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# THE USE OF OUTRIGGER AND BELT TRUSS SYSTEM FOR HIGH-RISE CONCRETE BUILDINGS

**A.NARENDRA REDDY,** Email id: narendrareddyarikatla66@gmail.com
**B.ANJANA DEVI**, Email id: anjanadevi2001@gmail.com

CHEBROLU ENGINEERING COLLEGE

**Abstract:** The outrigger and belt truss system is commonly used as one of the structural system 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. The storey structural model 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 20 level.20−storey model, 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 40−storey three dimensional models are subjected to earthquake load, analyzed and compared to find the lateral displacement reduction related to the outrigger and belt system location.

**Key words:** *outrigger, truss, earthquake load.*

## 1. INTRODUCTION

Tall Building has always been a vision of dreams and technical advancement leading to the progress of the world. Presently, with the rapidly increasing urbanization, tall building has become a more convenient option for office and residential housing. Tall buildings are usually designed for Residential, office or commercial use. They are primarily a reaction to the rapid growth of the urban population and the demand by business activities to be as close to each other as possible.

Nowadays, in modern tall buildings, lateral loads induced by wind or earthquake forces are often resisted by a system of multi-outriggers. An outrigger is a stiff beam that connects the shear walls to exterior columns. 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, which would have arisen in a free core. During the last three decades, numerous studies have been carried out on the analysis and behavior of outrigger structures. But this question is remained that how many outriggers system is needed in tall buildings.

Tall building is need of developing scenario. Rapid development of tall building in the world has been creating impact on innovative development of structural system for tall building, result of which buildings are growing taller. There is no specific definition of tall building however Council on Tall Building and Urban Habitat (CTBUH) gives some measures to define tall building . Tall building phenomenon will continue in a greater scale to meet the needs of the growing population in future large cities.

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Recently, belt truss and outrigger 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.

A. Concept of Outrigger

Structurally, the primary structural skeleton of a tall building can be visualized as a vertical cantilever beam with its base fixed in the ground. The structural columns and core walls have to carry all of the gravity load and the lateral wind and earthquake loads. The building must therefore have adequate stiffness to resist the applied lateral shear and bending, in combination with its vertical load-carrying capability. In fact, the increased height of a building will result in an increase in its total structural material consumption. Accordingly, column sizes have to increase down to the base of the building as a result of the accumulated increase in the gravity loads transmitted from the floors above. Furthermore, the core wall needs to be thickened and more heavily reinforced towards the base to resist the lateral loads. The net result is that, as the building becomes taller, the lateral action of the building, such as sway and wind-induced motion, becomes critical. 64 Hence, innovative structural schemes are continuously being sought in the design of high-rise structures with the intention of improving the building performance and reducing the wind drift to acceptable limits. Nowadays, the most commonly used lateralresisting structural systems for reinforced concrete tall buildings included moment resisting frame, shear wall-frame system, shear wall-outrigger-braced system, framed tube system, tube-in-tube system with interior columns and modular tubes system.

Classification of Outrigger structural system:

On the basis of connection to the core there are two types of outrigger truss; Those are Conventional Outrigger system &Virtual Outrigger system

B.Summary

Tall building development has been rapidly increasing worldwide introducing new challenges. As the height of the building increases, the stiffness of the building reduces. The Outrigger and Belt trussed system is the one of the lateral load resisting systems that can provide significant drift control for tall buildings. Thus, to improve the performance of the building under seismic loading, this system can prove to be very effective. The outrigger and belt truss system is commonly used as one of the structural system 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. The objective of this paper is to study, the performance of outrigger structural system in high-rise RC Building subjected to seismic load and Wind Load in 40 storey building with the different plan aspects. Study of the literature is reviewed in this paper on various aspects of outrigger structural system as; Behaviour of

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outrigger structural system in High-Rise RC building, Behaviour of Outrigger structural system in High-Rise Steel and composite Building, Behavior of outrigger structural system in vertically irregular structures and Effect of seismicity on irregular shaped structure.

