Assessment Of Seismic Response of Tall Buildings Using Spectrum-Compatible Artificial Ground Motion Records

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***Abstract*—Artificial ground motion records were generated using SeismoArtif by matching the target response spectra specified in Bureau of Indian Standards IS 1893 (Part 1):2016 for hard soil, medium soil, and soft soil conditions at 5% damping. The generated accelerograms were used as input ground motions for nonlinear time history analysis of the G+40 RCC outrigger structure modelled in ETABS. Nonlinear properties were assigned to structural components to capture realistic inelastic behaviour under severe seismic excitation. The study focuses on evaluating important seismic response parameters such as storey displacement, inter-storey drift, base shear, time period, stiffness variation, and overall dynamic response under different soil conditions.**

I. INTRODUCTION

Earthquake engineering relies heavily on ground motion records to evaluate structural performance. However, real recorded earthquake data are often limited in number, may not match the seismic characteristics of a specific site, or may not represent the design spectrum required by building codes. To overcome these limitations, spectrum-compatible artificial ground motion records are generated. These records are mathematically synthesized to match a target response spectrum, ensuring that structural analyses reflect expected seismic demands.

1.To generate spectrum-compatible artificial ground motion records corresponding to the target response spectra specified in Bureau of Indian Standards IS 1893:2016 for hard soil, medium soil, and soft soil site conditions.
2.To develop analytical models of tall RCC outrigger structural systems suitable for nonlinear seismic time history analysis.
3.To perform nonlinear time history analysis of outrigger buildings subjected to artificial ground motion records generated for different soil conditions.
4.To evaluate and compare important seismic response parameters of the outrigger structure under hard, medium, and soft soil ground motion. To investigate the influence of varying soil conditions on the seismic performance and dynamic behavior of tall outrigger buildings.
5.To compare the structural responses obtained from different spectrum-compatible artificial ground motion records and assess their effect on seismic demand.
6.To assess the effectiveness and reliability of spectrum-compatible artificial ground motions in predicting realistic seismic behavior of tall buildings with outrigger systems under different site conditions.

II. LITERATURE REVIEW

Zhenning Ba et al. (2025), published in Engineering Applications of Artificial Intelligence, introduces an advanced framework for generating spectrum-compatible ground motion records using a Conditional Generative Adversarial Network (CGAN). Unlike conventional spectral matching methods—which often distort the natural characteristics of earthquake records while forcing them to match a target response spectrum—the proposed approach integrates key seismic parameters such as earthquake magnitude, source-to-site distance, and local site conditions directly into the learning process.

Ha (2025), published in Applied Sciences, presents a systematic and sequential approach for the selection of bi-directional spectrum-compatible ground motion records that satisfy modern seismic code requirements for structural analysis. The research highlights that, in performance-based seismic design especially for tall and flexible buildings it is not sufficient to match only the target mean response spectrum; instead, it is equally important to capture the variability and dispersion of ground motion characteristics to ensure realistic structural response predictions. The proposed method focuses on selecting pairs of horizontal ground motion components that collectively match the target design spectrum while maintaining statistical consistency. A key observation from the study is that the number of ground motion records significantly influences the accuracy of seismic demand estimation.

Ji et al. (2024), published in Soil Dynamics and Earthquake Engineering, presents an advanced methodology for generating spectrum-compatible ground motion records with explicit consideration of strong-motion duration—an important parameter that is often neglected in conventional spectral matching techniques. Traditional approaches primarily focus on matching the target response spectrum, but they may fail to accurately represent the temporal characteristics of earthquake shaking, particularly the duration and energy distribution of ground motions. In this study, the authors incorporate duration as a governing parameter in the record generation process, ensuring that the synthesized motions not only satisfy spectral compatibility but also realistically simulate the time-dependent features of seismic excitation

Chen et al. (2026), published in Engineering Structures, introduces an advanced evolutionary optimization framework for the selection and spectral matching of ground motion records aimed at improving the reliability of nonlinear dynamic analysis. The research addresses a key limitation in conventional record selection procedures, where subjective choices and inadequate matching techniques can introduce bias and increase uncertainty in predicted seismic demands. By employing optimization algorithms—such as genetic or evolutionary strategies—the proposed framework systematically identifies and modifies a suite of ground motions to achieve closer agreement with a target response spectrum while preserving essential physical characteristics of the records.

Model Information

Model 1: First building is modelled with regular beams, Columns, Shear Core walls, and Slabs. The lateral load resisting structural system is adopted by studying IS 1893:2016 and labelled as regular model without outrigger and belt truss.

