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Comparative investigation on Optimized Shear Wall Layout and Conventional Model

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Abstract: This paper compares an optimized shear wall layout obtained from an existing research paper and a conventional model. The objective of the study is to evaluate the structural efficiency of both designs while considering constraints related to drift and displacement. Shear walls are important components that provide lateral stability to buildings, particularly in regions susceptible to seismic activities. The optimized shear wall layout, sourced from a relevant peer-reviewed paper, serves as the basis for comparison. The conventional model adheres to established design practices and code requirements. The study evaluates the response of the structures under various load combinations, including seismic and wind forces. Through rigorous comparative analyses, the study reveals the relative advantages and limitations of the optimized shear wall layout compared to the conventional design in terms of structural performance and efficiency. The findings highlight the significance of considering drift and displacement constraints to ensure the safety and resilience of buildings in seismic-prone regions. The implications of this study offer valuable insights for the architectural and engineering community, showcasing the potential for enhanced structural performance through optimization techniques. The paper contributes to a deeper understanding of the benefits of incorporating optimized shear wall layouts in structural design, ultimately promoting more sustainable and safer construction practices in the future.

Keywords: RC Shear wall, Optimization, story drift, displacement

I. INTRODUCTION

In the realm of structural engineering, ensuring the efficiency and safety of buildings is of paramount importance. Shear walls, as integral components in structural design, play a critical role in providing lateral stability and resisting lateral loads, especially in regions susceptible to seismic activities. The optimization of shear wall layouts has emerged as a promising avenue to enhance structural performance, reduce construction costs, and promote sustainable building practices.

This paper delves into a comparative study that assesses the structural efficiency of an optimized shear wall layout in contrast to a conventional model. The optimization process draws inspiration from the principles of Darwinian evolution, employing genetic algorithms to evolve and refine the shear wall arrangement. The optimized shear wall layout is derived from a pertinent peer-reviewed paper, while the conventional model adheres to established design practices and code requirements. By evaluating both designs under various loading conditions, including seismic and wind forces, the study seeks to unveil their respective strengths and limitations.

The primary objective of this research is to explore the benefits of incorporating optimized shear wall layouts, specifically in the context of drift and displacement constraints. The chosen constraints are crucial for ensuring the structural integrity of buildings during lateral movements induced by external forces, such as earthquakes or high winds. Understanding how the optimized layout compares with the conventional design in terms of drift and displacement can provide valuable insights into its potential for mitigating damage and improving overall safety.

To achieve these goals, finite element modelling and structural analysis have been employed to simulate the behaviour of both designs. This approach enables a comprehensive evaluation of the shear wall layouts' performance, allowing for an in-depth understanding of their behaviour and efficiency.

The findings of this study aim to contribute to the body of knowledge within the field of structural engineering. By shedding light on the efficacy of Darwinian-inspired optimization techniques for shear wall layouts, this research seeks to advance the understanding of optimization methods in structural design. Additionally, the insights garnered from this investigation can serve as a basis for further research and development in the pursuit of more resilient, cost-effective, and sustainable building practices.

In the subsequent sections of this paper, we will detail the methodology used for the comparative study, present the results obtained from the analysis, and discuss the implications of our findings. Through this examination, we aim to provide practical recommendations and encourage the adoption of optimized shear wall layouts to bolster the structural efficiency and safety of buildings in seismic-prone regions.

