Retrofitting Strategies for Enhancing Structural Performance and Redesigning

Alpesh H. Patil[1], Smita B. Patil[2], Sikandar A. Rasal[3]

[1]*Post Graduate Student, Dept. of Civil Engineering, Datta Meghe College of Engineering, Airoli, Navi Mumbai 400708, Maharashtra, India*

[2] *Associate Prof. Department of Civil Engineering, Datta Meghe College of Engineering, Airoli, Navi Mumbai 400708, Maharashtra, India*

[3] *Assistant Professor, Dept. of Civil Engineering, Datta Meghe College of Engineering, Airoli, Navi Mumbai 400708, Maharashtra, India*

***Abstract*— Inappropriate way of construction is a critical issue that can result in structural failures, safety hazards, costly repairs, and legal complications. This paper focuses on identifying construction defects, assessing their impact, and implementing retrofitting techniques to enhance structural integrity. The study evaluates various causes of faulty construction, including design errors, substandard materials, workmanship failures, and environmental factors. Structural defects such as foundation issues, inadequate load distribution, and poor waterproofing are analysed to determine their effects on a building's longevity and safety. The paper utilizes ETABS software for structural analysis and validation, comparing computational results with manual calculations. The project applies retrofitting techniques, including foundation strengthening, reinforcement with carbon fiber-reinforced polymer (CFRP), and seismic retrofitting strategies like base isolation and shear wall installation. These methods aim to restore the structural capacity of buildings while ensuring compliance with modern safety standards. A case study on a G+1 residential structure with identified defects is conducted to demonstrate the effectiveness of retrofitting solutions. The study assesses the economic feasibility of these solutions, emphasizing cost-effective and sustainable approaches. Findings indicate that strategic retrofitting not only improves structural safety but also extends the lifespan of buildings, reducing maintenance costs and environmental impact. The project highlights the importance of stringent construction quality control, periodic inspections, and adherence to building codes. By integrating structural assessment and retrofitting techniques, this research provides a comprehensive approach to mitigating construction failures and ensuring the resilience of buildings in diverse environmental conditions.**

Index Terms*— ETABS software, concrete jacketing, steel jacketing, CFRP wrapping, retrofitting solutions.

I. INTRODUCTION

Inappropriate way of construction is a complex issue that can arise from design flaws, substandard materials, poor workmanship, and inadequate oversight. These problems can lead to severe consequences such as structural failures, safety hazards, expensive repairs, legal disputes, and even a decrease in property value. The root causes often include inaccurate designs, the use of low-quality materials, errors in construction techniques, and a lack of proper inspections. Preventing faulty construction requires careful planning, strict adherence to building codes, the use of skilled labour, and regular inspections at every stage of work. By maintaining quality in design, materials, and execution, and ensuring proper supervision, it is possible to avoid costly and dangerous outcomes. When these measures are followed, buildings remain safe, durable, and compliant with safety standards. However, many existing structures suffer from such defects due to poor practices during construction. To overcome these problems, retrofitting techniques are widely used. Retrofitting allows old or defective buildings to be strengthened and upgraded without demolition. Methods such as concrete jacketing, steel jacketing, CFRP wrapping, and seismic retrofitting not only restore strength but also extend the building’s lifespan. Thus, retrofitting ensures safety, sustainability, and resilience for present and future demands.

II. REVIEW OF LITERATURE

Recent The literature review explores case studies and research findings on faulty construction and retrofitting methods. Common causes of failures include improper material selection, insufficient reinforcement, poor drainage systems, and non-compliance with regulations. Several studies emphasize the benefits of seismic retrofitting, strengthening beam-column joints, and using advanced materials like Carbon Fiber Reinforced Polymer (CFRP).

Fabian C. Hadipriono *et al.* (1986) analyzed 85 falsework collapses over 23 years and found three main causes: triggering events, weak designs, and poor monitoring. Failures worsened due to unclear roles among contractors, engineers, and owners. The study emphasizes proper design review, monitoring, and clear responsibilities to prevent future collapses.

