Comparative Study on RC and Steel Outrigger with Vertical Irregularity Subjected To Lateral Load

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Abstract— The outrigger system has become the one of the most efficient lateral load resisting system in modern tall buildings. By providing the outrigger, the stiffness of the building increases, so that which increases the performance of building under the lateral loads. In the present comparative study the static and dynamic behavior of the reinforced concrete structure for different cases in vertical irregular building 40 storey 3D RC structure is modeled in ETABS software program. In this comparative study mainly the bare frame is compared with RC and Steel outrigger with core for irregular building. Efficiency of the structure measured in terms of lateral displacement, drift, Base shear and time period for different cases of models. Parameter should be in such a way that it should prevent the structural and non-structural damages to the building.

Key words: SDOF, Linear Static Procedures, RC and Steel Outrigger

I. Introduction

Today's increased need for housing in metropolitan cities leads to the emergence of high rise buildings. Tall buildings are becoming more and more slender and this leads to more possible sway during the occurrence of lateral loads. When building height increases tremendously, the structure should have lateral load resisting system other than shear walls for avoiding the effect of these loads, since the shear walls when used alone are suitable only up to 20 stories high. Outrigger systems are one such prominent system and are now considered to be the most popular and efficient because they are easier to build, save on costs and provide good lateral stiffness. Outrigger braced structures is an efficient structural form in which the central core is connected to the outer columns. The structural concept of these systems is that when the central core tries to tilt, its rotation at the outrigger level induces a tension-compression couple in the outer columns acting in opposition to that movement. Most importantly, outrigger braced structures can strengthen building without disturbing its aesthetic appearance and this is a significant advantage over other lateral load resisting systems. Advanced different architectural and structural forms are improved by the finite element approach which implements the development of structural and design software. This made very easy to analyze the structure in accurate way. The fundamental aspect which change the manner of designing the structure are the analyzing the behavior of structure and influence on computing tools. Lateral load imposed on the structure is the important factor in the study of Tall building. Structural Engineer has been facing challenges to access the imposed drift requirements and minimizing the architectural strength of the structure as the building have got taller and taller. In response to this above concept, a large number of lateral resisting schemes are introduced for the tall buildings.

II. Outriggers

From past four decades, Outrigger has been used in the construction industry but it has significance as a structural member from long ago. Sailing ship industry have been used the outrigger from a long back in order to resists wind effect on ships. Outriggers are provided with regard of slender mast. As a resemblance, slender mast is act as core, outriggers are emerging out from the mast like spreaders and exterior columns represent the shrouds or stays. The Structural Design of tall structures should be in such a manner that it should give least lateral drift by using minimum steel tonnage which in turn reduces the cost. In this regard numerous bracing techniques have been introduced in the construction field. Among them outrigger System is the most efficient which increases the stiffness of the building which in turn increases the resistance towards overturning ability of the building.

III. Objectives

- The objective of present study is the use of outrigger in vertical irregular building under earthquake loads.
- Reinforced 40 storey framed structure is considered in this study.
- Both RC and Steel outriggers are considered for this comparative study.
- Parameters kept constant in analytical study are height and Outrigger location for the different cases of building.
- The buildings with and without outrigger are compared.
- The outriggers are introduced at three levels in the building.
- The results of different parameters such as displacement, drift, Base shear and time period are studied.
- The reduction in drift, deflections and fundamental time period of the irregular building are studied.

IV. Methodology and Analysis Method

The analysis procedures can be divided into linear procedures (linear static & linear dynamic) and nonlinear procedures (nonlinear static and nonlinear dynamic). The analysis procedures considered in this study are discussed below.

A. *Linear Static Analysis*

In linear static procedures the building is modeled as an equivalent single-degree of freedom (SDOF) system with a linear static stiffness and an equivalent viscous damping. The seismic input is modeled by an equivalent lateral force with the objective to produce the same stresses and strains as the earthquake it represents. Based on an estimate of the first fundamental frequency of the building using empirical relationships or Rayleigh"s method, the spectral acceleration Sa is determined from the appropriate response spectrum, which, multiplied, by mass of the building M, results in the equivalent lateral force V;

(Design seimic base shear) $V_b = A_h \times W$ (1)

Where, A_h = Design horizontal acceleration spectrum value using the fundamental natural period T in the considered direction of vibration.
W = Seismic weight (mass) of the building.