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II. LITERATURE SURVEY

[1]Banerjee et al. optimize shear wall placement in 'C' shaped concrete frames to reduce torsional effects. Objective: best location meeting structural and technical requirements. G+15 building case study with 14 shear wall models analyzed. Analytical comparisons include base shear, tale displacement, drift, eccentricity, time period, and modal behaviour. The closeness of the centre of mass and stiffness is emphasized.[2] Jin et al. optimize shear wall layouts in multi-tower structures using extended evolutionary structural optimization (ESO). Practical approach considering design, and construction restrictions. ESO with conceptual design improves efficiency, and balance among towers. Application to real-world engineering stressed for effective optimization. [3]Cerè et al. enhance seismic resilience using risk-oriented optimization of shear walls. Combined risk factors optimize reinforced concrete frame configuration. Validation on earthquake-damaged buildings shows an 80% risk reduction. Offers financial benefits, improved performance, and disaster management applications. [4]Chou et al. use machine learning (XGBoost) to predict shear wall capacity in concrete structures. Hybrid models like JS-XGBoost outperform single and ensemble models. Reliable prediction, increased safety, and generic framework for design models. [5]Lou et al. propose hybrid discrete size optimization for high-rise concrete buildings. Mixed response surface model, discrete Particle Swarm optimization used. Reduces structural weight up to 14.3%, applicable to various structures. [6]Abualreesh et al. optimize shear wall quantity and placement in concrete multistory structures. Reliability constraint governs optimization, influencing safety levels. Optimal strategies vary based on earthquake direction, and floor symmetry. [7]Desale et al. focus on shear wall systems in high-rise constructions. Position impacts floor stiffness, the centre of mass movement, and drift. Shear walls are vital for lateral and gravity loads and mitigate earthquake distortions. [8]Lou et al. use the ESO approach for shear wall arrangement optimization. Discretized shear walls gradually eliminate less stressed parts. Effective material savings of up to 14% in shear wall construction. [9]Lou et al. optimize shear wall layouts using a tabu search algorithm. The surrogate model generated by support vector machines (SVM) guides optimization. Focus on reducing structural weight while complying with limits. [10]Parsa et al. forecast peak shear strength using Support Vector Regression with meta-heuristic optimization. Models outperform existing equations and codes, increasing accuracy. [11]Zakian et al. employ topology optimization for economical shear wall architecture. Material distribution, placement, and connection are considered under seismic stress. Significant advantages of using steel link beams were observed. [12]Shah et al. study shear wall performance in reinforced concrete structures. Inner core shear walls are effective in reducing displacement and drift. [13]Shreelakshmi et al. optimize shear wall thickness and position in G+20 structure. Results indicate 150mm thickness is cost-effective and sufficient.[14]Li et al. study seismic performance enhancement using coupled shear walls with steel link beams. Steel link beams exhibit higher load resistance and resilience. [15]Vatandoust et al. estimate optimal shear wall hole size using a continuous approach. A simple equation helps determine optimal opening dimensions. [16]Deepna et al. compare the seismic behaviour of RCC, steel plate, and composite shear walls. Thickness modifications impact base shear and drift. [17]Nikam et al. emphasize shear wall importance for seismic resistance. Optimal placement improves seismic stress resistance. [18]Zhang et al. stress shear walls' importance in resisting lateral stresses. Shear walls at corners, centrally, and mid-span improve structural resilience. [19]Takada et al. use a branch-and-bound approach for shear wall allocation to reduce torsional moments. Optimization process detailed for multi-storey constructions.

III. METHODOLOGY

Definition of Constraints: First we define the specific constraints related to drift and displacement that are relevant for ensuring structural integrity under lateral loads, such as seismic and wind forces. These constraints will guide the evaluation of both shear wall layouts. The allowable drift and displacement limits in a building structure are typically specified by building codes to ensure structural safety, occupant comfort, and functionality during various loading conditions, including seismic events. In India, the National Building Code (NBC) provides guidelines for structural design, including drift and displacement limits. The NBC 2016 version does not specify a maximum allowable drift or displacement in terms of an absolute value. Instead, it provides guidelines based on the relative displacement between adjacent floors, often referred to as "inter-story drift." As per NBC 2016, the maximum allowable inter-story drift for different types of buildings under seismic loads is as follows:

- Regular Structures (RCC Frame with Shear Walls): Inter-story drift limit of 0.004 times the story height under Design Basis Earthquake (DBE) and 0.002 times the story height under Maximum Considered Earthquake (MCE).
- Irregular Structures (Soft/Weak Story, Torsional, etc.): Inter-story drift limit of 0.002 times the story height under DBE and 0.001 times the story height under MCE.

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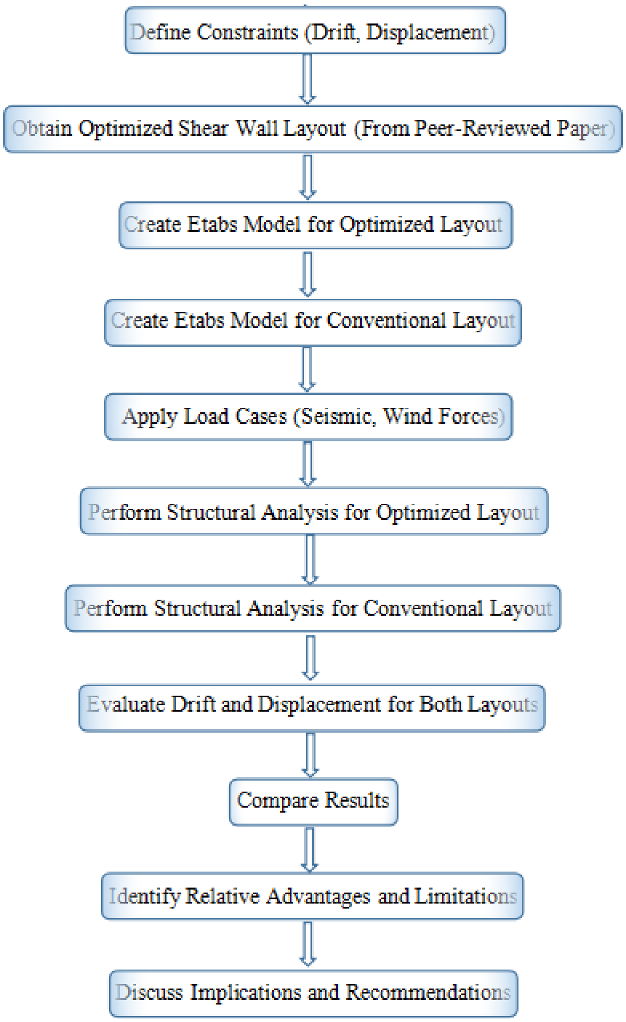

