Composite Outrigger Structural System for High Rise Buildings

Mohd Minhajuddin Zuhabe[1], MR. Md Parvez Affani[2]
[1]*M.Tech Student, Department of Civil Engineering,*
[2]*Guide, Assistant Professor, Department of Civil Engineering, Global Institute of Engineering and Technology*

Abstract - Today, the outrigger concept is widely applied in tall structure design. According to this design, "outrigger" trusses, or occasionally girders, extend from a core that resists lateral loads to columns outside the structure. Braced frames or shear walls could make up the core. By mobilizing the axial strength and stiffness of outer columns to withstand a portion of the overturning moment caused by lateral loading, outrigger systems can result in a very effective use of structural materials. The goal of this study is to illustrate the impact of outriggers, SMA outrigger systems, and outriggers as BRBs for both regular and irregular high-rise buildings, taking into account geometric irregularities in high-rise constructions when outriggers are positioned at different floors. This section examines a 40-storey reinforced concrete special moment-resistant space frame building that uses nonlinear dynamic analysis to be designed for seismic and gravity loads. The ETABS version 2020 software (CSI Ltd) analytical engine is used to conduct nonlinear time history analysis in order to evaluate the structure in compliance with seismic code IS-1893:2016.

Keywords: Tall buildings, composite outrigger system, SMA, BRB

I.INTRODUCTION

In the past, the development of tall structures has been a major worry. Additionally, the risk of both vertical and horizontal load forces is increased with building height. Above a certain height, an auxiliary system is needed in order for the moment-resisting frames with the braced core to effectively provide rigidity against seismic and wind stresses. To achieve the required strength and stiffness in the structure, the lateral displacement should be controlled during the study and design of a tall building. One of the auxiliary devices that guarantees tall buildings have adequate rigidity is the outrigger system. When the core rotates at the level of the outriggers under high lateral loads, a tension-compression couple occurs in the outer columns. Seismic control methods such as the OUTRIGGER must be used to regulate the structure's response. Consequently, to investigate the structure's post-yield response, a major post-yield analysis—also referred to as a non-linear time history analysis—is necessary. Therefore, this thorough analysis aids in comprehending the effects of real-time earthquake ground acceleration loading on the structure. The present work aims at the following objectives:

• To use non-linear time history analysis to conduct a parametric study by altering the outriggers' bottom, mid, and full height locations in high-rise building models.

• To research various outrigger system kinds, such as BRB and SMA types.

• To compare seismic action outcomes in terms of story displacement, story drift, story stiffness, and period in order to identify the optimal placement of potential outriggers.

II.LITERATURE REVIEW

Gholamreza Abdollahzadeh, Hadi Faghihmaleki, and Reza Alghosi (2022) [2]:The outrigger arm system, combined with a belt truss surrounding a braced core, is recognized as a reliable and efficient solution for high-rise structures subjected to intense lateral forces from earthquakes and wind. This study aims to evaluate the performance of such systems under lateral loads and determine the optimal outrigger location to minimize roof drift and displacement. Nonlinear time-history and spectral analyses were conducted for models with 30, 45, and 60 stories, situated in high seismic risk zones. The proposed method yielded superior results compared to previous approaches, significantly reducing absolute roof displacement and maximum inter-story drift. Additionally, the

optimized outrigger configuration reduced stress concentration in the floors where outriggers were installed, further enhancing performance.

Alaa Habrah and Mustafa Batikha (2022) [3]: The positioning and number of outriggers in a core–outrigger lateral load-resisting system greatly affect both structural performance and cost efficiency in tall buildings. This research derives a general equation to estimate the top lateral displacement for systems with up to four outriggers under various static lateral load distributions (uniform, triangular, and parabolic). The optimal outrigger positions for maximum displacement reduction are identified, and guidelines are proposed for determining the maximum permissible building height based on displacement limits, number of outriggers, and their locations. For practical application, design curves are provided to help allocate displacement targets and outrigger requirements in the early design stages.