## 2. OBJECTIVE

An R.C.C. structure is taken into consideration and the analysis is done as per the Indian standards. This building does not represent a particular real structure that has been built or proposed. In this present study a total of four different arrangements of outriggers analyzed using ETABS software are:

1. Structural model of rectangular building with three out riggers at 40 storey's with Equivalent static analysis
2. Structural model of H shaped building with three out riggers at 40 storey's with Equivalent static analysis
3. Structural model of O shaped building with three out riggers at 40 storey's with Equivalent static analysis
4. Structural model of rectangular building with three out riggers at 40 storey's with Response spectrum analysis
5. Structural model of H shaped building with three out riggers at 40 storey's with Response spectrum analysis
6. Structural model of O shaped building with three out riggers at 40 storey's with Response spectrum analysis

## 3. BUILDING DETAILS

| S.No | Structural details | Type of location |
|---|---|---|
| 1 | Utility of Buildings | Office Building |
| 2 | No of Storey | G+40 |
| 3 | Area | 1350 sq.mts |
| 4 | Height of Building | 124 mts |
| 5 | Shape of the Building | Rectangle, H shaped, O shaped building |
| 6 | Types of Walls | SHEAR Wall -230 mm thickness<br>Masonry wall – 230 mm thickness |
| 7 | Geometric Details | |

| | | |
|---|---|---|
| | Ground Floor | 4mtrs |
| | Story to story height | 3mtrs |
| | Beam | 0.550X0.550 mts |
| | Columns (outer) | 0.600X0.80 mts |
| | Columns (Inner) | 0.750X0.750 mts |
| | Slab | 0.150 mts |
| 8 | Materials details<br><br>Concrete grade<br><br>All steel grades | <br><br>M40 (all structural elements)<br><br>FE 415 (all structural elements) |
| 9 | Type of construction | R.C.C Framed structure |
| 10 | Place of construction | Bhuj - Gujarat |
| 11 | Loads considered in Buildings | Dead load, Live load, Earthquake ,Wind load |
| 12 | Wind Speed | 50 m/s (Bhuj wind speed) |
| 13 | Seismic Zone | Zone - V (Bhuj) |
| 14 | Method of analysis | RESPONSE SPECTRUM ANALYSIS<br>EQUIVALENT STATIC ANALYSIS |
| 15 | NON DUCTILE PROPERTIES | 5 (Response reduction factor ) |
| 16 | STATIC COMBINATION USED | 1.2(Dead load+ Live load+ Earthquake in X direction) |

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| | | |
|---|---|---|
| 17 | IS codes used | IS456 :2000,IS1893:2002,IS 16700:2017,IS 875:1987 (Part 1, Part 2, Part 3) |

## 4. RESULTS AND DISCUSSIONS

The seismic analysis of (G+40) of three different shapes of high rise concrete buildings are analyzed by using ETABS software with and without outriggers considering the seismic zone V under medium soil condition and the results are given in following sections. The parameters studied are base shear, torsion, storey drifts and storey displacements.

### A. EQUIVALENT ANALYSIS RESULTS

a. Storey drifts

Storey drift is defined as ratio of displacement of two consecutive floors to height of that floor. Drifts in frame structure are a result of flexure and shear mode contributions. In high rise structures, higher axial forces and deformations in columns and accumulation of their effects over greater heights cause flexure component displacement to become dominant. The buildings are unsymmetrical in shape so drifts considered in both x and y direction.

The storey drifts for the (G+40) of rectangle, H and O shapes buildings in X-direction for seismic zone V are tabulated below and their variations is seen in Fig 6.1

Storey drifts of three different shape buildings when outriggers are placed at (G+14) (G+27) and (G+41) in X-direction

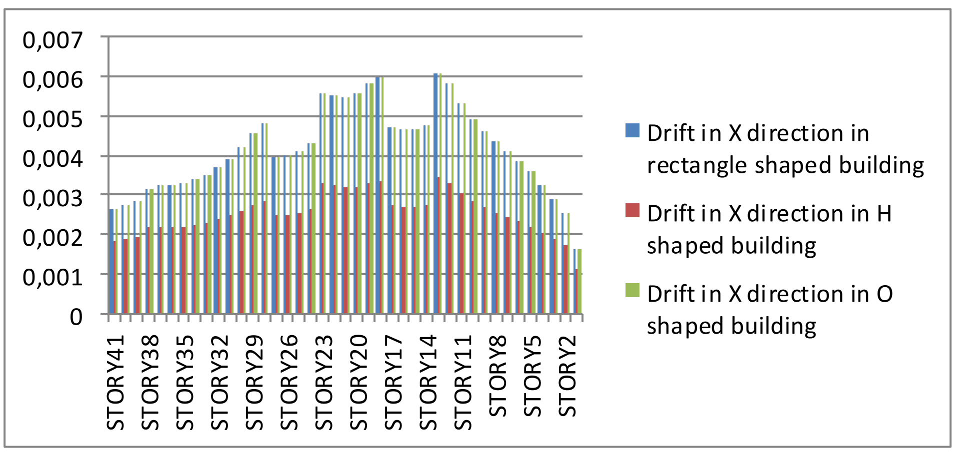


Figure.1 X-drifts of Rectangle, H and O shape buildings

From the figure it is observed that storey drift in X-direction for (G+40) building with outriggers the maximum and minimum storey drift occurs at top and bottom for rectangle shape 0.00266 and 0.00164. Maximum and minimum top and bottom drifts for H shape building 0.00181 and 0.00112. Maximum and minimum storey drift occurs at top and bottom for O shape 0.00266 and 0.0016. Storey drift occurs at middle for rectangle shape is 0.00398, H

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shape is 0.00249 and O shape is 0.00398 of Zone V.