Model 2 – Outrigger and Belt Truss with Cross-Bracing Topology This model includes outrigger beams and belt trusses configured in a cross (X) bracing arrangement connecting the central core to exterior columns. Three height positions are examined:

Case 2A – Outrigger at 10th storey (≈ 0.25 h = 30 m)
Case 2B – Outrigger at 20th storey (≈ 0.5 h = 60 m)
Case 2C – Outrigger at 40th storey (top level)
Each case is analyzed for hard, medium, and soft soil conditions.

Model 3 – Outrigger and Belt Truss with V-Bracing Topology In this configuration, the outrigger and belt truss form a V (chevron) bracing system. Outrigger levels:

Case 3A – 10th storey (30 m)
Case 3B – 20th storey (60 m)
Case 3C – 40th storey (top)
Each case is analyzed under hard, medium, and soft soil to study how SSI modifies stiffness and drift behavior.

Model 4 – Outrigger and Belt Truss with Single Diagonal Bracing Topology This model features a single-diagonal brace connecting the core and perimeter columns at each outrigger level. Outrigger elevations:
Case 4A – 10th storey (30 m)
Case 4B – 20th storey (60 m)
Case 4C – 40th storey (top)

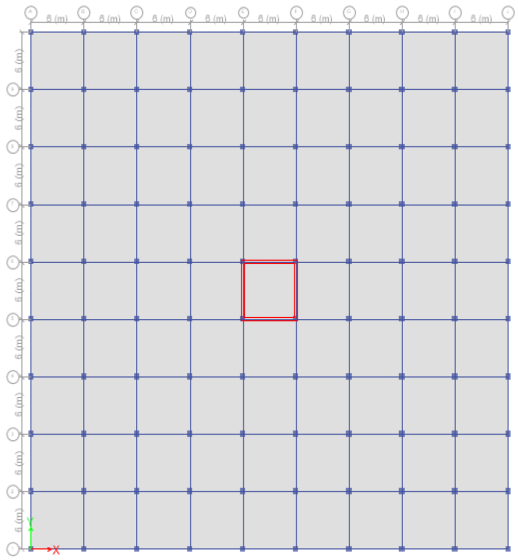


Figure 1 presents the plan view of the normal (conventional) building model used as the baseline reference for comparison in this study