Pradeep Gunda and Vimala Anthugar (2022) [4]: The dynamic response of tall buildings under lateral forces is complex and significantly influenced by outrigger placement. This study investigates the optimal height for positioning outriggers without belt trusses across buildings with varying aspect ratios (0.91, 0.61, 0.45, 0.36, and 0.30). Five structural models were designed according to IS 456 and IS 1893 standards, and three-dimensional analyses were performed. Results show that optimal performance in reducing displacement, drift, and overturning moments is achieved when the outrigger is located at 65–80% of the building height for aspect ratios between 0.45 and 0.95.

1. Module And Building Configuration

REGULAR MODEL

Model 1: The first building configuration consists of regular beams, columns, shear core walls, and slabs. The lateral load-resisting system is designed in accordance with IS 1893:2016 and designated as the *regular model* without any outrigger or belt truss elements.

Model 2: The second building incorporates a lateral load-resisting system enhanced with an outrigger and belt truss system integrated with Shape Memory Alloy (SMA). Three configurations are examined:

- Outrigger and belt truss positioned at the 10th story
- Outrigger and belt truss positioned at the 20th story
- Outrigger and belt truss positioned at the 40th story

Model 3: The third building is modeled with a lateral load-resisting system using an outrigger and belt truss integrated with Buckling-Restrained Braces (BRB). The following configurations are considered:

- Outrigger and belt truss positioned at the 10th story
- Outrigger and belt truss positioned at the 20th story
- Outrigger and belt truss positioned at the 40th story

VERTICAL IRREGULAR MODEL

Geometric Irregularity

Model 4: This configuration represents a building with vertical geometric irregularity, comprising beams, columns, shear core walls, and slabs. The lateral load-resisting system follows IS 1893:2016 provisions and is labelled as the *irregular model* without any outrigger or belt truss.

Model 5: The configuration introduces an outrigger and belt truss system with SMA to the vertically irregular building. Three placement scenarios are analyzed:

- Outrigger and belt truss at the 10th story
- Outrigger and belt truss at the 20th story
- Outrigger and belt truss at the 40th story

Model 6: The configuration applies an outrigger and belt truss system with BRB to the vertically irregular building. The same three configurations are investigated:

- Outrigger and belt truss at the 10th story
- Outrigger and belt truss at the 20th story
- Outrigger and belt truss at the 40th story

Geometric + Mass Irregularity

Model 7: This configuration represents a building with both vertical geometric and mass irregularity, comprising beams, columns, shear core walls, and slabs. The lateral load-resisting system is designed in

accordance with IS 1893:2016 and designated as the *irregular model* without any outrigger or belt truss elements.

Model 8: The configuration integrates an outrigger and belt truss system with Shape Memory Alloy (SMA) into the vertically irregular and mass-variant building. Three scenarios are examined:

- Outrigger and belt truss located at the 10th story
- Outrigger and belt truss located at the 20th story
- Outrigger and belt truss located at the 40th story

Model 9: The configuration applies an outrigger and belt truss system with Buckling-Restrained Braces (BRB) to the vertically irregular and mass-variant building. The same three placement scenarios are analyzed:

- Outrigger and belt truss at the 10th story
- Outrigger and belt truss at the 20th story
- Outrigger and belt truss at the 40th story

Geometric + Stiffness Irregularity

Model 10: This model depicts a building with vertical geometric and stiffness irregularity, consisting of beams, columns, shear core walls, and slabs. The lateral load-resisting system follows IS 1893:2016 provisions and is labelled as the *irregular model* without outrigger and belt truss systems.

Model 11: The building is modeled with an outrigger and belt truss system using SMA, placed at three alternative heights:

- Outrigger at the 10th story
- Outrigger at the 20th story
- Outrigger at the 40th story

Model 12: The configuration incorporates an outrigger and belt truss system with BRB into the vertically geometric and stiffness-irregular building, evaluated under the following placement conditions:

- Outrigger at the 10th story
- Outrigger at the 20th story
- Outrigger at the 40th story