From the figure it is concluded that the storey drift at top for H shape building is 68.04% less than when compared to rectangle and O shape. Similarly at bottom storey drift of H shape building is 68.29% less than when compare to rectangle and O shape buildings. The storey drifts in middle of the H shape building is 62.56% is less than when compare to rectangle and O shape building.

The storey drifts for the (G+40) of rectangle, H and O shapes buildings in Y-direction for seismic zone V are tabulated below and their variations is seen in Fig 6.2

Storey drifts of three different shape buildings without outriggers in X-direction

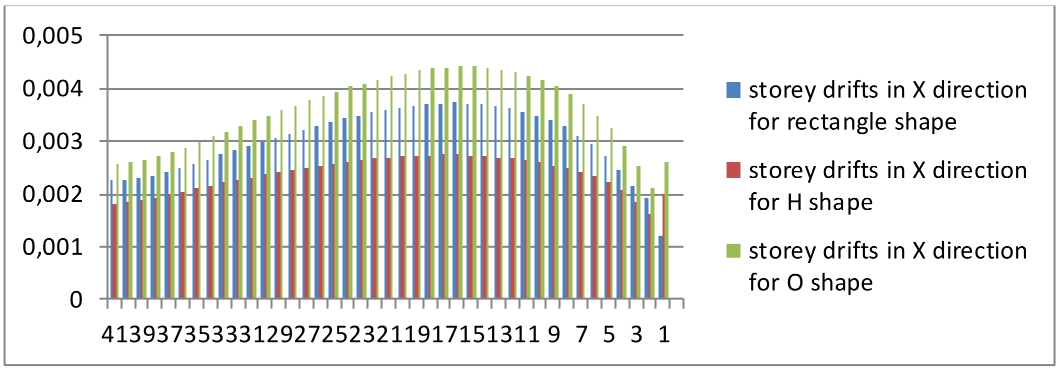


Figure.2 X-drifts for rectangle, H and O shape without outrigger.

From the figure 6.2 it is observed that the top and bottom drift for rectangle shape is 0.00227 and 0.00122 and at middle 0.00322. For H shape top and bottom storey drifts are 0.00183 and 000257 at middle 0.00250. For O shape top and bottom drifts are 0.00257 and 0.00262 at middle 0.00201. It is observed that 25% reduction in H shape building when compare to rectangle and O shape buildings in storey drifts.

Storey drifts of three different shape buildings when outriggers are placed at (G+14) (G+27) and (G+41) in Y direction

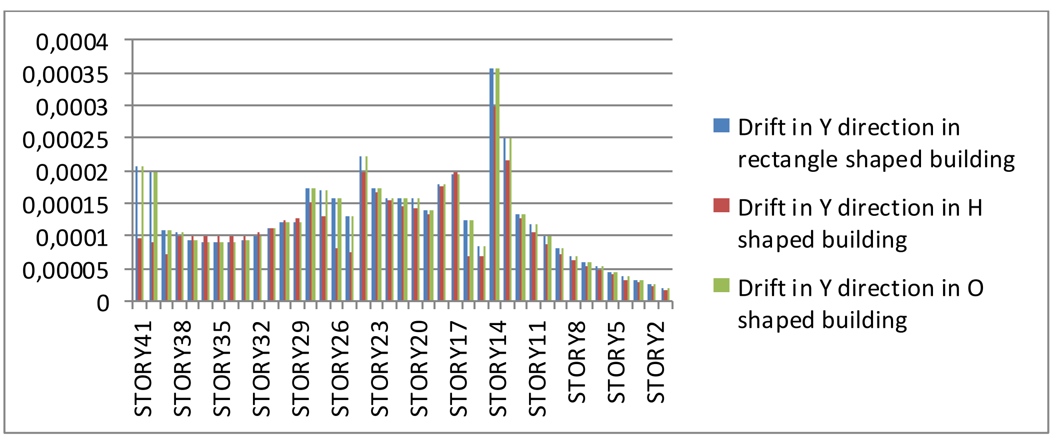


Figure.3 Y-drifts of Rectangle, H and O shape buildings

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From the figure it is observed that storey drift in Y-direction for (G+40) building with outriggers the maximum and minimum storey drift occurs at top and bottom for rectangle shape 0.000206 and 0.000021. Maximum and minimum top and bottom drifts for H shape building 0.000095 and 0.000016. Maximum and minimum storey drift occurs at top and bottom for O shape 0.000206 and 0.000021 middle storey for rectangle is 0.00017, H shape is 0.000131 and O shape is 0.00017 for Zone V.