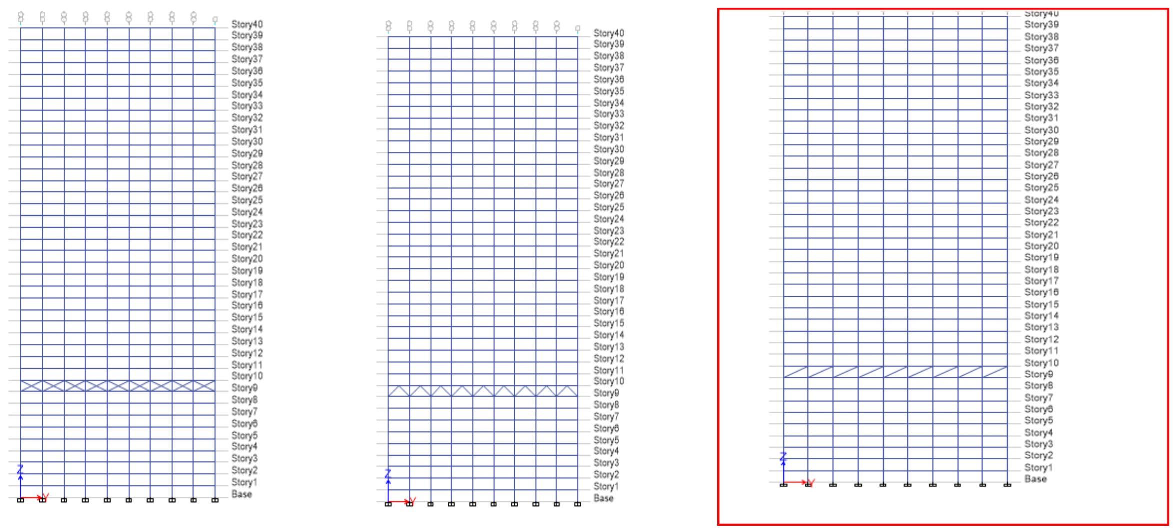


Figure2: Diagonal cross, single cross and V topology outrigger at 10th story

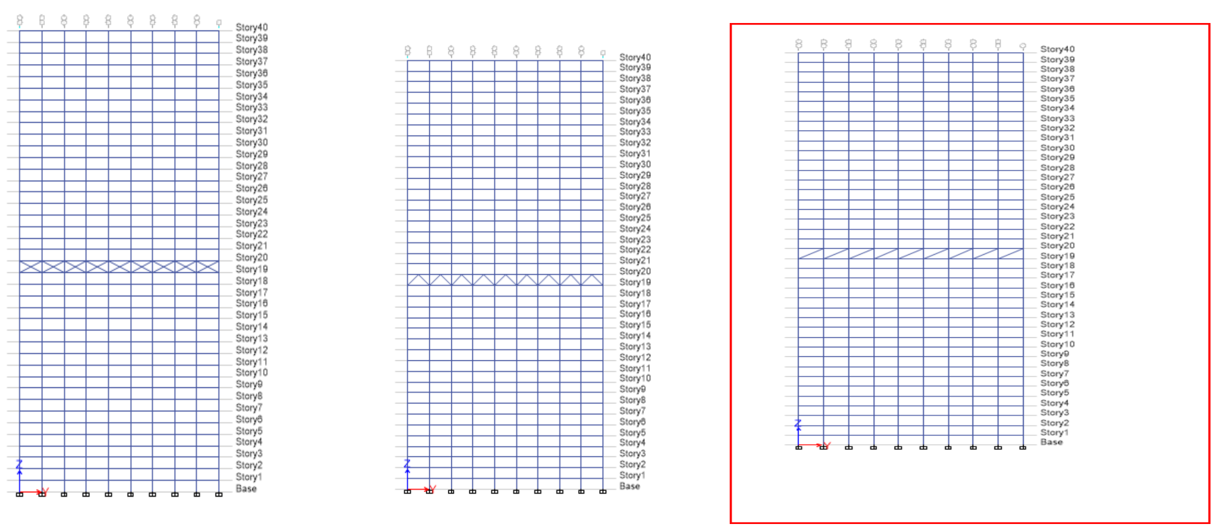


Figure3: Diagonal cross, single cross