Geometric + Stiffness + Mass Irregularity

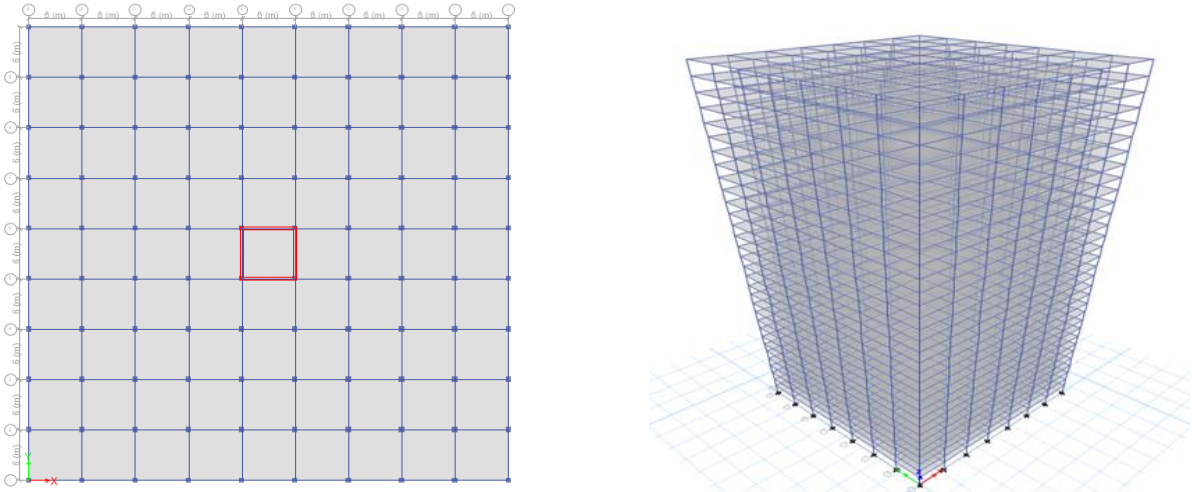
Model 13: This model combines vertical geometric, stiffness, and mass irregularities, with the structural composition including beams, columns, shear core walls, and slabs. The lateral load-resisting system is developed per IS 1893:2016 and identified as the *irregular model* without outrigger and belt truss.

Model 14: The building is enhanced with an outrigger and belt truss system incorporating SMA, tested with three placement options:

- Outrigger at the 10th story
- Outrigger at the 20th story
- Outrigger at the 40th story

Model 15: This configuration applies an outrigger and belt truss system with BRB to the vertically geometric, stiffness, and mass-irregular building, considering the same three placement positions:

- Outrigger at the 10th story
- Outrigger at the 20th story
- Outrigger at the 40th story



