Influence of Concrete and Steel outrigger and belt truss in high rise Moment Resisting Frames

A SURESH[1] ,B BHANUPRIYA [2], A RAMAKRISHNAIAH [3]

[1]M.Tech(student),Civil Department, BES GROUP OF INSTITUTIONS, Angallu, Andhra Pradesh, India
[2]Assistant professor, Civil Department, KKC INSTITUTETECHNOLOGY , PUTTUR, Andhra Pradesh, India
[3]Associate professor, Civil Department, BES GROUP OF INSTITUTIONS, Angallu , Andhra Pradesh, India

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Abstract - *The outrigger and belt truss 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 44 storey two dimensional models of outrigger and belt truss system are 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 44 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, base shear and fundamental time periods. Loads are considered as per Indian Standards IS: 875(Part1)-1987, IS: 875(Part2)-1987, IS: 875(Part3)-1987 and IS: 1893(Part-1)- 2002. The modeling and analysis were performed using finite element software ETABS 15.2.2.*

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.

Wind and earthquake load plays major impact on building deflection. To overcome lateral load due to earthquake and wind concrete core has been provided at center of building. Concrete core is a very effective and practical structural system which helpful in reducing the deflection due to seismic and wind forces. During recent years, the frame-concrete core wall hybrid structure has been rapidly developed and highly concerned by owners with its performance and economic advantages.

Recently, Outrigger and belt truss system is widely used to reduce lateral drift. To achieve required stiffness of tall building increase of bracings sizes as well as introduction of additional lateral load resisting system such as belt truss and outriggers is required. The placement of outrigger trusses increases the effective depth of the structure and significantly improves the lateral stiffness under lateral load.

OBJECTIVES OF THE STUDY

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- To study the effect of introduction of Outriggers in high rise building subjected to dynamic wind loading.
- To study the influence of core wall and braced core wall with X braced outriggers.
- To study the parameters with different types of Outriggers, i.e. X Bracings and V Bracings and Inverted V Bracing

SCOPE OF PRESENT STUDY

The scope of study is to know the seismic quality and firmness of frame structure which can be efficiently increased using Outriggers and Belt truss System. For Steel framed buildings Steel Outriggers is used to resist seismic forces. There is also provision to use Steel Outriggers for RC frame buildings. This technique aim at evaluating and comparing the storey displacement, storey drift and base shear with different shaped braced outriggers. The present study in turn is useful for various research persons involved in design the tall buildings by using outrigger and belt truss system.

Structure and loading

- The study is analyzed by considering a RC frame building with the effect of Outriggers and belt truss systems.
- Earthquake load and Dynamic Wind load is applied on the RC frame structure.

Preparation and analysis of model

- Equivalent static method, Response spectrum method and Dynamic Wind Analysis are chosen for the analysis of 3D models using E-tabs.
- The Models has been analysis with earthquake& wind forces for x and y direction.

METHODS OF SEISMIC ANALYSIS

The main aim of seismic analysis is to make the building earthquake resistant rather earthquake proof. The building designed for this purpose will resist the actions of ground shaking although the building may get damaged but will not collapse during the severe seismic effects. In the other sense the main objective of earthquake analysis is to evaluate the forces developed, their remedies and to calculate the ability of structure and their elements against these forces. The seismic analysis methods that are adopted are as follows.

i) Linear Methods

a) Linear static analysis (Equivalent static method)
b) Linear dynamic analysis (Response spectrum analysis)

ii) Dynamic Wind Analysis

In this study a 44 storey Moment resisting steel frame building is analyzed by Equivalent static method, Response Spectrum method as well as Dynamic Wind Analysis. The performance of building is noted in terms of lateral displacement, storey drift, base shear and time period for structure.

ANALYTICAL MODELING

Most of the old building structures, which are high, medium to low rise reinforced concrete (RC) frames, were not designed to resist major or moderate earthquakes. The design of such buildings is usually done by using gravity loading without considering the earthquake loads, which makes these building vulnerable during the event of an earthquake. Therefore it is essential to consider the earthquake loads while designing such buildings to mitigate the effects of major earthquake.

In the present study the lateral load analysis for the RC frame building with the provision of introduction of outriggers as per seismic codes for zone V 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. The static and dynamic analysis is carried out using ETABS software.

ASSUMPTIONS FOR ANALYSIS

As mentioned before, the analysis was limited in a two dimensional model. The selected structural scheme under review necessitated some basic assumptions for this kind of structures which were also accounted for this analysis. These assumptions can be categorized into the following main points:

- The analysis and the behavior of the structure are linearly elastic.
- The frame sections of the core, the columns and the outriggers are constant along the height of the building.
- The outriggers are rigidly attached to the core and the core is rigidly attached to the foundation.
- The participation of horizontal members other than the outriggers, such as beams is neglected and therefore not included in the model.
- The sectional properties of the core, columns and outriggers are uniform throughout their height

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 behavior of space frames under static or dynamic loadings, taking into account material inelasticity. The software accepts static loads as well as dynamic loads and has the ability to perform static and dynamic analysis.