and V topology outrigger at 20th story

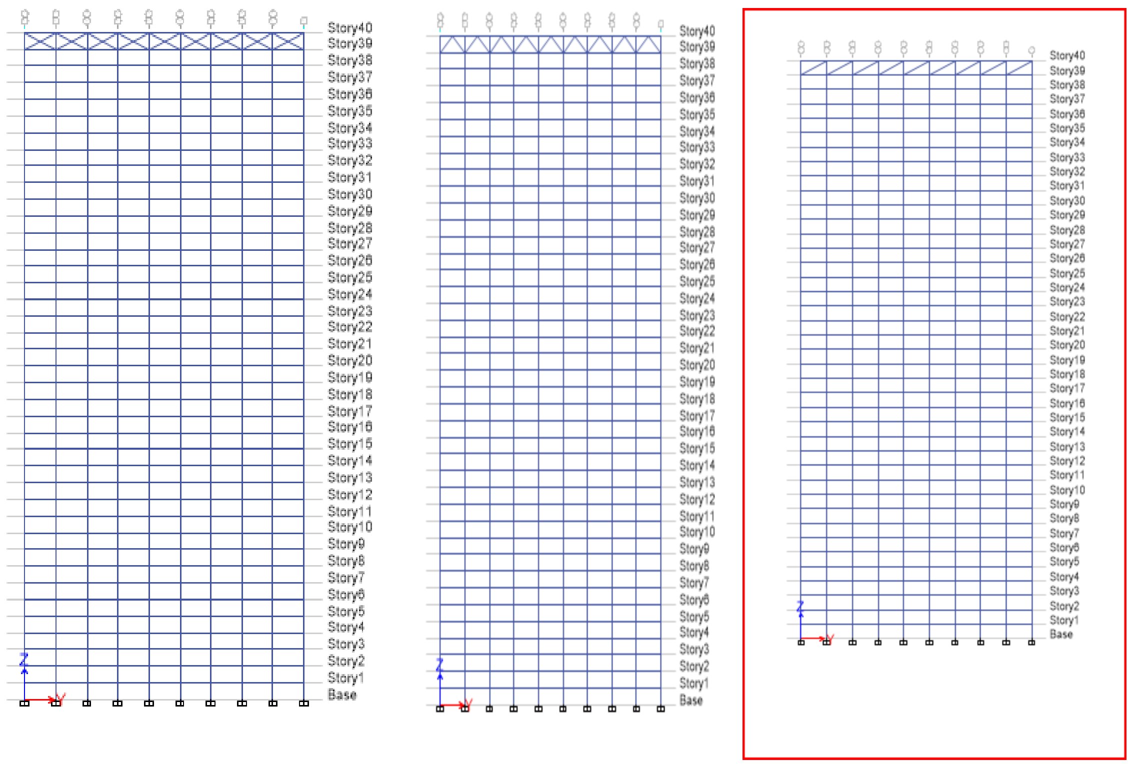
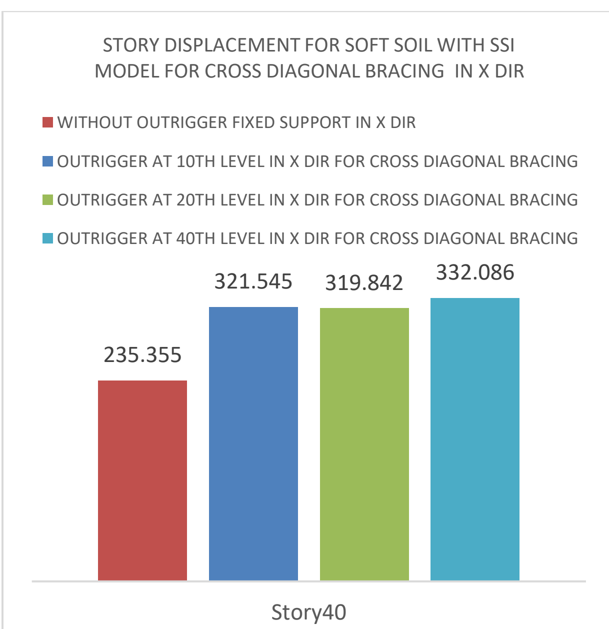
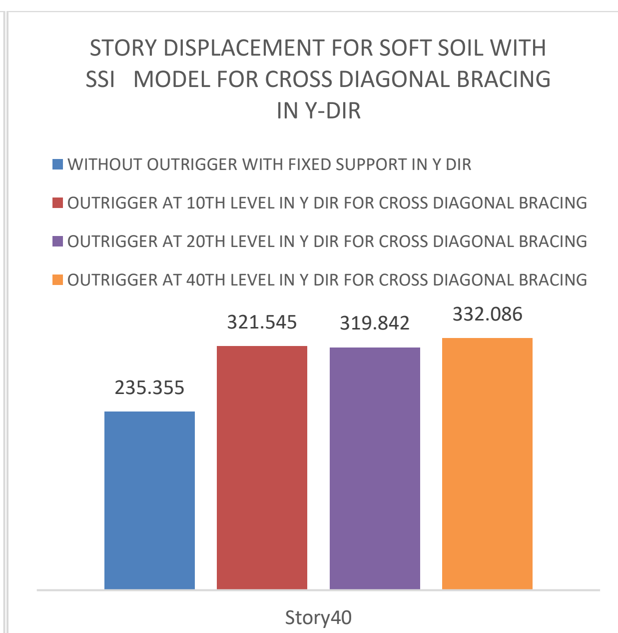
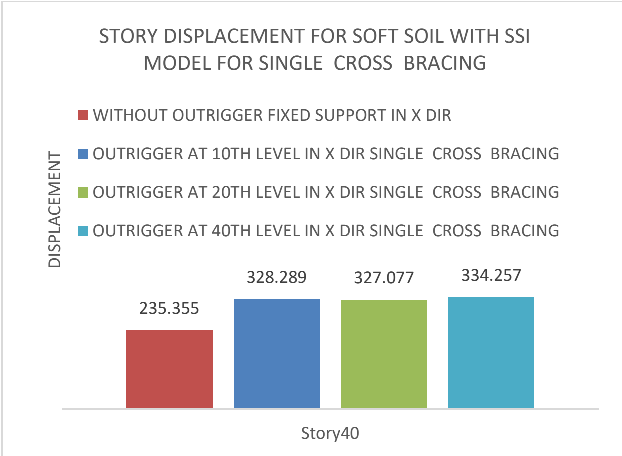