From the figure it is concluded that the storey drift at top for H shape building is 46.11% less than when compared to rectangle and O shape. Similarly at bottom storey drift of H shape building is 76.19% less than when compare to rectangle and O shape buildings Middle storey drift for H shape building is less than 77.05% when compared to rectangle and O shape building.

Storey drifts of three different shape buildings without outriggers in Y directio

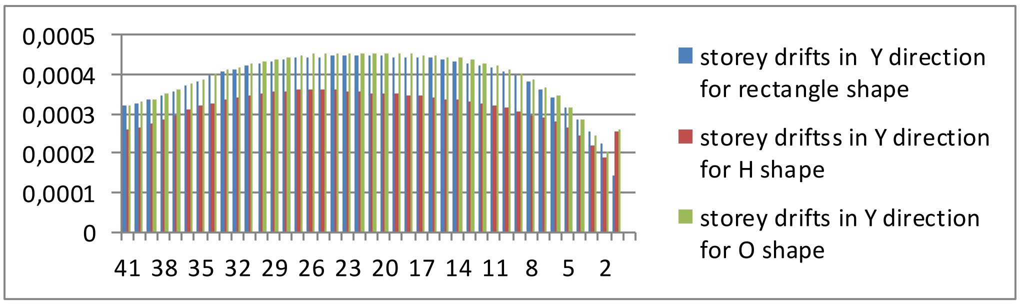


Figure.4 Y drifts for rectangle, H and O shape without outriggers

From the figure observed there is 34% reduction of y drifts in H shape structure when compared to rectangle and O shape structures.

b.Storey displacement

It is the total displacement of the all storey's of building with respect to the ground. In this since the buildings are in unsymmetrical the displacements are considered in two directions (i.e.,) x and y directions. The storey displacements of (G+40) storey building with outriggers in seismic zone V are tabulated below and their variations is seen in Fig 6.5.

Storey displacements of Rectangle, H and O shape (G+40) buildings in X direction (With outriggers)

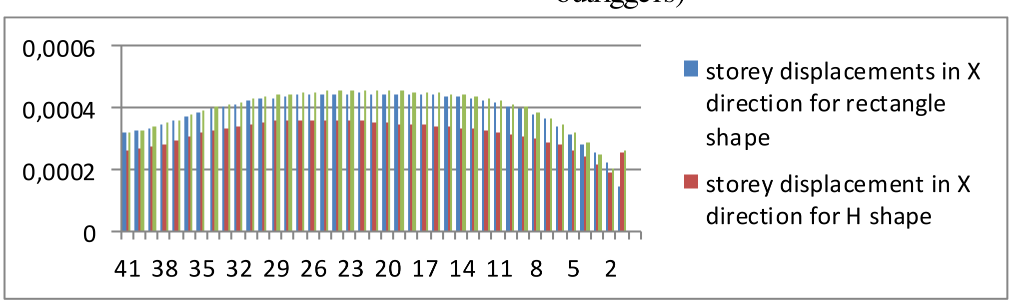


Figure.5 storey displacements with outriggers in X direction

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From the figure it is observed the maximum displacement is 171.47 and minimum is 3.24 in rectangle and O shape buildings and maximum displacement is 104.26 and minimum is 2.89 inH shape building there is 30% reduction in displacements in H shape building when compare to rectangle and o shape buildings.