Figure 1 Methodology Flowchart

The research methodology comprises several sequential steps to comprehensively compare an optimized shear wall layout with a conventional model while considering drift and displacement constraints:

Obtaining Optimized Shear Wall Layout: Source an optimized shear wall layout from a reputable peer-reviewed paper. This layout will serve as the benchmark for comparison. Ensure that the layout aligns with the research's objectives and scope. Optimized shear wall layout was derived from "Shear wall layout optimization for conceptual design of tall buildings. Engineering Structures" by Zhang, Yu & Mueller, Caitlin. (2017)[18] which employed a metaheuristic approach for the optimization process. The optimization process was based on a genetic algorithm inspired by Darwinian theory. GEN-6 shear wall layouts have been chosen for comparison as they prove to be the most optimal option.

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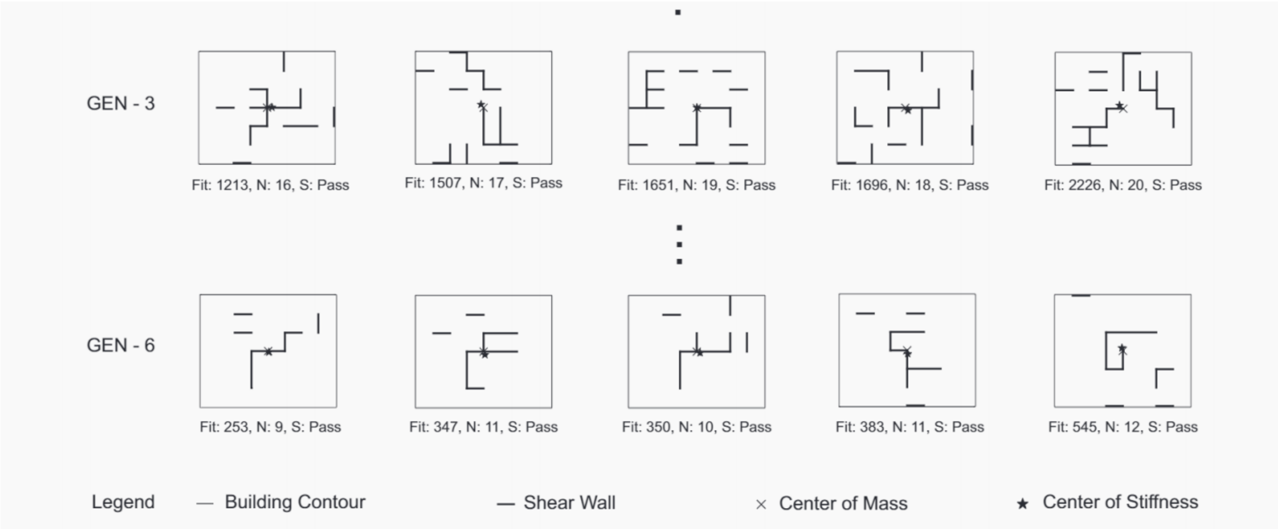

Figure 2 Optimized Shear Wall Layout

ETABS Model Creation for Optimized Layout and Conventional Layout: A detailed 3D model of the shear wall layouts is generated using the ETABS software. Define the geometry, material properties, and boundary conditions accurately. Adhere to established design practices and code requirements while constructing the model.