MODEL DESCRIPTION

The buildings are modeled as a series of load resisting elements. The lateral loads to be applied on the building are based on the Indian standards. The study is performed for seismic zones V as per IS 1893 (Part1): 2002. The building adopted consists of reinforced concrete and brick masonry elements. The buildings are assumed to be firmly fixed at the bottom storey and the soil structure interaction is neglected. The total height of the building was set to 141.6 m (i.e. 44 storeys) while the plan dimension were set to 35 X 20m. The frame sections were initially designed to satisfy the stress analysis criteria.

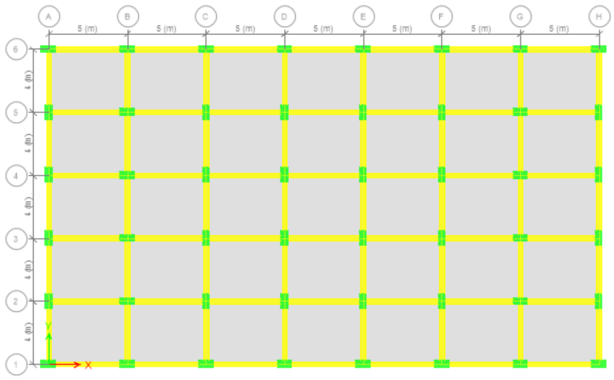


Fig. : Plan layout

Models

The models that were selected for the study are listed as follows,

- Model 1 – A Bare frame model without Outrigger.
- Model 2 – Model with Concrete Core wall and braced Outriggers (X Bracings).
- Model 3 – Model with Concrete core wall and braced Outriggers (V Bracings).
- Model 4 – Model with Concrete Core wall and Braced Outriggers (INVERTED V bracings).
- Model 5 – Model with Braced Concrete Core wall and Braced Outriggers (X Bracings).
- Model 6 – Model with Concrete Core wall and Outriggers with Belt Truss at Periphery (X Bracings).
- Model 7 – Model with Concrete Core wall and Steel Outriggers (X bracings).

Efficiency of Outrigger Structures

Considering the one-outrigger structure with a flexurally rigid outrigger, the maximum efficiency in drift reduction is 87.5%, and the corresponding efficiency in core base moment reduction is 58.3%. For two-,three-, and four-outrigger structure, the respective efficiencies are 95.5%, 70.3%; 97.8%, 77.1%; and 98.5%, 81.3%. Evidently, for structure with very stiff outriggers (i.e. with low values of ω) there is little to be gained in drift control by exceeding four outriggers. The optimum outrigger arrangement for the maximum reduction in the core base moment. For this, the outriggers would have to be lowered toward the base.

Optimum Locations of Outriggers

According to Bryan Stafford Smith[13], the outrigger in a one-outrigger structure should be at approximately half-height, the outrigger in a two-outrigger structure should be approximately one-third and two-thirds heights, in a three outrigger structure they should be at approximately the one-quarter, one-half, and three-quarters heights, and so on to minimize the deflection. Generally, therefore, for the optimum performance of an *n*-Outrigger Structure, the Outriggers should be placed at $(\frac{1}{n+1})$,$(\frac{2}{n+1})$ up to the$(\frac{n}{n+1})$height locations.

Therefore, positions of various Outriggers for all the models are as follows:

1st Outrigger= $\frac{1}{4+1}=\frac{1}{5}= 0.2H$
2nd Outrigger= $\frac{2}{4+1}=\frac{2}{5} = 0.4H$
3rd Outrigger = $\frac{3}{4+1} = \frac{3}{5} = 0.6H$
4th Outrigger = $\frac{4}{4+1}= \frac{4}{5} = 0.8H$

Therefore the outriggers are provided at every 10th storey.