Storey displacements in X direction without outriggers

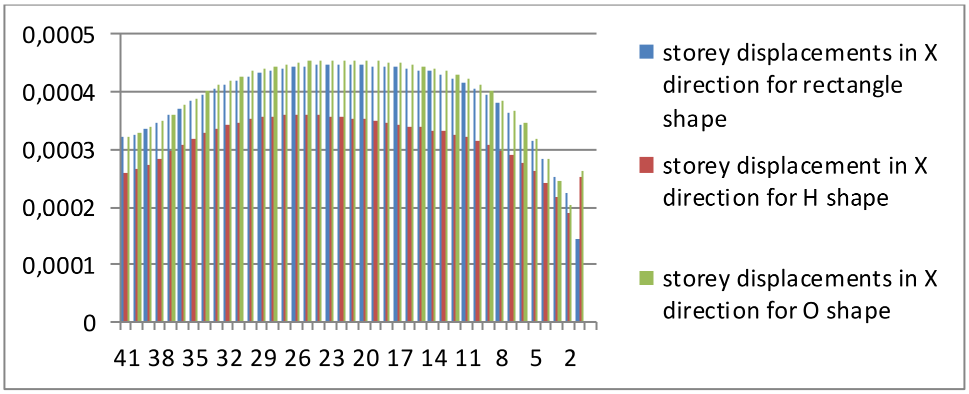


Figure.6 storey displacements in X direction without outriggers

From the figure observed that the maximum displacement is 124.32 and minimum is 1.2 for rectangle shape. For H shape maximum is 97.37 and minimum is 0.2. For O shape maximum is 147.27 and minimum is 4.22. There is 22.7% reduction in H shape building when compared to rectangle shape and 33.89% reduction in H shape when compared O shape building.

d. Torsion

When a building is hit by an earthquake, it is subjected to horizontal force at the floor levels and the whole building is deflected. If the building is regular shaped the deflection is uniform in all the parts of the building. The torsion for (G+40) storey building with outriggers in seismic zone V are tabulated below and their variations is seen in Fig 6.

Torsion for rectangle, H and O shape buildings with outriggers

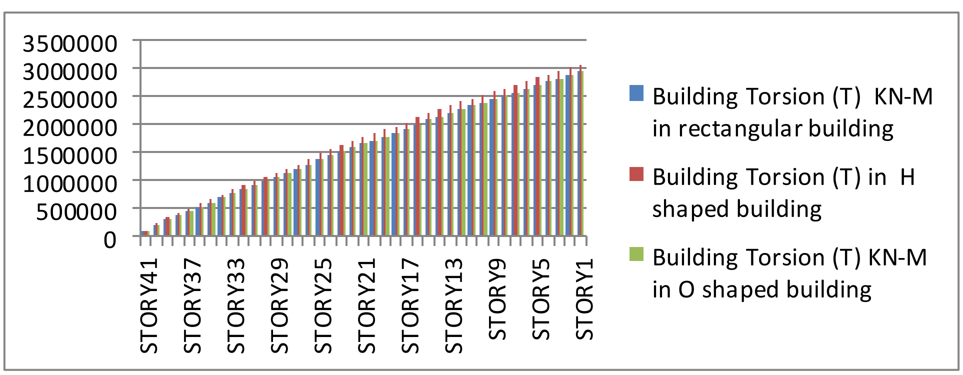


Figure.7 Torsion for rectangle, H and O shape buildings

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From the figure it is concluded the torsion for rectangle building at top and bottom is 2947022 KN and 106915.3 KN. For H shape building top and bottom torsion moment is 3072759KN and 115046 KN. For O shape building top and bottom torsion moment is 106915.3 KN and 2942319.5 KN. At middle the torsion of the rectangle shape building is 1195221KN, for H shape building torsion is 1291171KN and for O building torsion is 1195070 KN.

Torsion for rectangle, H and O shape buildings without outriggers

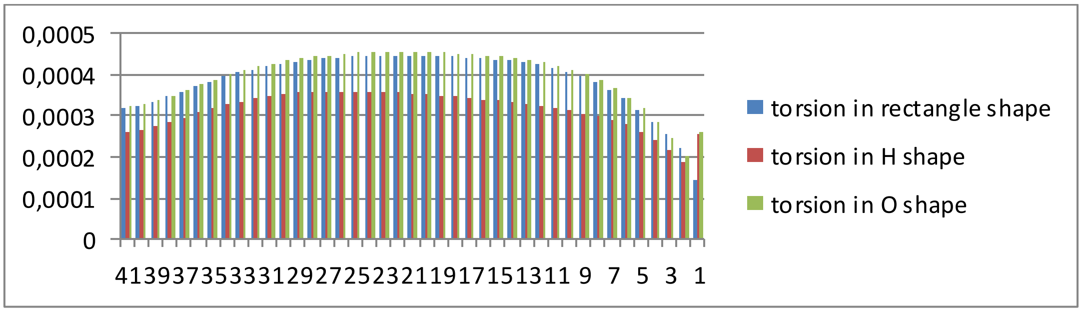


Figure.8 torsion for different buildings without outriggers

e. BASE SHEAR

| SHAPE | BASE SHEAR(KN) WITH OUTRIGGERS | BASE SHEAR(KN) WITHOUT OUTRIGGERS |
|---|---|---|
| RECTANGLE | 38941.5 | 21417.82 |
| H | 40274.23 | 22150.7 |
| O | 38645.5 | 21420.02 |

Table.2 Base shear values

From the table it is observed that the base shear values are increased when outriggers placed and decreased when outriggers are not placed. Due to increase in the base shear the stiffness increases in structures by placing outriggers at different levels.