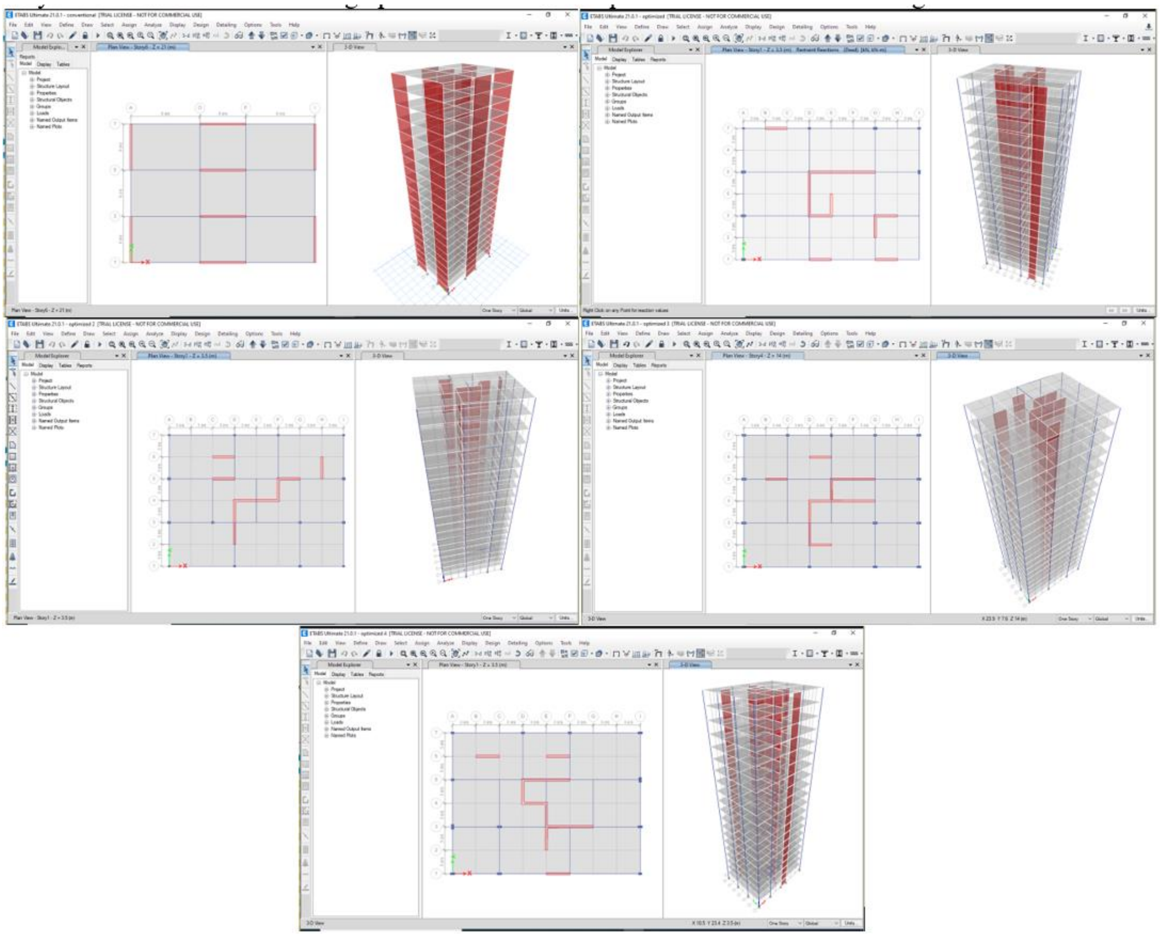

Figure 3 Plan and elevation of a Structure with Different shear wall layouts

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Load Application: A range of load cases are applied to all shear wall layouts, including seismic and wind forces. These loading conditions allow for a comprehensive assessment of structural behaviour. The following figure shows the load combinations employed. These load cases are the same for all the models used for comparison.

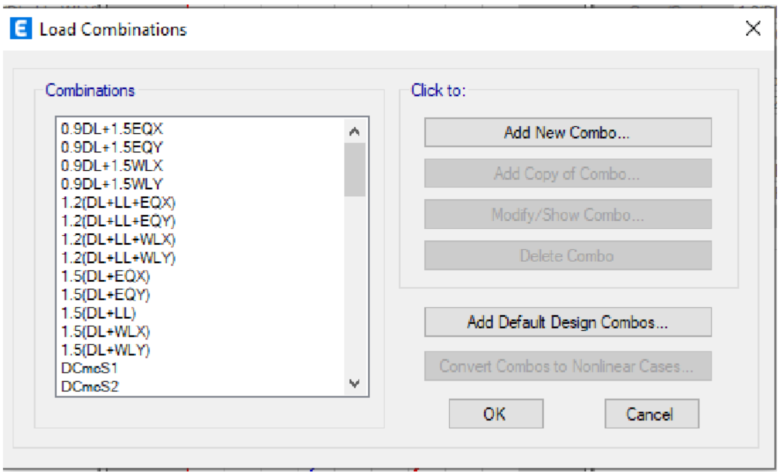

Figure 4 Load Combinations

Structural Analysis: We conduct a rigorous structural analysis of the optimized shear wall layouts using ETABS, perform analyses and design under various loading conditions, collect data on displacements, stresses, and deformations and perform an equivalent structural analysis for the conventional shear wall layout, mirroring the approach taken for the optimized layout ensuring consistency in load cases and analysis parameters.