Plan & Isometric Views view of normal building without outrigger

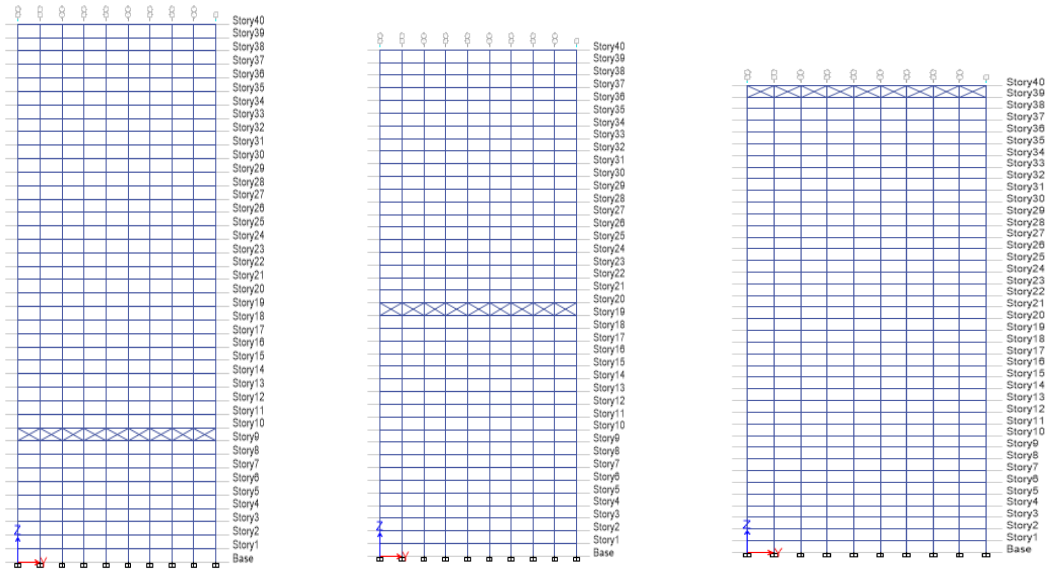


Figure1: outrigger at 10,20 and 40th story

Model 2 VERTICAL IRREGULAR MODEL

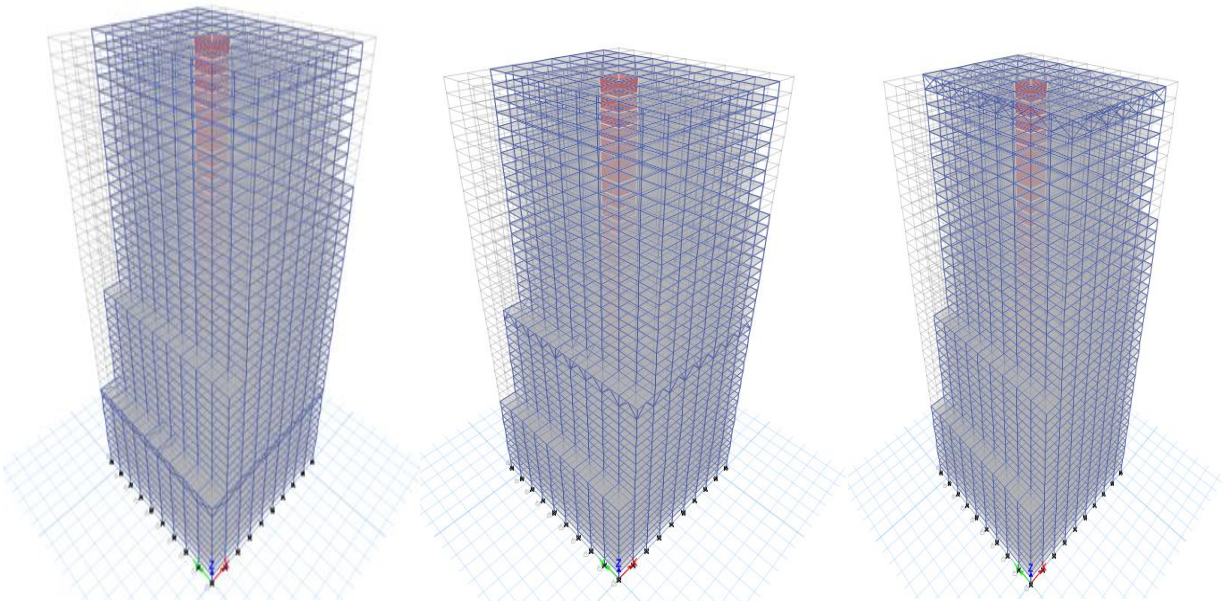


Figure 2: irregular model with outrigger at 40th story

2. RESULTS FOR MODELS

STORY DISPLACEMENT FOR REGULAR MODEL

It is the relative sway of building from its original position which is limited to h/250 which is mentioned in considered, as per IS 16700:2017 Cl 5.4.1 the displacement shall not exceed height of the building/250. When as structure has lesser displacements, its due to the increase in lateral stiffness and higher the lateral stiffness lesser is the damage due to lateral lo ad.