Sadi Assaf et al. (1995) studied construction defects in Saudi Arabia through surveys of contractors, owners, and engineers. They identified 35 defect factors in six groups. Key issues were poor supervision, unqualified workers, and non-compliance with standards. The study highlights prevention, defect identification, and improved communication to reduce maintenance costs.

Sadi Assaf *et al.* (1996) examined design and construction defects in large Saudi buildings through surveys of contractors and owners. Eleven defect groups were found, mainly poor structural design, weak concrete cover, and inspection gaps. Early detection and correction of such defects were emphasized to reduce maintenance costs and improve construction quality.

Farshid Jandaghi Alaee *et al.* (2003) introduced CARDIFRC, a high-performance fiber-reinforced concrete, as a retrofitting method for damaged beams. Unlike steel plates or FRP laminates, CARDIFRC offers higher strength, ductility, and durability. Tests confirmed its effectiveness in improving flexural and shear performance, with ongoing studies on long-term and dynamic behavior.

Te-Hsiu Chen *et al.* (2006) studied pre-1970s RC beam-column joints prone to shear failure in earthquakes. They proposed a metallic diagonal haunch retrofit, which improved seismic performance by shifting plastic hinges, reducing stress, and enhancing stability. Tests validated its effectiveness, and a simplified design method confirmed its cost efficiency.

Masoud Motavalli *et al.* (2007) examined Fibre Reinforced Polymer (FRP) composites for retrofitting aging civil structures. FRP's light weight, easy installation, and effectiveness in flexural, shear, and confinement strengthening make it valuable for RC and masonry structures. Despite higher initial costs, lifecycle savings and emerging guidelines support its widespread application.

N. Ahzahar *et al.* (2011) discussed the seismic vulnerability of masonry structures, originally designed only for gravity loads. The study emphasized machine learning for damage detection, SHM for real-time monitoring, and sustainable retrofitting using smart materials. It highlighted the need for cost-effective methods and further research to safeguard heritage structures.

Yasmin Bhattacharya *et al.* (2011) studied non-engineered houses in India's seismic zones, focusing on low-income groups in Gujarat, Jammu & Kashmir, and Sikkim. Using research-by-design, they explored integrating thermal comfort with seismic retrofitting. Despite conflicting principles, the study proposed cost-effective solutions to improve safety and energy efficiency for vulnerable communities worldwide.

Phil Jones *et al.* (2013) analyzed housing retrofits in the UK to achieve an 80% CO_2 reduction by 2050. Using prediction models, they found shallow retrofits affordable but deep retrofits financially challenging. The study emphasized that current funding and regulations are inadequate, urging new financial models and policies for large-scale implementation.

Isaac Ofori *et al.* (2015) examined factors affecting building maintenance through surveys of private homeowners. Aging, poor materials, obsolescence, and environmental conditions were key causes of deterioration. Condition-based and corrective maintenance dominated. The study urged early consideration of maintenance in design, quality materials, skilled professionals, and stronger policies to ensure sustainability.

Maria Bostenaru Dan *et al.* (2018) examined seismic retrofitting of historic buildings using finite element modeling. Results showed preventive retrofitting is far more cost-effective than post-earthquake repairs, which can cost 3–8 times more. The study emphasized timely retrofitting to reduce risks, safeguard heritage, ensure safety, and minimize disruption to occupants.

M. Leeladhar Reddy *et al.* (2019) investigated RCC retrofitting using CFRP jacketing after column failures from added floors. ANSYS analysis showed major improvements: deformation reduced by 46.82%, shear forces by 49.59%, and bending moments by up to 79.26%. Stress and strain reductions confirmed CFRP's effectiveness in enhancing strength and durability.

Amritha Ranganadhan *et al.* (2019) studied seismic retrofitting in Kerala, where many older buildings were designed for outdated seismic codes. Analyzed under revised IS 1893:2002, columns showed deficiencies needing retrofitting. The study recommended Fibre Reinforced Polymer (FRP) wrapping as a cost-effective method to enhance seismic strength, safety, and resilience.