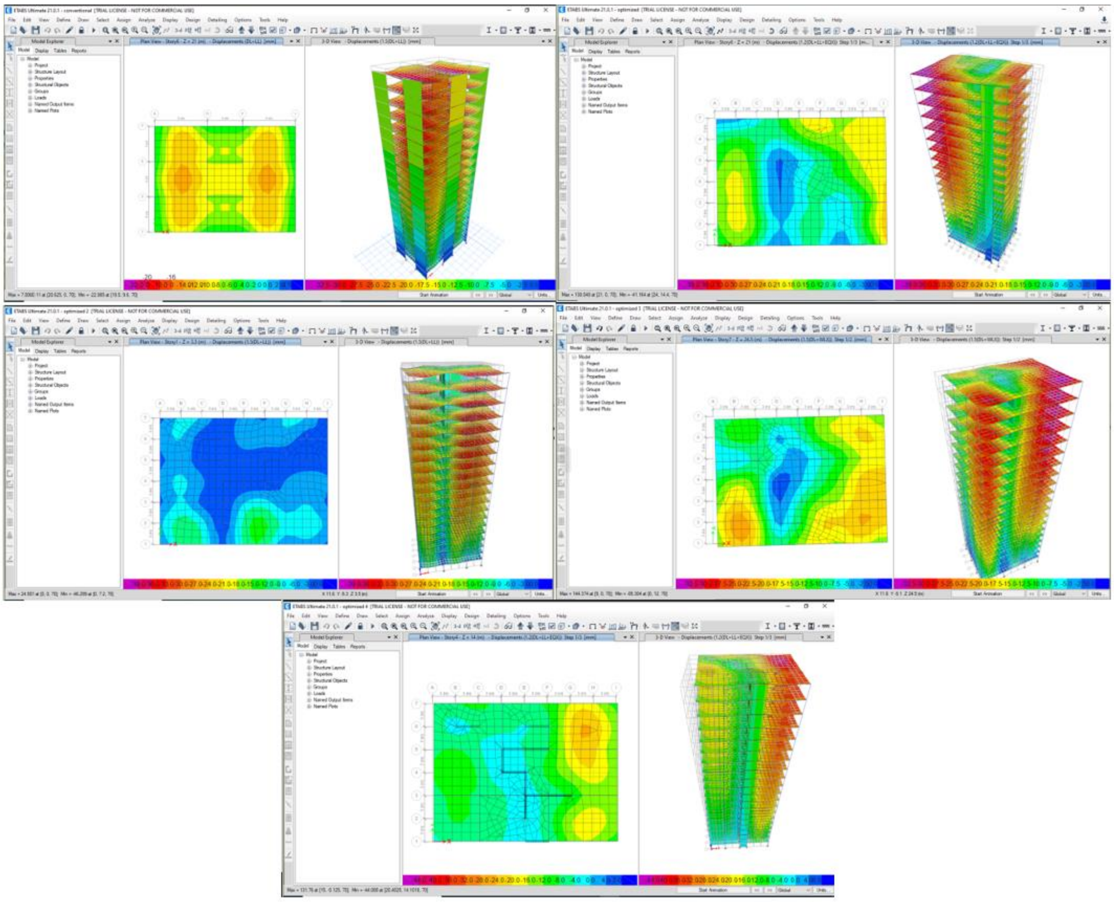

Figure 5 Deformation Plot After Analysis

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Drift and Displacement Evaluation: Here we evaluate the drift and displacement values for all shear wall layouts based on the defined constraints and measure and compare the lateral movements to assess the layouts' performance under lateral loading scenarios. The lateral loads refer to earthquake and wind loads applied based on IS 1893 and IS 875. After load application and analysis, drift and displacement plots show the structural performance at different stories.