A. RESPONSE SPECTRUM ANALYSIS RESULTS

The storey drifts for the (G+40) of rectangle, H and O shapes buildings in X-direction for seismic zone V are tabulated below and their variations is seen in Fig 6.

6.1.2.1 Storey drifts of three different shape buildings when outriggers are placed at (G+14) (G+27) and (G+41) in X-direction

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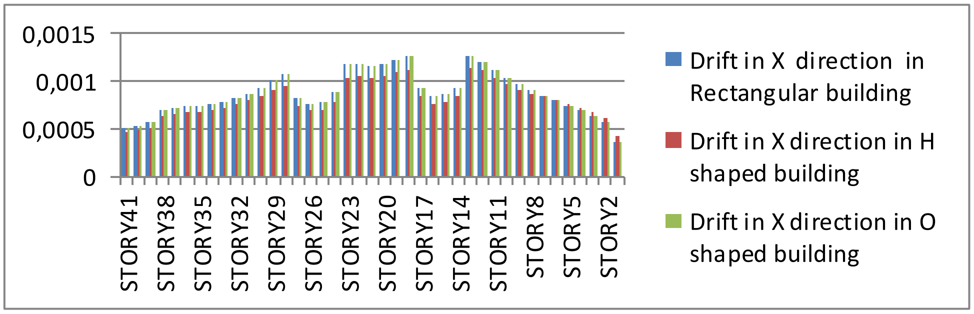


Figure.9 X-drifts of Rectangle, H and O shape buildings

From the figure it is observed that storey drift in X-direction for (G+40) building with outriggers the maximum and minimum storey drift occurs at top and bottom for rectangle shape 0.000518 and 0.00037. Maximum and minimum top and bottom drifts for H shape building 0.000464 and 0.000418. Maximum and minimum storey drift occurs at top and bottom for O shape 0.000518 and 0.00037 for Zone V. At middle storey drift for rectangle shape building is 0.000829, H shape building is 0.000792 and O shape building is 0.000829.

From the figure it is concluded that the storey drift at top for H shape building is 12% increased when compared to rectangle and O shape. Similarly at bottom storey drift of H shape building is 22% decrease than when compare to rectangle and O shape buildings.

At middle storey drift for 11% is less for H shape building when compared to rectangle and O shape buildings.

a. Storey drifts of three different shape buildings without outriggers

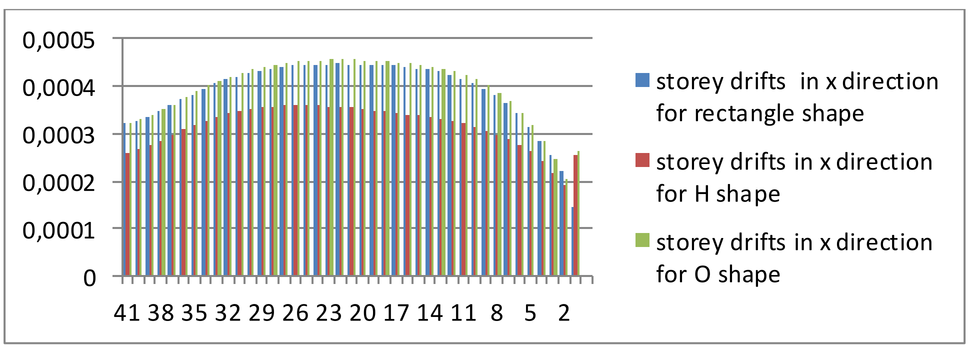


Figure.10 X -drifts of Rectangle, H and O shape buildings without outriggers

From the figure conclude that storey drift in H shape is 22% decreased when compared to rectangle building and 23% decreased when compared to O shape building.

The storey drifts for the (G+40) of rectangle, H and O shapes buildings in Y-direction for seismic zone V are tabulated below and their variations is seen in Fig 6.2

Storey drifts of three different shape buildings when outriggers are placed at (G+14) (G+27) and (G+41) in Y-direction

