories are more uniform than the building with outriggers. Energy-dissipation story system can effectively increase the model additional damping ratios of building, and its effective position is at the middle of the building.

2. Modeling of structures

The structural system of studied models consisted of concrete core with different outriggers in both directions. The plan of structures includes six 7m span in both directions, as shown in Fig. 2. The heights of all stories were taken 3.5 m. All beams are 350mm wide and 600mm deep, Grade 50 concrete is considered (Compressive strength 50 N/mm²) throughout the height of the building. Number of stories considered for all the cases are 50 stories, and roof height is considered as 175m. All columns of 1-

15 storey sizes are considered as 1000 x 1000 mm, columns of 16-30 storey sizes are considered as 900 x 900 mm, columns of 31-40 storey sizes are considered as 700 x 700 mm, columns of 41-50 storey sizes are considered as 600 x 600 mm, and shear wall thickness is considered as 350 mm. The different type of outrigger having X-type truss, N-type truss, V-type truss, K-type truss and concrete beam have been taken. Steel outriggers are of I-section having second moment of area is 753360.8 cm^3. The outrigger system will be provided at top level and top with middle storey height of the building.

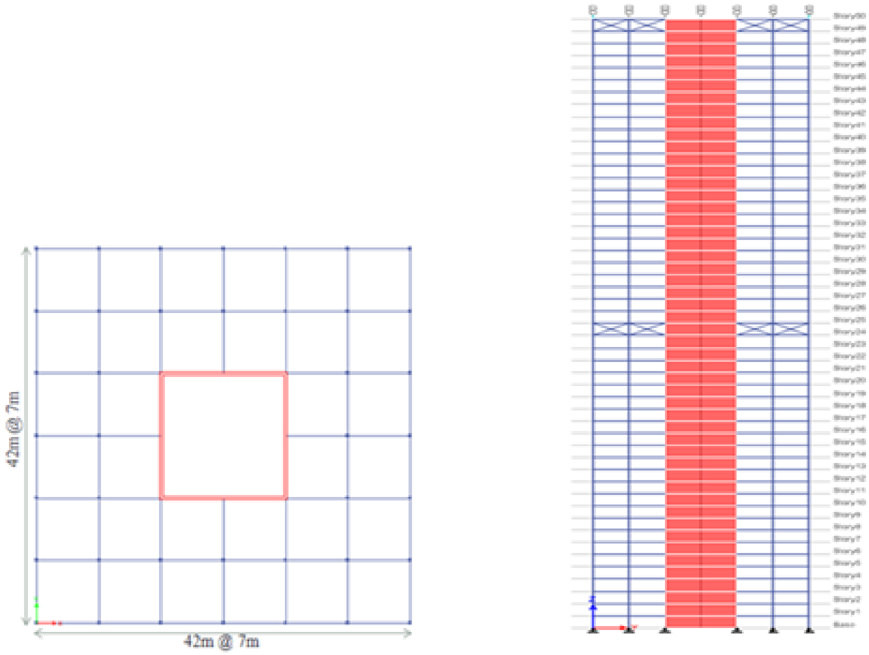

Figure 2 Plan and Elevation of building

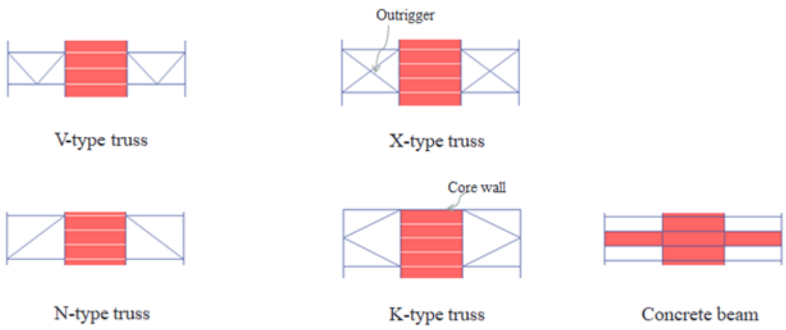

Figure 3 Different outrigger truss systems

2.1 Discription of models

Initially, main building models which did not utilize any outrigger system. Other model having different outrigger truss configuration at different position are listed bellow:

Model 1: without outrigger

Model 2: with outrigger at top storey having X-type truss

Model 3: with outrigger at top storey having N-type truss

Model 4: with outrigger at top storey having V-type truss

Model 5: with outrigger at top storey having K-type truss

Model 6: with concrete beam outrigger at top storey of structure.