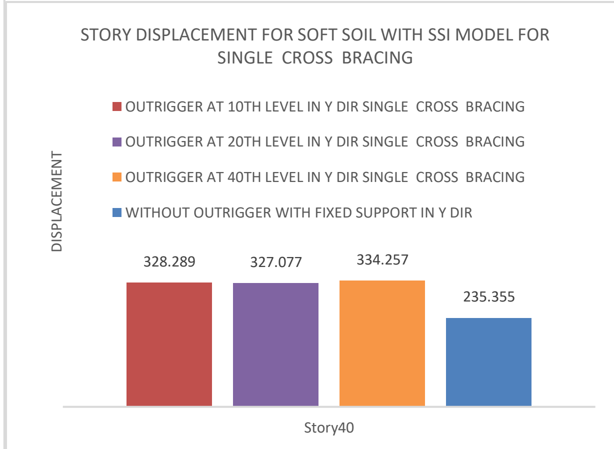
Figure 4: Diagonal cross, single cross and V topology outrigger at 40th story

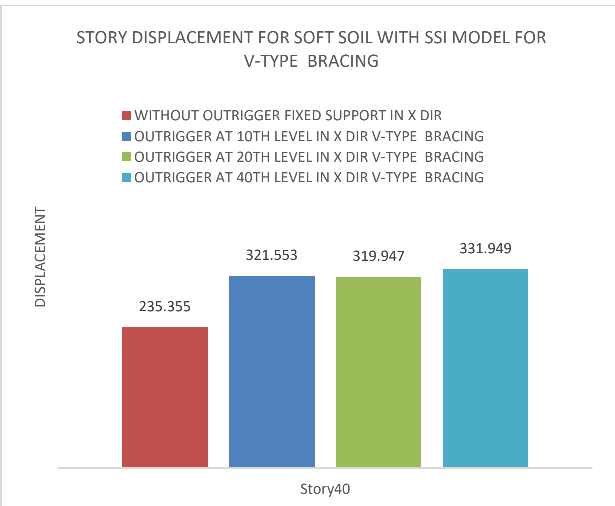
III. RESULTS AND DISCUSSION FOR SOFT SOIL