B. Linear Dynamic Analysis

A response spectrum may be visualized as a graphical representation of the dynamic response of a series of progressively longer cantilever pendulums with increasing natural periods subjected to a common lateral seismic motion of the base. The word spectrum in seismic engineering conveys the idea that the response of buildings having a broad range of periods is summarized in a single graph. For a given earthquake motion and a percentage of critical damping, a typical response spectrum gives a plot of earthquake-related responses such as acceleration, velocity, and deflection for complete range, or spectrum, of building periods The application of linear dynamic analysis is favored due to its ability to explicitly account for the effects of multiple modes of vibration. As a result of recent developments in desktop computing capabilities and seismic analysis software, there has been a shift among practicing engineers toward the routine application of linear dynamic analysis rather than linear static analysis for multistoried buildings.

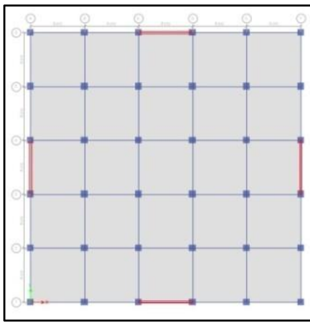
C. Non - Linear Dynamic Analysis

Static procedures are appropriate when higher mode effects are not significant. This is generally true for short, regular building. Therefore, for tall buildings, building with torsional irregularities, nonlinear dynamic analysis is most accurate method to determine the seismic responses of structures. Dynamic response of the structure at each increment of time when its base is subjected to specific ground motion. Alternatively, recorded ground motions database from past natural events can be a reliable source for time histories but they are not recorded in any given site. In this method the structure is subjected to actual ground motion which is the representation of the ground acceleration versus time.

D. Description of the Building Models

The description of each building model is given below as fallows.

1) Model 1: Bare frame model, however masses of brick masonry infill walls are included in the model with Core wall and Vertical Mass Irregularity is added.
2) Model 2: Bare frame model, however masses of brick masonry infill walls are included in the model with Core wall and Concrete X type of Belt Outrigger and Vertical Mass Irregularity is added.
3) Model 3: Bare frame model, however masses of brick masonry infill walls are included in the model with Core wall and Concrete V type of Belt Outrigger and Vertical Mass Irregularity is added.
4) Model 4: Bare frame model, however masses of brick masonry infill walls are included in the model with Core wall and Steel X type of Belt Outrigger and Vertical Mass Irregularity is added.
5) Model 5: Bare frame model, however masses of brick masonry infill walls are included in the model with Core wall and Steel V type of Belt Outrigger and Vertical Mass Irregularity is added.



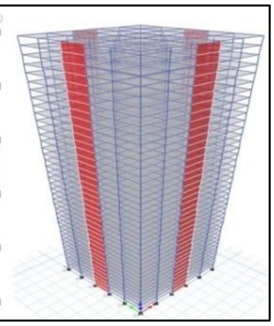
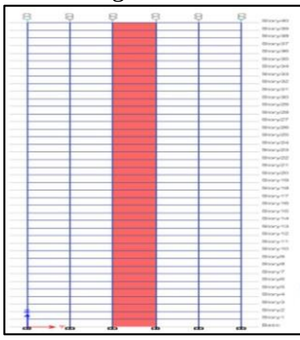


Fig. 1: Plan Fig. 2: Model-1 3D



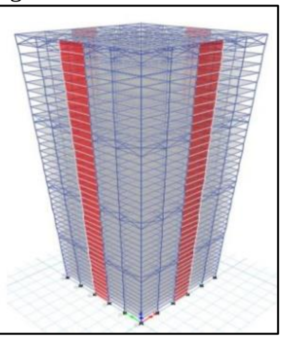


Fig. 3: Model-1 Elevation Fig. 4: Model-2 & Model-4 3D

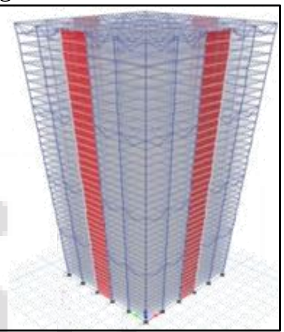


Fig. 5: Model-2 &4 Elevation Fig. 6: Model-3 &5 3D

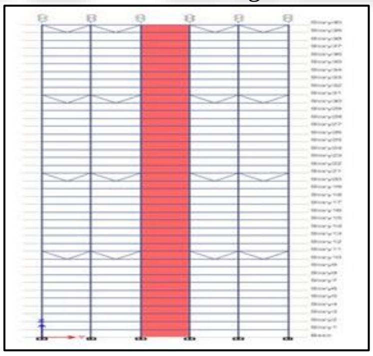


Fig. 7: Model-3 and Model-5 Elevation

V. RESULTS AND DISCUSSIONS

In this chapter, the results of natural period of vibration, base shear, lateral displacements, and storey drifts of different building models are presented and compared. An effort has been made to study the effect of shear wall both at Centre on exterior sides in longitudinal & transverse direction respectively.