Model 7: with outrigger at top and middle storey having X-type truss

Model 8: with outrigger at top and middle storey having N-type truss

Model 9: with outrigger at top and middle storey having V-type truss

Model 10: with outrigger at top and middle storey having K-type truss

Model 11: with concrete beam outrigger at top and middle storey of structure

2.2 Analysis of models

The method of analysis of the structure is based up on the assumptions that the outriggers are rigidly attached to the core. The core is rigidly attached to the foundation. The sectional properties of the core, beams and columns are uniform throughout the height. Tensional effects are not considered. Material behavior is in linear elastic range. The outrigger beams are flexurally rigid and induce only axial forces in the columns. The lateral resistance is provided only by the bending resistance of the core and the tie down action of the exterior columns connected to the outrigger. The rotation of the core due to the shear deformation is negligible.

Since the building is assumed to be a commercial building live load is considered as 3 kN/m². A floor load of 1.5 kN/m² is applied on all the slab panels on all the floors for the floor finishes and the other things.

Wind load in this study is established in accordance with IS 875 (part 3-Wind loads). Wind speed (V_b) is 47 m/s, Terrain category- 3, Risk coefficient(K_1)- 1, Topography factor(K_3)- 1, Windward pressure coefficient- 0.8 and Leeward pressure coefficient- -0.25 are taken.

Earthquake load in this study is established in accordance with IS 1893(part 1)-2002.The city of bhuj falls in "zone 5" (Z=0.36). The importance factor (I) of the building is taken as 1.0. The site is assumed to be medium site (Type II). The response reduction factor R is taken as 5.0 for all frames. Elcentro earthquake data is used for time history analysis.

3. Results and results assessments

3.1 Result of top storey displacement under response spectrum analysis and wind load analysis

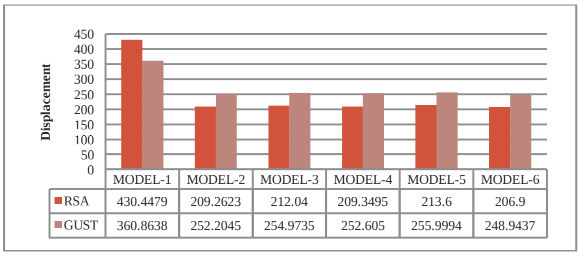

Figure 2 Results of displacement of different outrigger truss system are provided at top storey only under Response Spectrum Analysis and Wind load Analysis

Results assessments

- It is observed that nearly 50% and 30% of top storey displacement is reduced by providing outrigger at top storey only in response spectral analysis and wind analysis respectively.

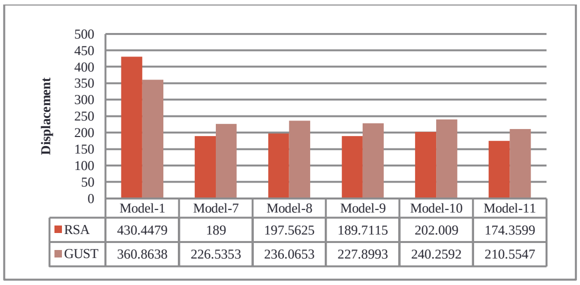

Figure 3 Results of displacement of different outrigger truss are provided at top and middle storey under Response Spectrum Analysis and Wind load Analysis

- It is observed that nearly 55% and 37% of top storey displacement is reduced by providing outrigger at top and middle storey in response spectral analysis and wind analysis respectively.
- It is observed that the X-type, V-type truss and N-type, K-type truss give nearly same reduction in top storey displacement.
- X-type truss is more efficient than K-type truss at top story only and top with middle storeyto reduce displacement by 2.07% and 6.44% respectively.
- It is observed that 52% and 31% of top storey displacement is reduced by providing concrete beam outrigger at top storey only in response spectral analysis and wind analysis respectively.
- It is observed that 59% and 42% of top storey displacement is reduced by providing concrete beam outrigger at top and middle storey in response spectral analysis and wind analysis respectively.

3.2 Results of the storey drifts under the response spectrum analysis and wind load analysis

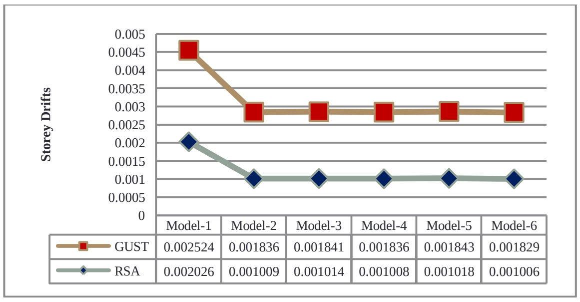

Figure 4 Results of maximum storey drifts of different outrigger truss system are provided at top storey only under Response Spectrum Analysis and Wind load Analysis

Result assessments

- It is observed that nearly 50% and 27% of storey drifts is reduced by providing outrigger at top storey only in response spectral analysis and wind analysis respectively.
- It is observed that nearly 55% and 35% of storey drifts is reduced by providing outrigger at top

and middle storey in response spectral analysis and wind analysis respectively.