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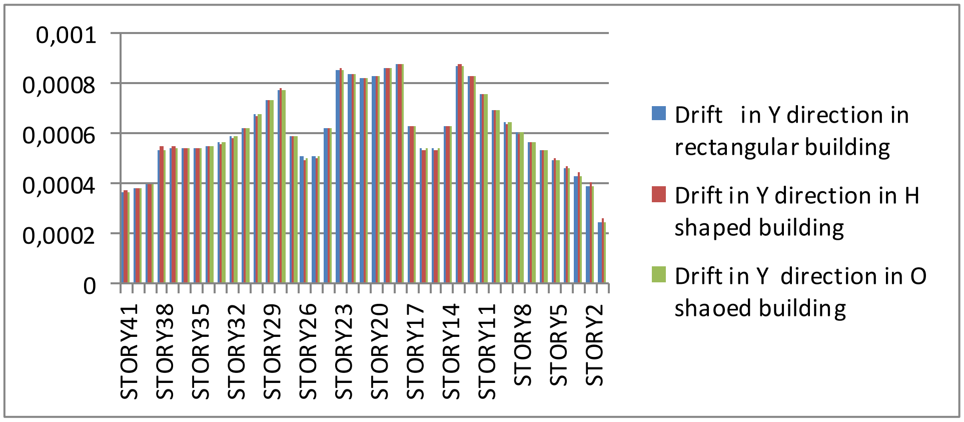


Figure.11Y-drifts of Rectangle, H and O shape buildings

From the figure it is observed that storey drift in Y-direction for (G+40) building with outriggers the maximum and minimum storey drift occurs at top and bottom for rectangle shape 0.000367 and 0.00025. Maximum and minimum top and bottom drifts for H shape building 0.000250 and 0.000262. Maximum and minimum storey drift occurs at top and bottom for O shape 0.000367 and 0.00025 for Zone V.

From the figure it is concluded that the storey drift at top for H shape building is 68.11% less than when compared to rectangle and O shape. Similarly at bottom storey drift of H shape building is 69.86% higher than when compare to rectangle and O shape buildings. Middle storey drift for H shape building is having lesser storey drift when compare to rectangle and O shape buildings.

Storey drifts of three different shape buildings without outriggers

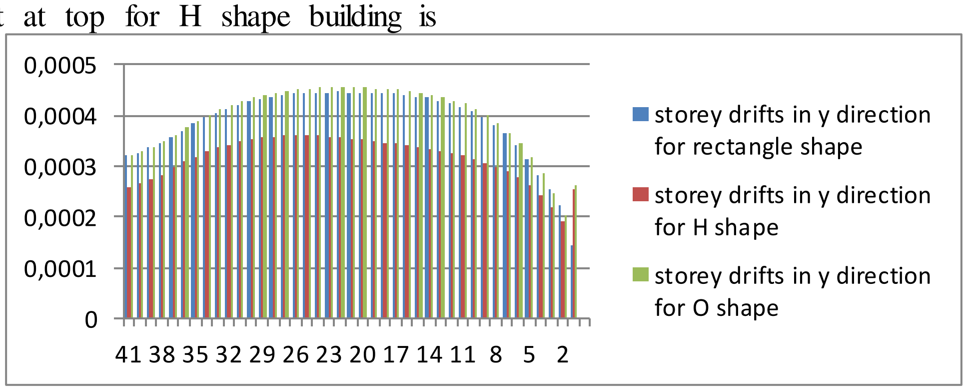


Figure.11 storey drifts in Y direction for without outriggers

From this conclude that the maximum drifts in y direction 23% reduction in drifts compare to rectangle building and 10% increased in H Shape when compared to O shape in top and 10% increase in drifts in y direction in H and O shape when compared to rectangle.

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b. Storey displacements of three different shape buildings with outriggers in X direction

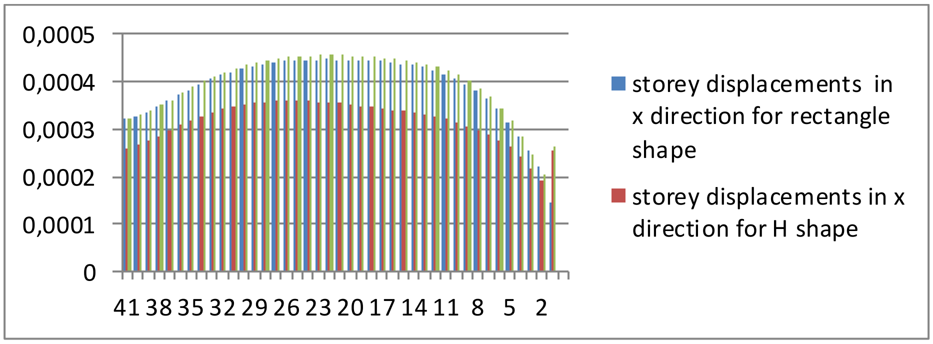


Figure.13 storey displacements in x direction when outriggers placed

From this can conclude that 10% reduction in H shape building when compare to rectangle and O shape buildings when outrigger placed.