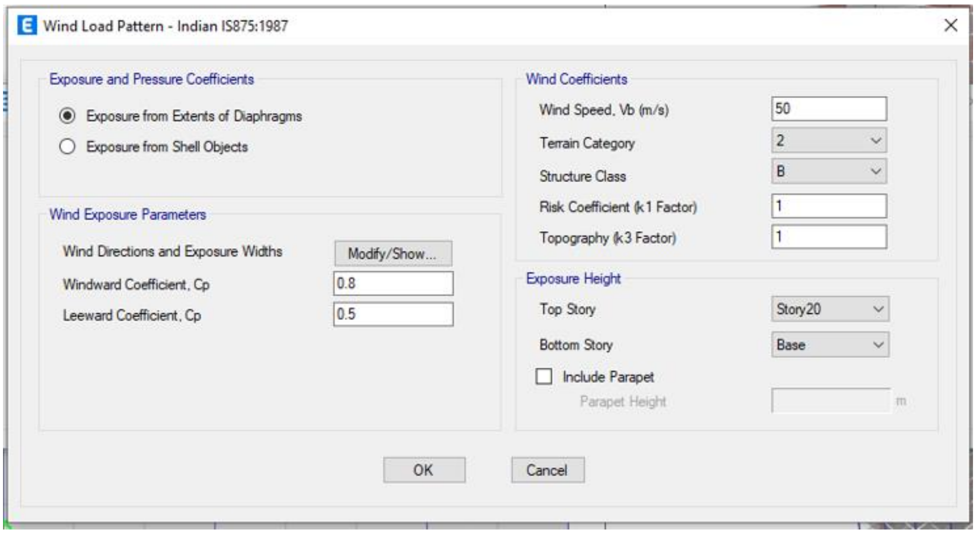

Figure 6 Wind Load specifications

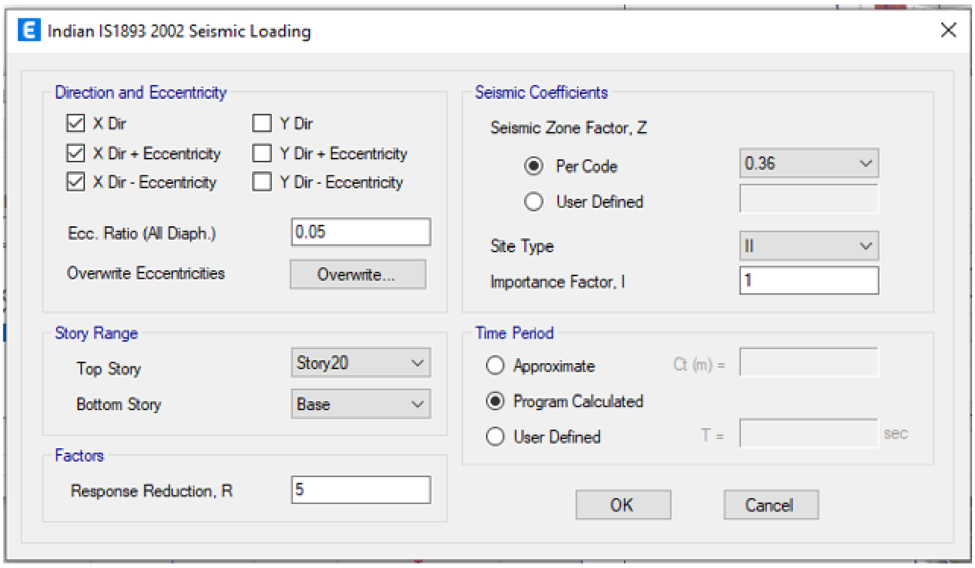

Figure 7 Seismic Load Specifications

10. **Comparative Analysis:** On systematic comparison, the results obtained from the analyses of the optimized and conventional shear wall layouts showed that the weight of the structure can be considerably reduced by using an optimized shear wall layout, but the minor drawback is that the drift and displacements are slightly increased in the intermediate stories. Analysis data related to drift, displacement and stiffness are shown in the below figures.

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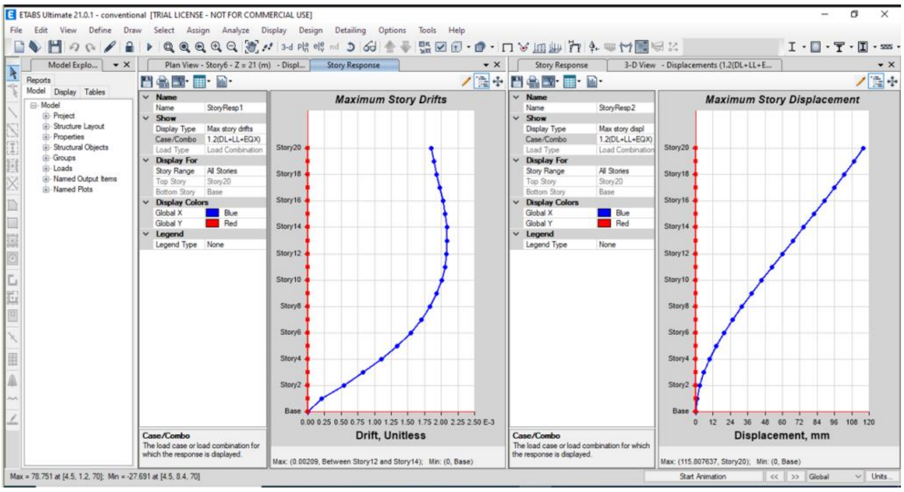