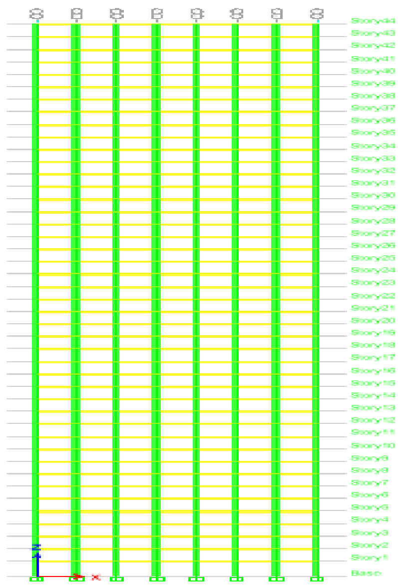


FIG 1: SECTIONAL ELEVATION OF BUILDING MODEL 1(WITHOUT OUTRIGGER)

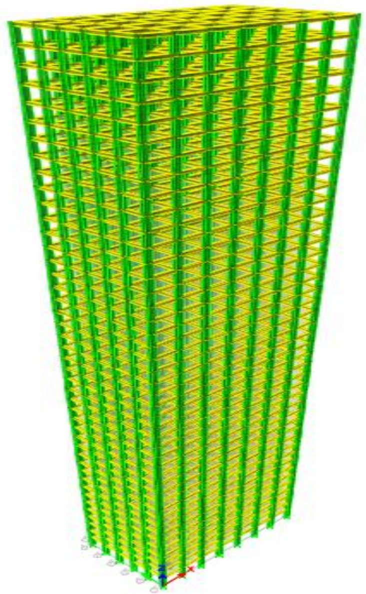


Fig 2: Perspective View Of A Storey At Outrigger Location Madel 2 (With X Outriggers)

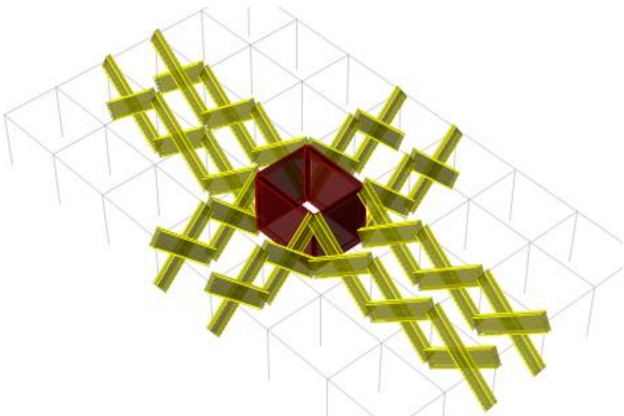


FIG 3: 3D VIEW OF BUILDING MODEL 1(WITHOUT OUTRIGGER)

RESULTS

Base Shear

Base shear can be defined as the maximum lateral force which will occur at base of structure because of seismic ground motion. The base shear for different models of moment resisting RC frame structure for seismic zone 5 in longitudinal and transverse direction by Response Spectrum Method and Dynamic Wind Analysis is found out. These results are compared with the building with different types of braced outriggers. The analysis values are tabulated in table

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

BASE SHEAR (KN)					
Model No.	**Type of Outriggers**	Response Spectrum Analysis		Dynamic Wind Analysis	
		RSA-X	RSA-Y	GUST-X	GUST-Y
1	Without Outrigger	5907.55	5907.37	6306.9	11978.2
2	X	7059.04	6577.12	5682.7	11149.6
3	V	6522.04	6367.43	5919	11489.2
4	Inverted V	6961.71	6506.51	5746.9	11149.6
5	X with Braced Core wall	6446.46	6352.99	5854.8	11450.8
6	X with belt truss	7283.10	6719.10	5725.2	11036.9
7	X Steel Outriggers	6248.86	6227.49	6005.5	11338.1

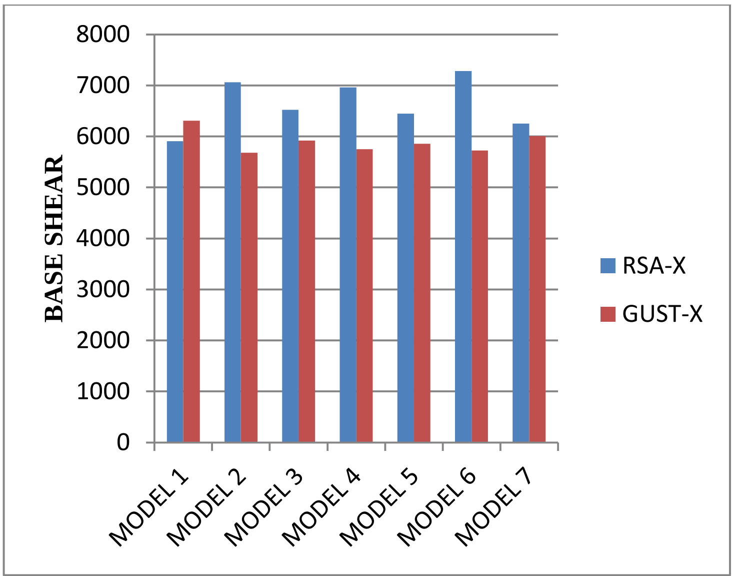


Fig. 6.21: Comparison of Base shear for different models by Response Spectrum Analysis & Dynamic Wind Analysis in Longitudinaldirection