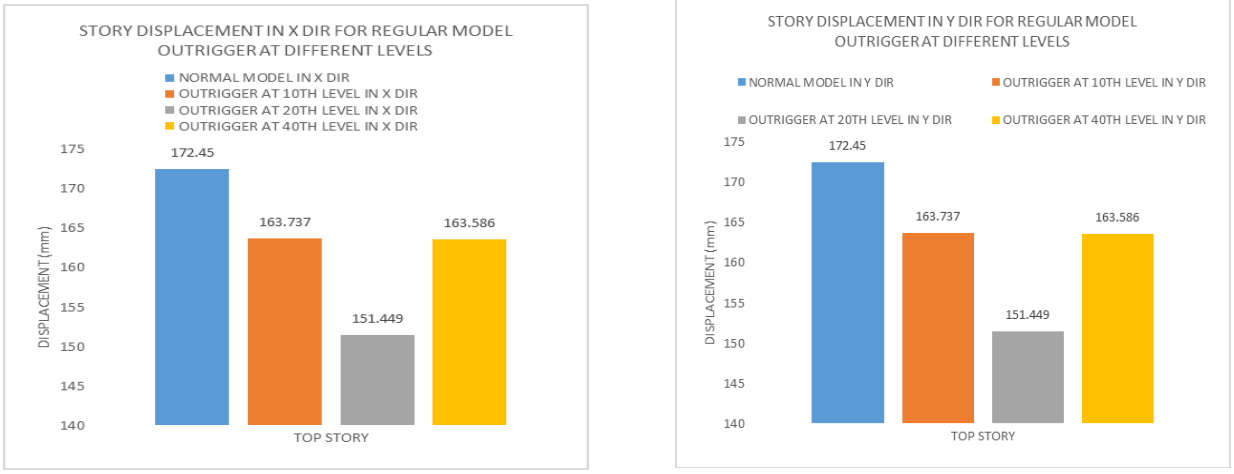


Figure 3: Story Displacement in x & y- dir. for Regular Model with SMA

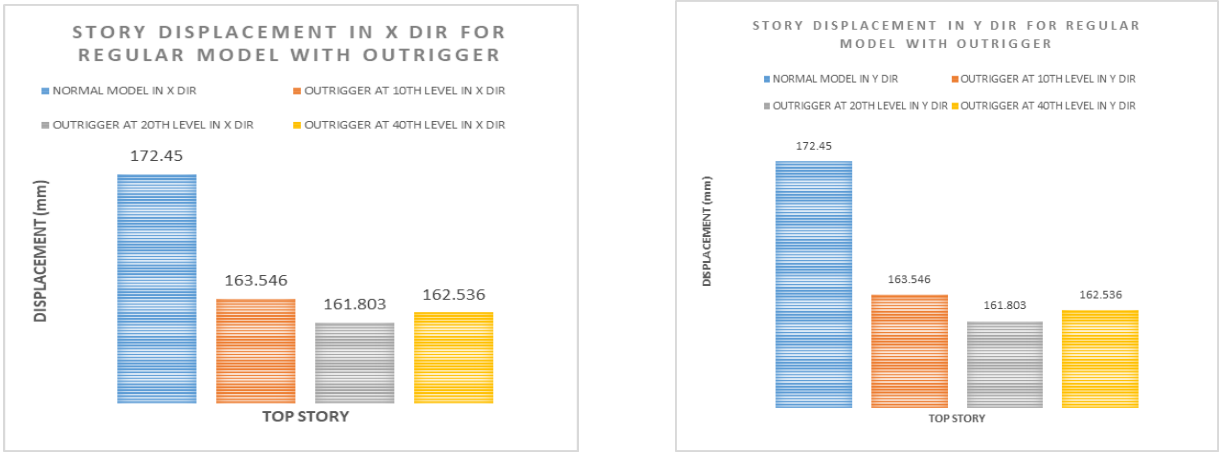


Figure 4. Story Displacement in x and y - dir for Regular Model with BRB

IRREGULAR MODEL RESULTS FOR IRREGULAR GEOMETRIC IRREGULARITY

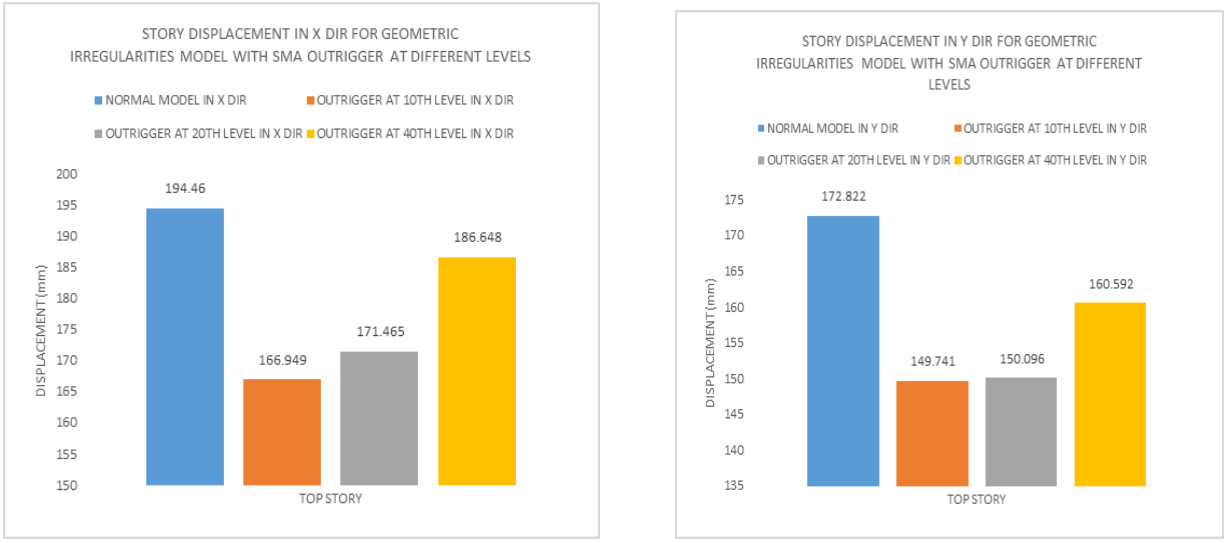