A. Time Period

All objects (including buildings and the ground) have a "natural period," or the time it takes to swing back and forth. If you pushed the flag pole it would sway at its natural period. As seismic waves move through the ground, the ground also moves at its natural period. This can become a problem if the period of the ground is the same as that of a building on the ground.

Model	Time Period
Model 1	4.632
Model 2	3.712
Model 3	3.71
Model 4	4.265
Model 5	4.301

Table 1: Model v/s Time Period for different models

Table-1 and Fig.-1 shows the time period obtained by ETABS for analysis, time period for Model-1 is compared to models with concrete outriggers i.e. model 2 & 3, and steel outriggers model 4 & 5, time period reduced by 19.86%, and 7.92% respectively.

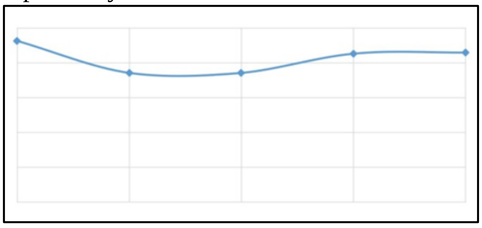


Fig. 8: Time Period v/s Model

B. Storey Drifts

The permissible storey drift according to IS1893(part1)-2002 is limited to 0.004 times the storey height, so that minimum damage would take place during earthquake and pose less psychological fear in the minds of people. The maximum storey drifts for various building models along longitudinal and transverse direction obtained from Non-linear time history analysis from ETABS

From fig. 9 shows the comparison of the drift values of all the model in x-direction and y-direction of all stories by ESA method and Fig 10 shows the comparison of the drift values of all the model in x-direction and y-direction of all stories by Response Spectrum Method. From that it can be seen that the storey drift in all storey for models (with Outrigger) has lower values as compare to that for models (without Outrigger). It can be seen that the model-2 and 3 yields drifts values as compared with the other models. The drift values gradually decrease from storey 1 to 15thstorey in longitudinal direction. Also the drift in both the directions satisfy the permissible drift limit i.e. 0.004*h = 0.004*3.5 = 0.014m

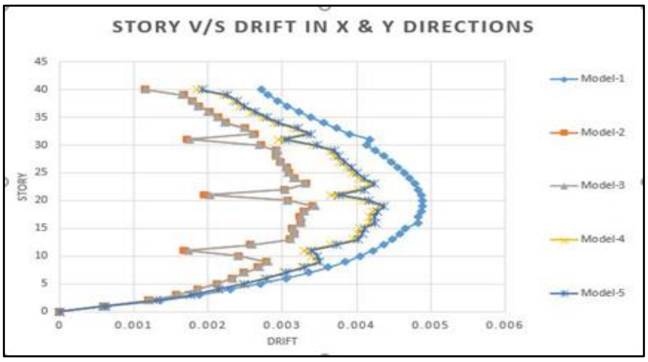


Fig. 9: Storey v/s Drift along X & Y direction by ESA Analysis.

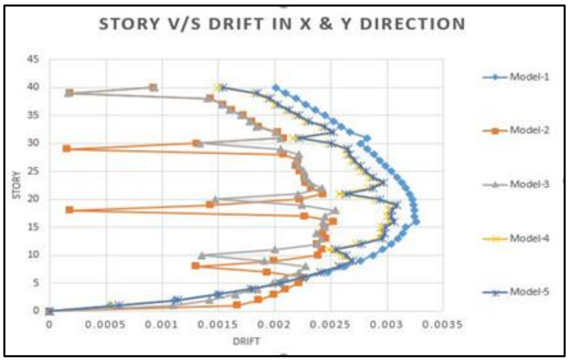


Fig. 10: Storey v/s Drift along X & Y direction by ESA Analysis

C. Storey Displacements

The maximum displacement at each storey with respective to ground level are presented in tables obtained from ESA and Response Spectrum analysis for different models. To understand in a better way, the displacements for each model along the longitudinal direction and transverse direction are plotted in fig. 11 below.