Gomasa Ramesh *et al.* (2020) emphasized repair and rehabilitation as vital for extending RCC structures' lifespan. While repairs enhance durability, retrofitting addresses seismic and environmental vulnerabilities. Techniques range from resin injection to specialized methods for major defects. Regular inspections and retrofitting ensure safety, functionality, and economic viability, keeping structures resilient over time.

Shreyash Dhage *et al.* (2022) highlighted the importance of structural auditing for modern buildings, many of which deteriorate before their service life ends. Using NDT and UPV tests, significant damage was identified in RCC components. The study recommended timely interventions like jacketing and modern repair techniques to ensure safety and longevity.

Sudha C *et al.* (2022) studied RC columns strengthened with RC and geopolymer concrete (GPC) jacketing under axial loads. Tests and FEM modeling showed load capacity tripled with RC jackets and increased 3.5 times with GPC. GPC outperformed RC, offering higher strength, stiffness, and reduced deflection, proving its superior retrofitting potential.

Elena Ciampa *et al.* (2023) investigated steel plate strengthening of RC structures, emphasizing cost-effectiveness, ductility, and stiffness compared to FRPs. Experimental tests assessed bond strength, load-displacement, and shear stress at the steel-concrete interface. Results showed steel plates' potential, but highlighted the absence of design guidelines, limiting broader application despite sustainability benefits.

Hoang An Le *et al.* (2024) studied RC stub columns jacketed with UHPC and UHPFRC under axial compression. Tests showed jackets significantly improved load capacity and ductility, especially with added steel fibers and thicker layers. FEM validation confirmed results, proving UHPC/UHPFRC jacketing an effective alternative for strengthening and repairing RC columns.

Mohammad Alharthai *et al.* (2024) analyzed RC beams strengthened with aluminum alloy (AA) plates using Abaqus. Epoxy-bonded plates improved shear capacity by 104%, while steel anchors alone caused buckling. A dual bonding system raised capacity by 164% and shifted failure to ductile bending. Side-plate configurations offered maximum load improvement and stability.

Ayoub Keshmiry *et al.* (2024) examine how masonry buildings, vulnerable to earthquakes, can be assessed, repaired, and retrofitted. Using machine learning and structural health monitoring, damage detection and maintenance are improved. The study promotes sustainable, cost-effective retrofitting with smart materials and climate-resilient strategies to enhance safety and preserve structures.

III. OBJECTIVES OF THE STUDY

1. To identify and analyze structural defects: The first step is to carefully study the building and detect any faults such as cracks, weak columns, poor materials, or design flaws. This helps in understanding the root causes of structural problems.
2. To assess the impact of defects on structural integrity: Once defects are identified, their effect on the building's safety, durability, and load-carrying capacity is evaluated. This ensures that the severity of the problem is properly understood.
3. To propose redesign solutions for the structure: Based on the analysis, redesign strategies are suggested to correct the faults and improve the overall performance of the structure.

4. To evaluate retrofitting techniques: Different retrofitting methods, such as concrete jacketing, steel jacketing, or CFRP wrapping, are studied to determine the most effective way to strengthen the defective parts of the structure.
5. To implement and test retrofitting solutions: The selected retrofitting techniques are applied to the model or structure, and their effectiveness is tested using software tools like ETABS or through practical analysis.
6. To provide cost-effective and sustainable solutions: Finally, the goal is to recommend solutions that are not only structurally sound but also economical and sustainable, ensuring long-term safety and efficiency.