Figure 5: Story Displacement in x & y-dir for Geometric Irregularity with SMA

Figure 6: Story Displacement in x and y -dir for Geometric Irregularity with BRB

STORY DISPLACEMENT FOR GEOMETRIC +MASS IRREGULARITY MODEL

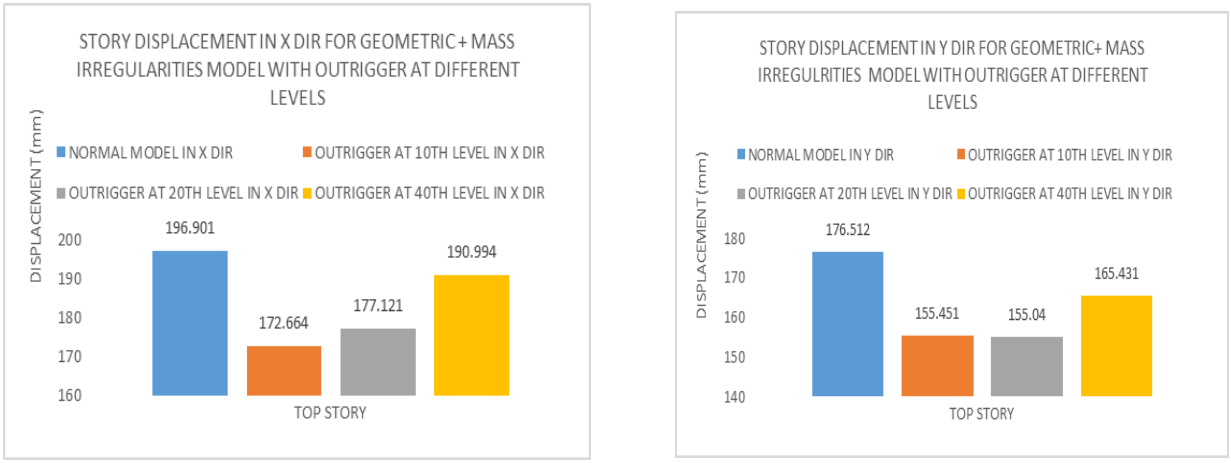


Figure 7: Story displacement in x and y dir for Geometric and mass Irregularity with SMA