Storey displacements of three different shape buildings without outriggers in X direction

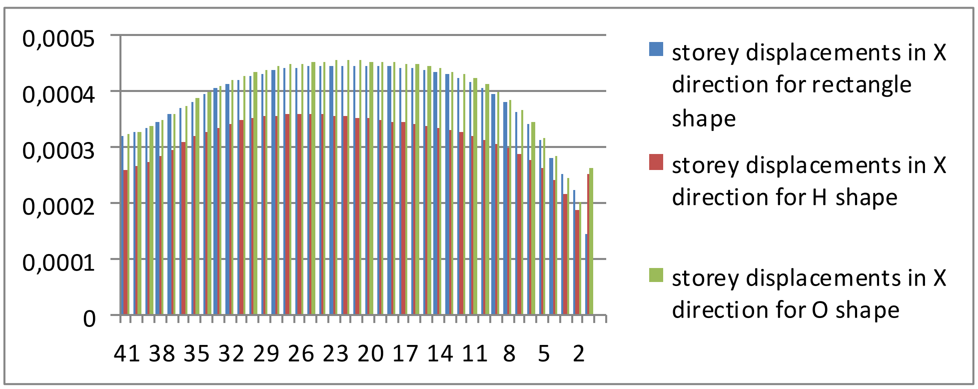


Figure.14 storey displacements without placing outriggers

From the figure can conclude there is maximum displacements occur in the buildings when compare to buildings in which outriggers are placed 15% reduction in the displacements.

d. Torsion for rectangle, H and O shape buildings with outriggers

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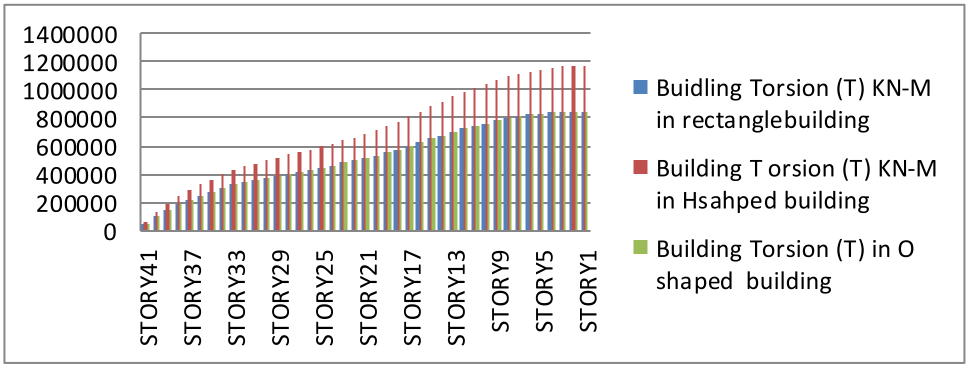


Figure.15 torsion for three buildings when outriggers placed

From the figure it is concluded the torsion for rectangle building at top and bottom is 44114.52KN and 848391.4 KN. For H shape building top and bottom torsion moment is 55940.5 KN and 1172987 KN. For O shape building top and bottom torsion momentis 44114.52 KN and 848391.4 KN.

e. BASE SHEAR

| SHAPE | BASE SHEAR(KN) WITH OUTRIGGERS | BASE SHEAR(KN) WITHOUT OUTRIGGERS |
|---|---|---|
| RECTANGLE | 44011.99 | 27725.54 |
| H | 48797.34 | 32742.32 |
| O | 51619.072 | 30520.01 |

Table.3 Base shear values for three shapes of buildings without outriggers

## 5. CONCLUSION

After performing analysis and studying the results we can come to the below conclusions: The behavior of a formation under earthquake freight is different from earthquake to earthquake. This well-known phenomenon is well presented in the tangential displacement results obtained for both options. The location of the outrigger beam has a critical influence on the tangential behavior of the formation under earthquake freight and the optimum outrigger locations of the edifice must be carefully selected in the edifice design. Comparison drift values both in the equivalent static analysis and response spectrum analysis the drift values show the less values in Rectangle shaped edifice (symmetrical) in static analysis. The response spectrum analysis shows much higher values due to the combination of all forces including static and dynamic freight. Considering the shear force in the both static and response spectrum analysis the static analysis is having the least values in negative as compared to the response spectrum analysis. The edifice minute demonstrates that the minute in response spectrum having less qualities as compared to the static analysis. Considering all the above results and graphs the best reasonable formation is O formed edifice for the unsymmetrical shapes as compared to other edifice H molded edifice both in static and response spectrum technique. The utilization of outrigger and belt truss scheme in elevated formations increase the stiffness and make the anatomical form efficient under tangential burdens. Outrigger scheme is observed to be efficient in controlling the tangential freight s and has proved to be Economical. Considering all the above buildings the most advantage building when compared to the other building's types are H shaped building shows the least displacements, least building moments so the most advantages building is H shaped building. when compared in all seismic zones of India.

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