Figure 8 Drift and displacement Plot for Conventional Model

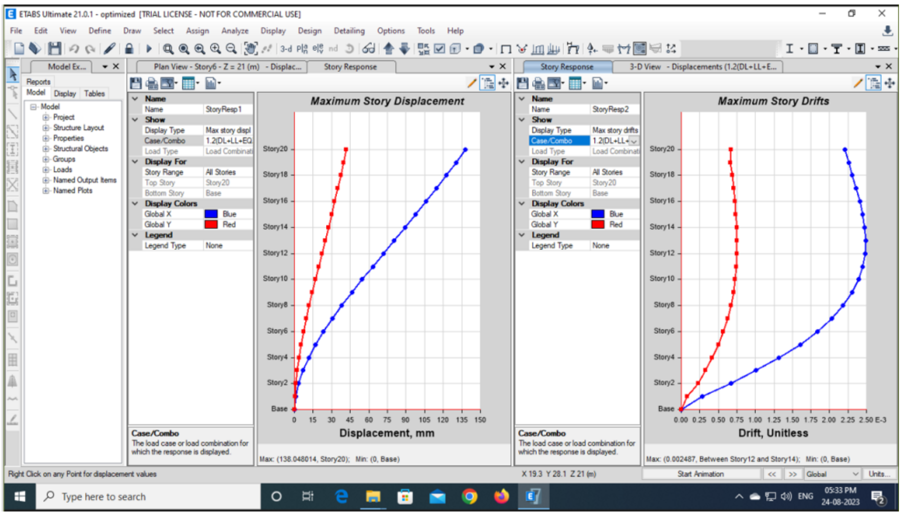

Figure 9 Drift and Displacement for Optimized Model1

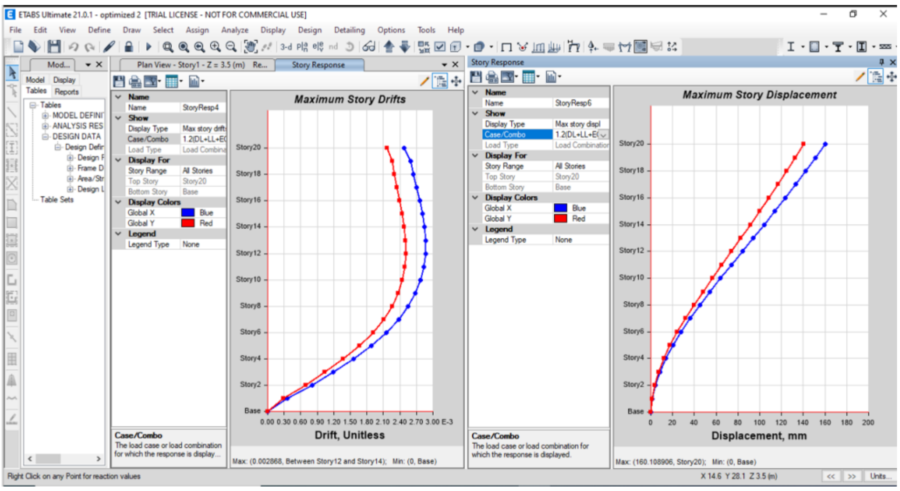

Figure 10 Drift and Displacement for Optimized Model2

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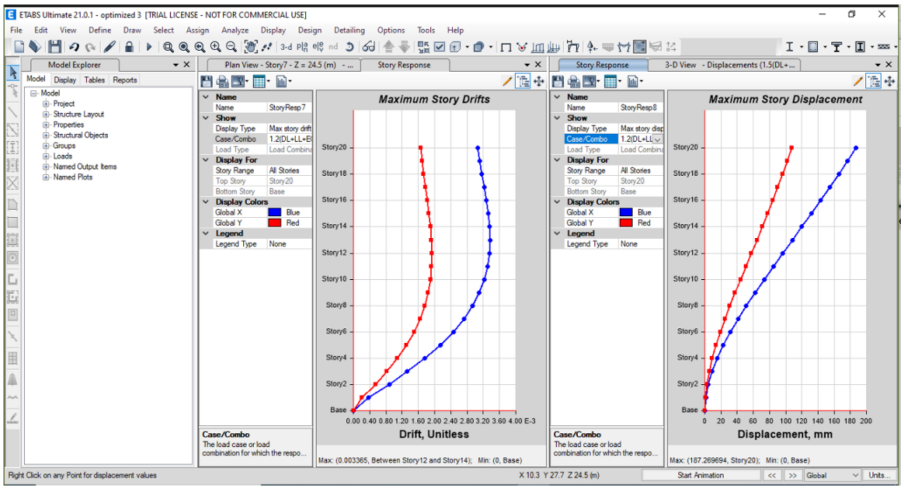