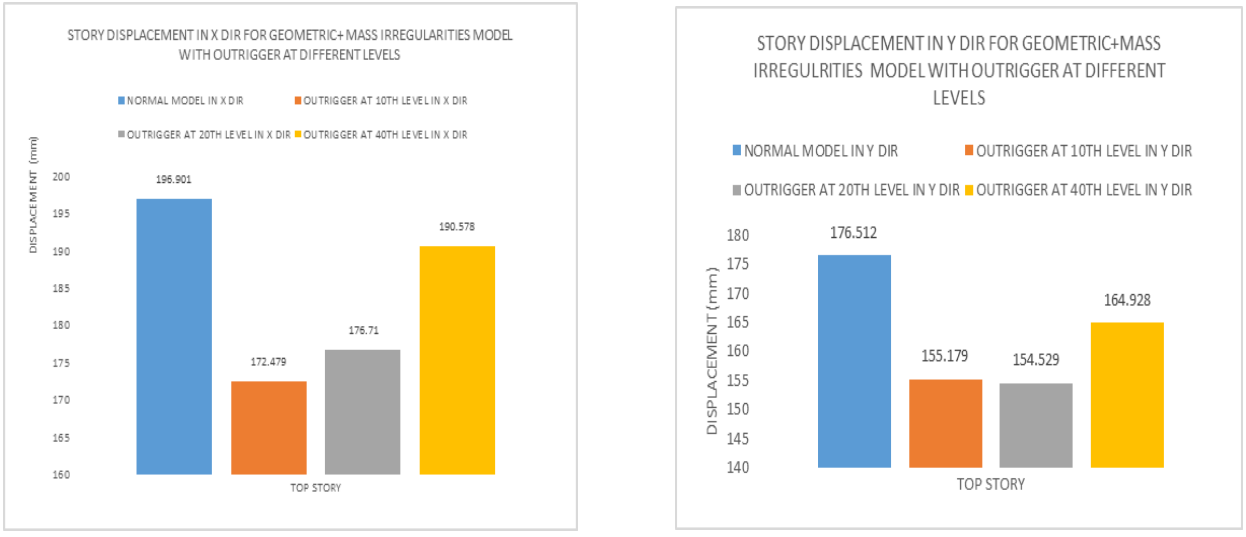


Figure 8: Story displacement in X &Y dir for Geometric and mass Irregularity with BRB

STORY DISPLACEMENT FOR GEOMETRIC +STIFFNESS IRREGULARITY

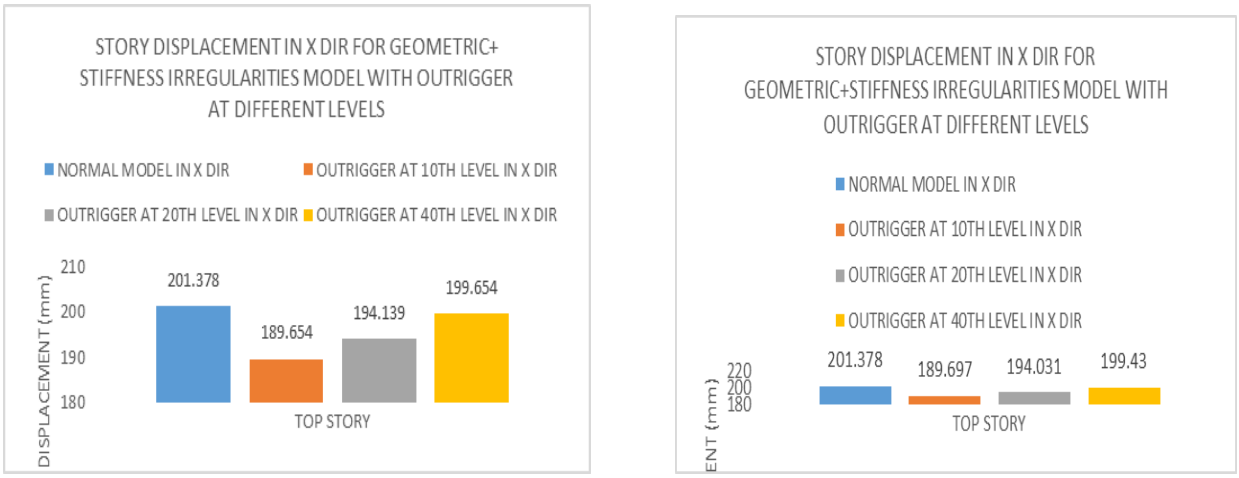


Figure 9: Story displacement in x dir for Geometric and stiffness Irregularity with SMA & BRB