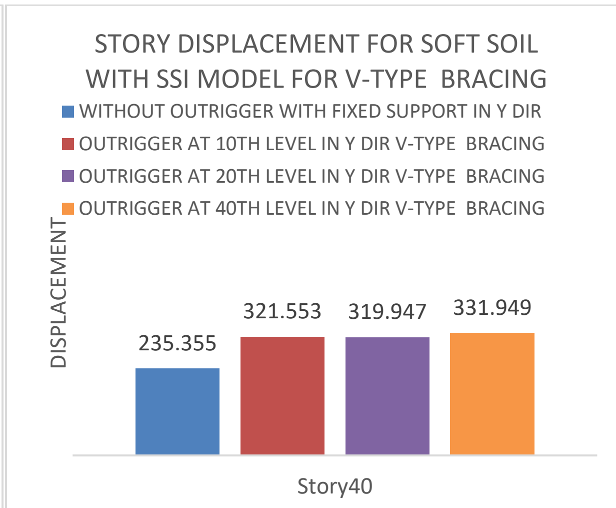




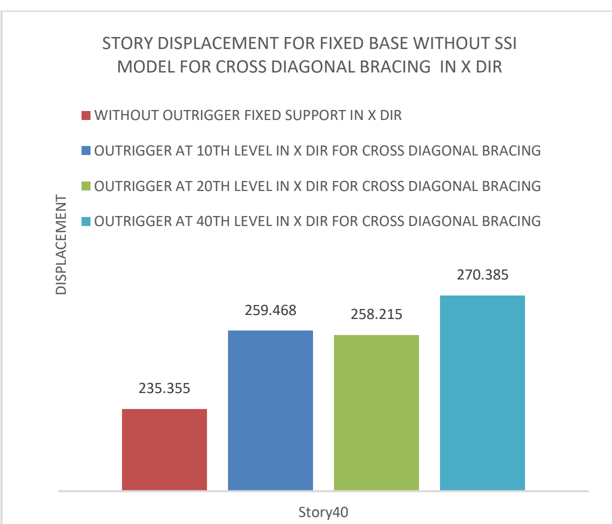


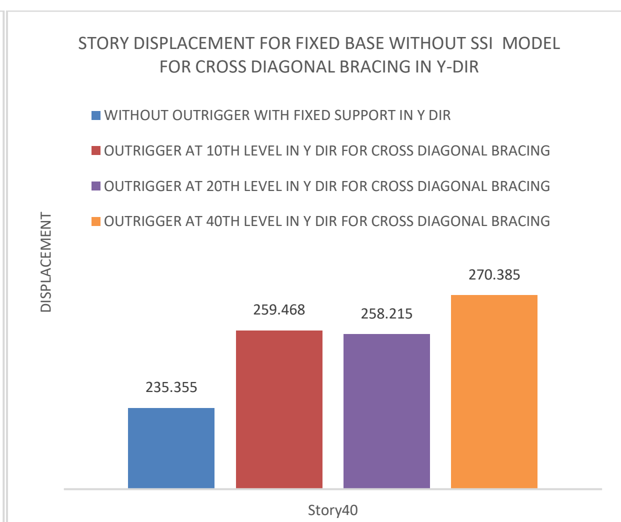


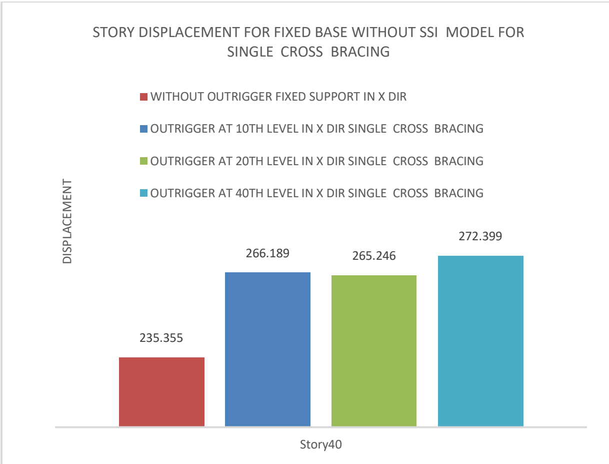


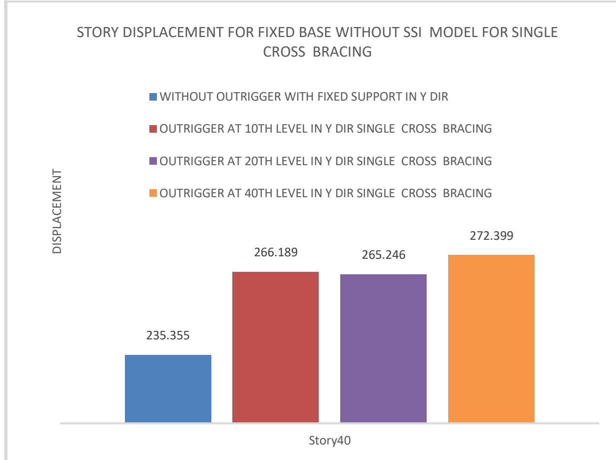


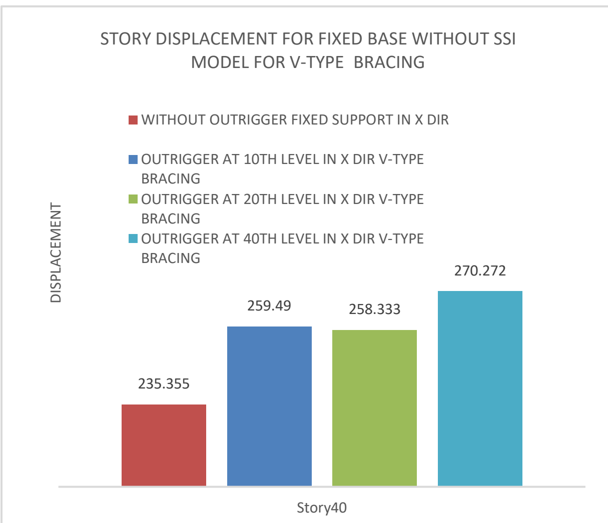
IV. RESULTS AND DISCUSSION FOR MEDIUM SOIL