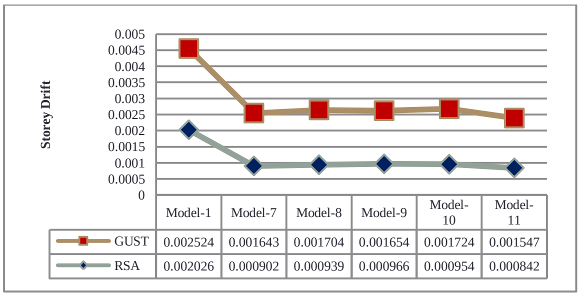

Figure 5 Results of maximum storey drifts of different outrigger truss are provided at top and middle storey under Response Spectrum Analysis and Wind load Analysis

- It is observed that the X-type, V-type truss and N-type, K-type truss give nearly same reduction in storey drifts.
- X-type truss is more efficient than K-type truss at top story only and top with middle storey to reduce storey drift by 1% and 7% respectively.
- It is observed that 50% and 28% of storey drifts is reduced by providing concrete beam outrigger at top storey only in response spectral analysis and wind analysis respectively.
- It is observed that 58% and 39% of storey drifts is reduced by providing concrete beam outrigger at top and middle storey in response spectral analysis and wind analysis respectively.

3.3 Results of pseudo spectral acceleration of structure under time history of elcentro earthquake

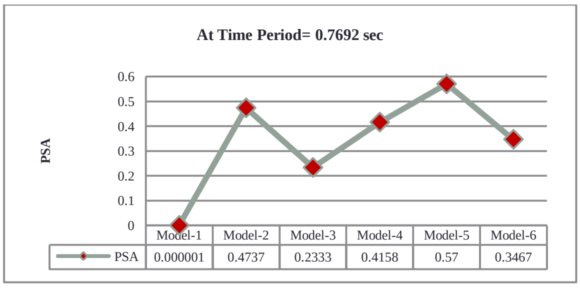

Figure 6: Results of PSA of structure having different outrigger truss are provided at top storey only under Response Spectrum Analysis and Wind load Analysis

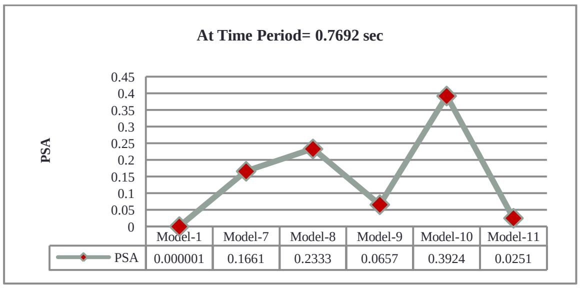

Figure 7 Results of PSA of structure having different outrigger truss are provided at top and middle storey under Response Spectrum Analysis and Wind load Analysis

Result assessments

- It is observed that K-type of truss have more PSA and N-type truss have least PSA by provide outrigger at top storey only.
- It is observed that K-type of truss have more PSA and V-type truss have least PSA by provide outrigger at top and middle storey.
- It is observed that concrete beam outrigger have less PSA than steel truss outrigger.

4. Conclusion

In this paper, results of utilization of the outrigger in tall buildings with concrete core are presented. The structure was designed based on the requirements of IS code. Dynamic analysis of the structures was performed under Earthquake and Wind load. Nonlinear dynamic time history analysis of the structures was performed under the Elcentro Earthquake records.

Following conclusions can be made:

- By providing outrigger in high rise structures, increase the stiffness and reduce the top storey displacement and storey drift under lateral load.
- From the study it can be concluded that wind is a dominating factor and outriggers are effective in reducing wind effect as compared earthquake forces.
- X-type, V-type truss and N-type, K-type truss have nearly same results under lateral load.
- The variation in results of different outrigger truss configuration is more when we can provide outrigger at more than one storey in structure.
- X-type truss system of outrigger is very efficient to reduce the top storey displacement and storey drifts under lateral load than other type of outrigger truss system.
- The K-type truss outrigger has more PSA and V-type truss outrigger have least PSA.
- The steel outriggers are fount least effective compared to concrete beam outrigger. Although steel outriggers can be employed as the light weight substitute for concrete.

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