III.CONCLUSION

This dissertation investigates the comparison of the high-rise buildings, considering 40-story buildings with different outrigger topology as SMA and BRB types. All the buildings have a floor size of 54 m X 54 m and a typical story height of 3 m. The first structural system, i.e., the RCC moment-resisting frame, is one in which the elements, or the structural members, are designed for gravity and lateral loads. In the second structural system, i.e., the regular model outrigger with SMA and BRB topology at the 10th, 20th, and 40th floors, it is a system commonly used in high-rise buildings to increase lateral stiffness, and in the third structural system, i.e., the vertical irregular outrigger with SMA and BRB topology at the 10th, 20th, and 40th floors. The fourth structural system is a vertical irregular mass irregularity outrigger with SMA and BRB topology at the 10th, 20th, and 40th floors. The fifth structural system is a vertical irregular outrigger with SMA and BRB at the 10th, 20th, and 40th floors. Thus, by investing in the response of the structure, like lateral displacement, storey drift, storey stiffness, and time period. The seismic performance is studied using nonlinear dynamic analysis.

- The use of outrigger systems in high-rise buildings increases the stiffness and makes the structural form efficient under lateral load. When the outrigger is at 10th and 40th, the displacement with SMA topology is reduced by 5.23% and 5.47%, whereas with BRB topology, it is 5.45% and 5.81%.
- ·For a regular model with an outrigger at 20 stories, it has better results compared to an outrigger at a different level, as the displacement is reduced by 12.2% with an SMA topology outrigger and 7.15% with a BRB topology outrigger.
- The percentage of reduction in displacement when SMA topology and BRB outriggers are used on a regular model is 6.67% when SMA topology is compared to BRB outriggers; thus, SMA topology outriggers are more effective than BRB in a regular model.
- The time period with SMA topology is reduced by 7.66%, whereas with BRB it is reduced by 4.80% when compared to the normal model.
- ·The increases in displacement can be seen when comparing geometric irregularity with geometric+mass, geometric+stiffness, and geometric+mass+stiffness; the percentage increases are 1.2%, 3.48%, and 4.90% for the normal model.
- ·As the combination of irregularities changes, as geometric+mass, geometric+stiffness, and geometric+mass+stiffness, the displacement has increased. The combination of irregularities has a significant effect on the performance of the structure.
- The reduction of displacement for all structures, regular or irregular, with mass, stiffness, and geometric irregularity, with the outrigger at half height, gives good results, as the percentage of displacement is reduced significantly compared to outriggers at different heights.

- ·Outriggers have been increasingly used in buildings in recent decades. Due to their excellent lateral stiffness and aesthetic features, they have the potential to become a more widely used structural system in high-rise buildings.
- As the lateral loads are resisted using outriggers with SMA and BRB braces, the top-story displacement is less as compared to the normal building.
- As the time period is less, the mass of the structure is lesser and the stiffness is greater; the time period is observed less in the outrigger structure, which reflects more stiffness of the structure and less mass of the structure.
- The reduction in time period for all the models, regular and irregular, is more for the outrigger at the 20th level, as the time period is inversely related to its stiffness; the reduction is 40% compared to the normal model.
- In both the mass and stiffness irregular cases, the time period of the bare frame is highest. The first mode period of the building increased for mass stiffness and geometric irregularity cases. That concludes the time period of the building that is directly affected by the irregularity.
- The displacement of the structure has been increased due to the effect of irregularities when compared to an irregular model with vertical geometric irregularity.
- Storey The drift of all the buildings is within permissible limits as per IS1893 2016, which is 0.004 times the difference in the level. When comparing, it was found that at the 20th story there is a drop of drift for about 58% less than the normal model.
- From the performance of the structures based on displacement, drift time period, and story stiffness, it can be concluded that the building with outriggers for the regular or irregular building model has better control for roof displacement compared with the normal model.

IV. SCOPE OF FURTHER STUDY

Further research can be carried out by considering the effect of wind loads on irregularly shaped structures and also by considering the impact effects due to the blast loading on structures. Further research can be carried out by using the same system with soil interaction properties

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