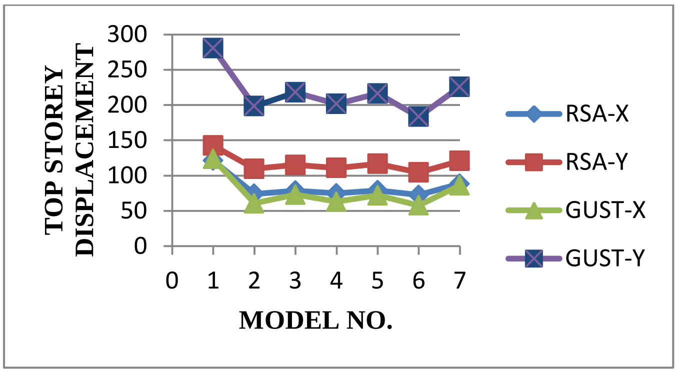
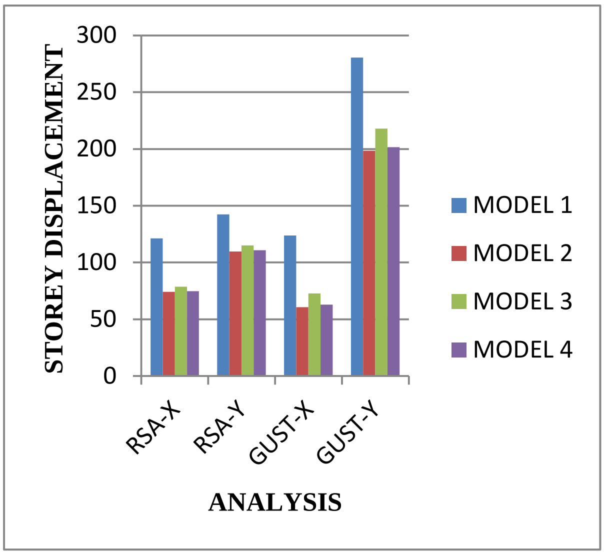


Fig. 6.6: Comparison of Top Storey Displacement by Response Spectrum Analysis and Dynamic Wind Analysis along Longitudinal and Transverse direction



SUMMARY AND CONCLUSION

SUMMARY

1. The model with Steel Outriggers proves to be less efficient in controlling displacement by 19.49% and of storey drift by 17.27%.This observation validates the literature[10].
2. The Outriggers with Belt truss (Model 6) experienced less displacement and controlled lateral displacement by about 34.57% and about 30.75% inter storey drift is controlled.
3. The natural period decreases as the stiffness of the building increases and thereby leading to increase in frequency.
4. The building frame with X-braced Outriggers will have minimum possible lateral displacements in comparison to other shapes of Outriggers.

OBSERVATIONS

1. It is observed that 29.21% of top storey displacement and 26.64% of maximum story drift is controlled by providing X-braced outriggers, 28.1% of top storey displacement and 25.44% of maximum story drift by inverted V-braced Outriggers and 22.32%of top storey displacement and 19.50% of maximum story drift is controlled with V-braced outriggers.
2. Also 8.22% of displacement and 9.64% of storey drift is controlled if braced core wall is employed with X-braced outriggers (Model 5)and is compared with X-braced outriggers (Model 1).
3. The model with Steel Outriggers proves to be less efficient in controlling displacement by 19.49% and of storey drift by 17.27%.This observation validates the literature[10].
4. The Outriggers with Belt truss (Model 6) experienced less displacement and controlled lateral displacement by about 34.57% and about 30.75% inter storey drift is controlled.
5. The natural period decreases as the stiffness of the building increases and thereby leading to increase in frequency.
6. The building frame with X-braced Outriggers will have minimum possible lateral displacements in comparison to other shapes of Outriggers.

CONCLUSIONS

The following Conclusions were drawn based on the Observations made:

1. The X-braced Outriggers is very much effective; as it shows minimum lateral displacement followed by Inverted V-braced Outriggers and V-braced Outriggers.
2. The Outriggers provided with Braced core wall were less effective in reducing lateral displacement compared with Solid Core wall by a small margin, hence it can be employed as the cost effective construction.
3. The Outriggers provided in the interior frames of a building studied are found to be effective as compared to Outriggers provided in the exterior frames i.e. Belt truss.
4. The steel outriggers are found least effective compared to Concrete one. Although Steel outriggers can be employed as the light weight substitute for concrete.
5. 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.

6. Steel Outriggers can be used as an alternative to the other strengthening techniques available as the total weight of the existing building will remain almost same.

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