Figure 11Drift and Displacement for Optimized Model3

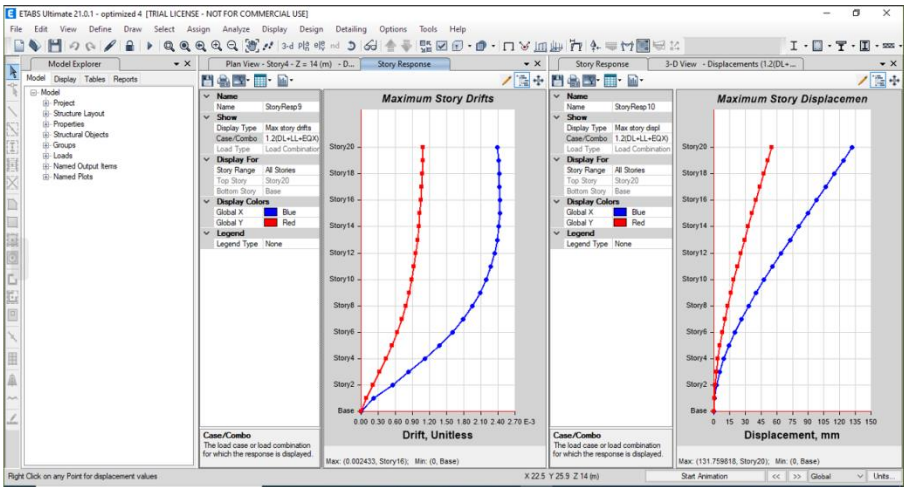

Figure 12 Drift and Displacement for Optimized Model4

IV. RESULTS AND DISCUSSION

Optimized shear wall layouts in structural engineering involve strategically designing the arrangement and distribution of shear walls within a building to effectively counter lateral loads like seismic forces and wind pressure. In this work, it was found that, on using the optimised shear wall layout instead of the conventional design, the structural weight can be reduced by about 20%, but on the other hand the inter-story drift increases by about 5% on average in the intermediate floors. Here are some benefits and drawbacks associated with opting for optimized shear wall layouts over conventional designs:

Benefits:

- Enhanced Structural Reliability: Optimized shear wall layouts are grounded in advanced structural analysis techniques, ensuring heightened resilience of the building against lateral forces. This translates to improved safety during seismic events and other lateral load scenarios.
- Efficient Resource Allocation: Optimized designs often employ fewer shear walls while still upholding the necessary structural robustness. This efficient utilization of materials could potentially lead to cost savings during construction and reduced environmental impact.
- Space Optimization: Optimized layouts can grant greater flexibility in planning interior spaces. With fewer shear walls, there's more creative freedom to design open floor plans or allocate space for diverse functions without compromising the structural soundness.
- Accelerated Construction: By streamlining the design for efficiency, optimized layouts have the potential to simplify the construction process. This might result in reduced construction time and related expenses.

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- Encouragement of Innovation: The pursuit of optimized layouts often involves employing sophisticated computational tools and algorithms. This can stimulate structural engineers to explore inventive solutions that might not be evident through conventional design approaches.

Drawbacks:

- Complex Analytical Requirements: Creating an optimized shear wall layout necessitates the application of advanced structural analysis methods and software. This could demand a higher level of expertise among structural engineers and potentially introduce greater complexity to the project.
- Risk of Excessive Optimization: There's a risk that excessive optimization could yield designs that are overly sensitive to minor changes or variations. This might lead to unexpected complications during construction or the building's service life.
- Limited Applicability: Not all buildings or locations are suitable for optimized layouts. Factors such as local building codes, site conditions, and architectural constraints could hinder the feasibility of implementing such designs.
- Higher Initial Costs: While optimized layouts might reduce material consumption, the upfront costs linked with advanced analysis and design tools could counterbalance the material savings, especially for smaller projects.
- Acceptance and Perception: The adoption of optimized layouts might encounter resistance within the construction industry, particularly if they significantly deviate from established practices. Convincing stakeholders of their effectiveness might require additional effort.
- Maintenance and Repairs: Unconventional layouts could pose challenges for maintenance and repair work. Contractors and maintenance personnel might not be as familiar with these designs, potentially leading to difficulties in addressing issues over time.

V. Conclusion

In conclusion, this research methodology entails a systematic progression of steps, from literature review to practical comparison, aimed at assessing the structural performance of an optimized shear wall layout against a conventional model. The evaluation is conducted while considering crucial constraints related to drift and displacement, contributing to informed design decisions and safer construction practices. The decision to employ an optimized shear wall layout should be based on a comprehensive evaluation of the project's specific needs, constraints, and the expertise available within the design team. While such layouts offer the potential for heightened structural performance and resource efficiency, they also come with challenges tied to complexity, applicability, and industry acceptance.

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