IV. METHOD OF ANALYSIS

A. The study follows a four-phase methodology to assess and improve structural performance:

1. Preliminary Assessment
   - Visual inspections to detect cracks, misalignment, and material deterioration.
   - Review of design documents to identify structural weaknesses.
2. Structural Analysis using ETABS
   - Load distribution study to evaluate weak points.
   - Simulation of stress concentrations and failure points.
3. Retrofitting Implementation
   - Application of, concrete jacketing, and steel reinforcements.
   - Seismic retrofitting for enhanced earthquake resistance.
4. Post-Retrofit Evaluation
   - ETABS simulations to verify strength improvements and load redistribution.
   - Cost analysis comparing post-retrofit performance

B. Retrofitting Techniques and Implementation

To address structural deficiencies, the following techniques are applied:

1. Concrete Jacketing
   Description: Adding reinforced concrete layers to columns and beams.
   Advantages: Increases strength, improves ductility, and extends service life.
2. Steel Jacketing
   Description: Encasing structural elements with steel plates.
   Advantages: High tensile strength, ideal for seismic retrofitting.

V. STRUCTURAL MODELLING

Analyzing the data: Following data are used in the model

1. Size of Building: 20.3 m X 6 m.
2. Grade of concrete: M 30
3. Grade of steel: Fe 415
4. Slab thickness: 200 mm
5. Size of columns,
   a. 500mm × 500mm (C1 to C5)
   b. 350mm × 600mm (C6 to C10)
6. Size of beam: 300mm × 500mm
7. Dead load: 3.kn/m^2
8. Live load on top slab: 5 KN/m ^{2}
9. Floor finishes is 3 KN/m ^{2}
10. Density of concrete: 25 KN/m ^{3}

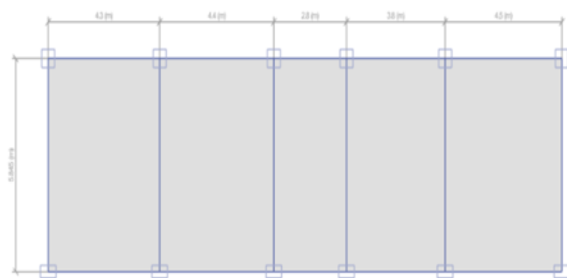

Fig. 1: Plan view of the actual structure

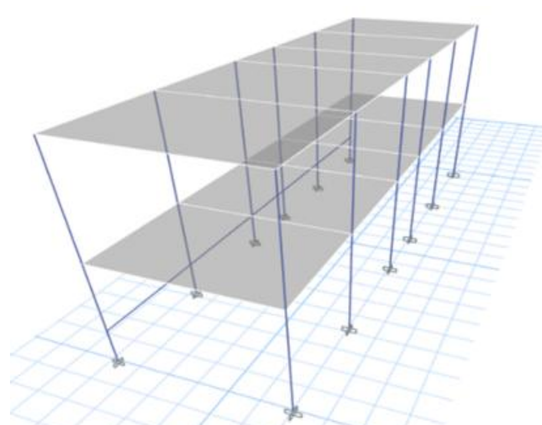

Fig. 2: 3D view of the Plan of the actual structure

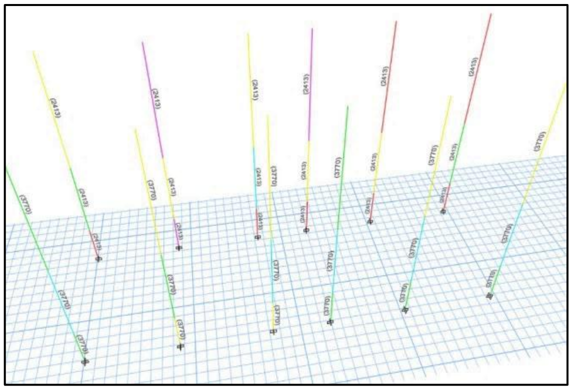

Fig. 3: Result of analysis on the ETABS of the actual structure plan.

Figure 3 shows the analysis results of the model. After applying the loads, and the red color highlights the columns with major failures.