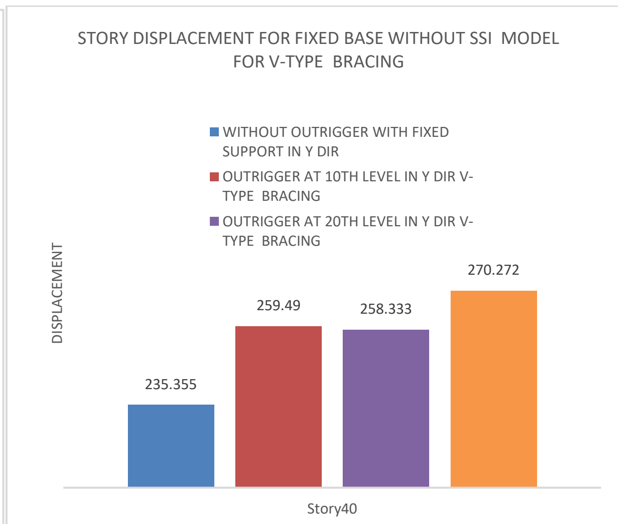




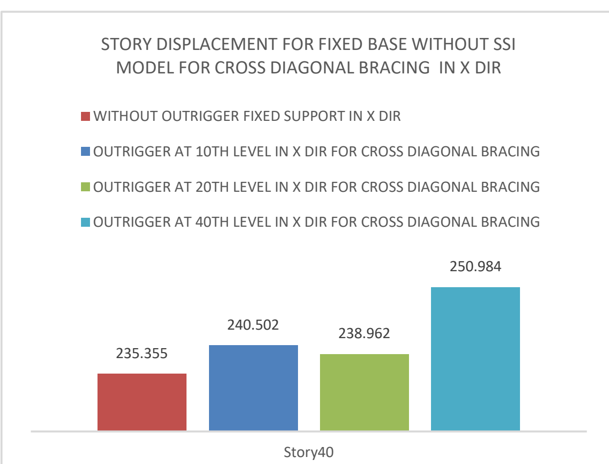


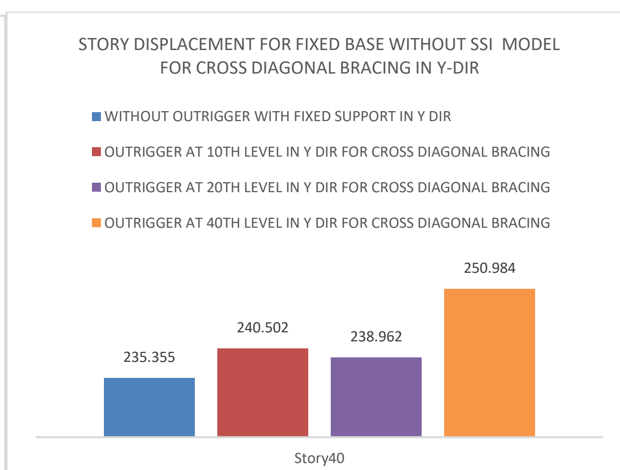


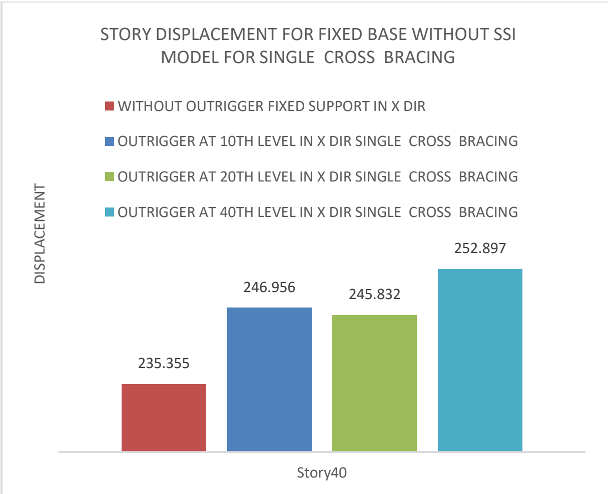


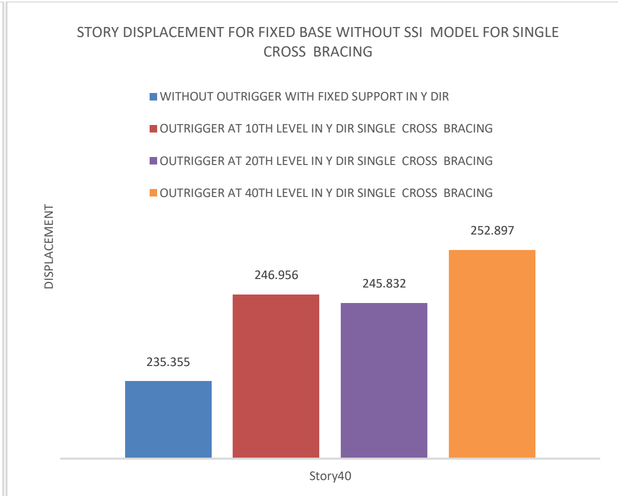


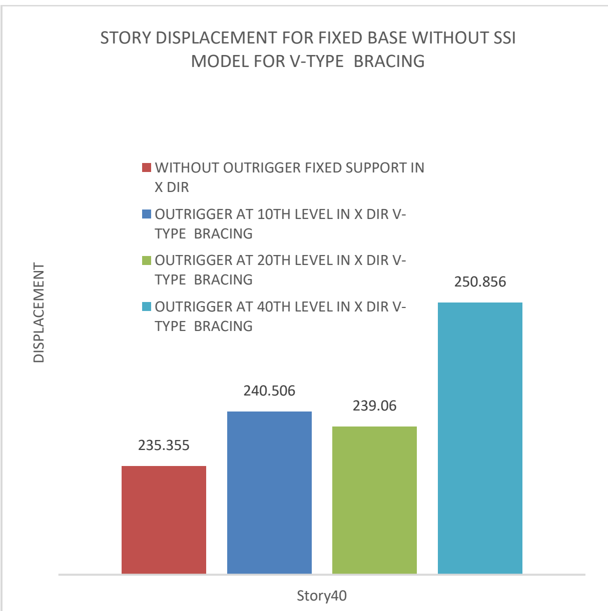
V. RESULTS AND DISCUSSION FOR HARD SOIL

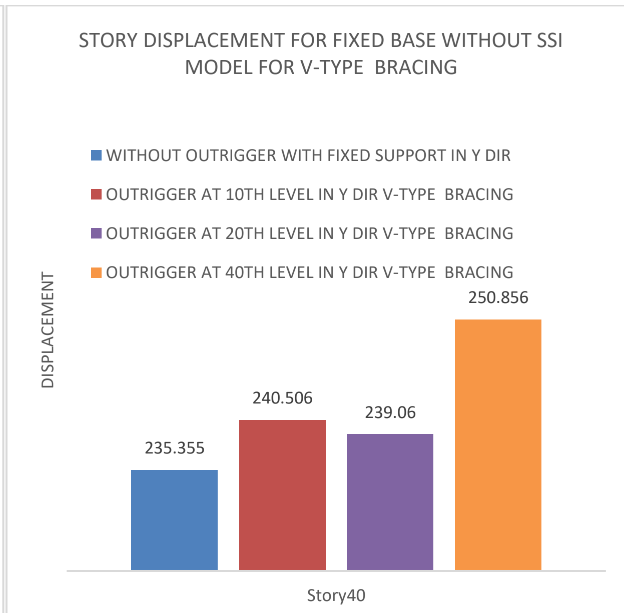












VI. CONCLUSION

The incorporation of the outrigger system significantly improved the seismic performance of the high-rise building by increasing the overall lateral stiffness and reducing excessive structural deformation.

The placement level of the outrigger system greatly influenced the effectiveness of seismic response control, particularly in terms of storey displacement, inter-storey drift, and overturning moment reduction.

Outriggers provided efficient interaction between the central core and exterior columns, thereby enhancing the resistance against lateral loads induced by earthquake excitation.

The outrigger system placed near the mid-height of the structure showed moderate improvement in stiffness and displacement control compared to the base model.

When the outrigger was provided at higher levels, especially around the top-third region of the building height, the structure exhibited maximum reduction in roof displacement and storey drift.

The top-level outrigger configuration effectively reduced overturning effects by mobilizing axial action in exterior columns, leading to better lateral load distribution.

Structures with outriggers demonstrated improved dynamic characteristics with reduced fundamental time period and increased structural stability under seismic loading.

The nonlinear time history analysis indicated that buildings with optimally placed outriggers experienced lower hinge formation and reduced damage concentration compared to conventional frame systems.

The effectiveness of the outrigger system was observed to vary with soil conditions, where soft soil produced higher displacement demands, although the outrigger still considerably enhanced seismic resistance.

Overall, the study concludes that the outrigger system is an efficient structural control mechanism for high-rise buildings, and the optimum outrigger location generally lies near the upper-middle or top-third portion of the building height for achieving superior seismic performance.

6.2 Future Scope

Exploration of Additional Outrigger Configurations Future studies may analyze as Belt truss outriggers, Wall-type outriggers, Virtual outriggers, Hybrid steel–RC outriggers evaluating these configurations can further enhance understanding of stiffness distribution and seismic performance.

To improve seismic behavior, outrigger systems can be combined with: Tuned mass dampers (TMDs), Fluid viscous dampers and Base isolators these systems in ETABS using nonlinear link elements would provide deeper insights into energy dissipation mechanisms

Further investigation can include, nonlinear static pushover analysis, Incremental dynamic analysis (IDA), and Collapse prevention checks. This will help evaluate ductility, plastic hinge formation, and failure mechanisms more comprehensively

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