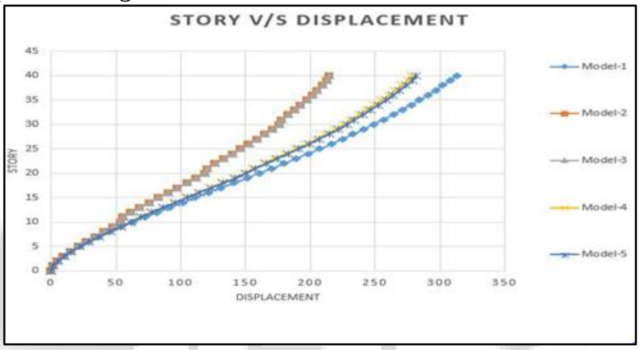


Fig. 11: Storey v/s Displacement along X and Y direction by ESA Analysis

Fig. 11 shows all Model storey displacements. The model-1 bare frame has highest storey displacement values as compared to all other models. The effect of outriggers reduces the displacement values of all models in both x and y direction. Model-2 & 3 shows considerable reduction in storey displacement with use of concrete outriggers and similarly compared with model-4& 5(refer tables and fig.s). Thus it can be concluded that addition of outriggers reduces displacement controlled elements in RC buildings. Therefore, it can be concluded that as far as tall buildings are concerned, different types of Concrete and Steel outriggers can be a good solution to minimize the effect displacement in stories.

D. Seismic Base Shear

Table-2 and Fig.-12 shows comparison of highest values of seismic base shear of different models along X & Y directions by equivalent static analysis and Response Spectrum analysis. Therefore, it has been found that calculation of earthquake forces by considering building by ordinary frame will leads to underestimation of base shear. Table represents the seismic base shear for various models obtained from Equivalent Static Analysis. And Table represents the seismic base shear for various models obtained from Non-Linear Time history Analysis.

Model	Base Shear
1	32946.07
2	34113.29
3	33640

4	32972.29
5	32990.18

Table 5: Base Shear v/s Model by ESA and RSA analysis

From the table-2 it can be seen that the seismic base for all models. Models-2 (shear wall and concrete outriggers) having more base shear compared to model-1 without outriggers system. Model-4 and 5are approximately near values. Form this we can conclude that use of steel outriggers in system cant increase base shear more, compared to model-1.

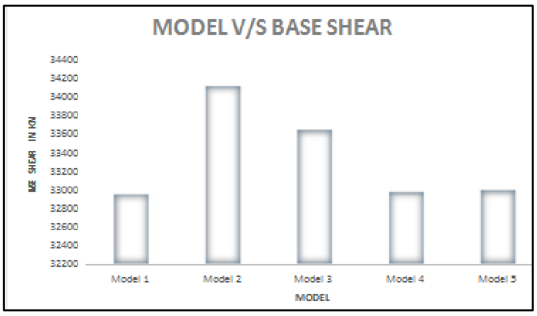


Fig. 12: Base Shear v/s Model along X and Y direction by ESA & RSA Analysis

E. Location of Outrigger

According to Bryan Stafford Smith, for Optimum performance of an n-Outrigger Structure, the Outriggers are placed at 1/ (n+1), 2/ (n+1) up to the n/ (n+1) height locations.

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

- 1st Outrigger = 1/ (4+1) = 1/5= 0.2H
- 2nd Outrigger = 2/ (4+1) = 0.4H
- 3rd Outrigger = 3/ (4+1) = 0.6H
- 4th Outrigger = 4/ (4+1) = 0.8H

Therefore, the outriggers are provided at every 10th storey.

VI. Conclusions

The present work attempts to study the seismic response RC buildings located in seismic Zone-V. In this study all important components of the building that influence the mass, strength, stiffness and deformability of the structure are included in the analytical model. To study the effect of shear-wall and different shapes of concrete and steel outriggers in building models. The fundamental time period, seismic base shear, storey displacement, storey acceleration and storey drifts are compared by performing Equivalent static analysis, and Response spectrum analysis. The study leads to the following conclusions

- Use of concrete outriggers decreases the Time period of structure as compared with use of steel outrigger.
- The storey drift are found within the limits, use of concrete outrigger reduces the drift more than use of steel outrigger in the model.
- The displacement values can reduced by use of concrete core wall with concrete X-type of outrigger.
- Displacement values are decreased more when using concrete outriggers, as compared to steel outrigger.
- Base shear is getting increased when using concrete outriggers as compared with steel outrigger in the model.
- Storey accelerations are increased with respect to weight of the storey decreased so use of concrete outrigger increases the weight of storey and reduces the storey acceleration when compared to steel outrigger in the model.
- So from this research it can be conclude that use of core wall with concrete outriggers can improve or stabilizes the displacement, time period, storey acceleration and drift values of the building when compared with core wall and steel outriggers.

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