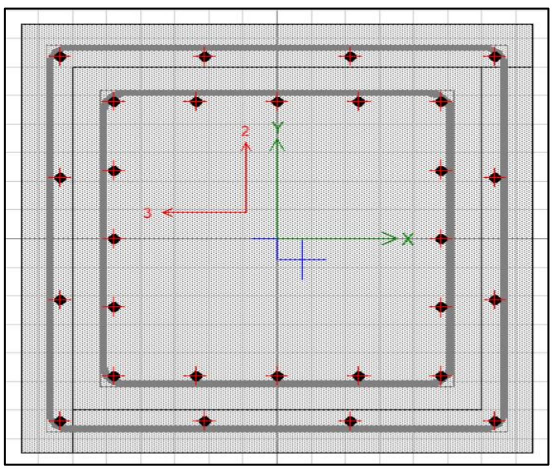

Fig. 4: concrete jacketing details of columns (C1 to C5)

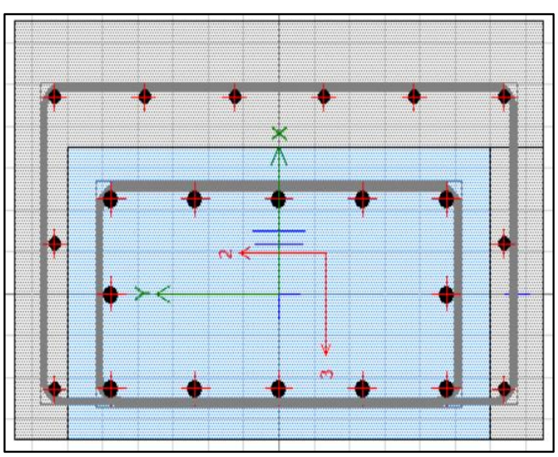

Fig. 5. concrete jacketing details of columns (C6 to C10)

Figure 4 shows jacketing details of columns from C1 to C5 with 12 bars of T16 ϕ as main bar and T10 ϕ 150mm c/c for stirrups covering all 4 sides. Figure 5 shows jacketing details of columns from C6 to C10 with 10 bars of T16 ϕ as main bar and T10 ϕ 150mm c/c for c type stirrups covering 3 sides.

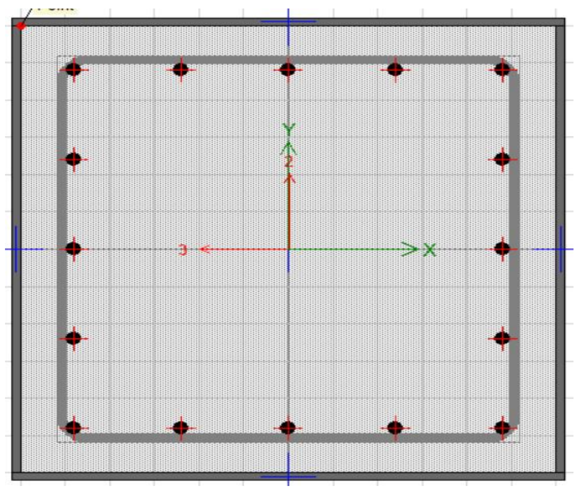

Fig. 6: Steel jacketing details of columns (C1 to C5)

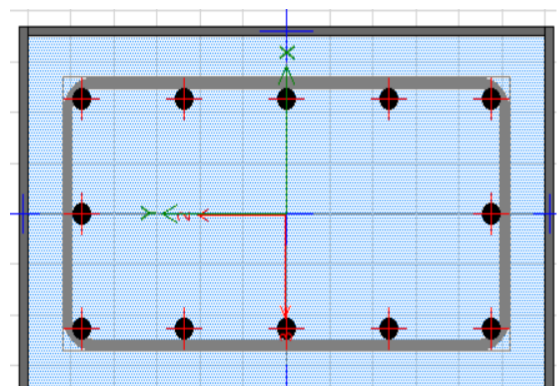

Fig. 7: Steel jacketing details of columns (C6 to C10)

Figure 6 shows steel jacketing details of column from C1 to C5 with 10mm thick steel plate covering all 4 sides. Figure 7 shows steel jacketing details of column from C6 to C10 with 10mm thick steel plate covering 3 sides.

Table 1: Story response (story displacement X-direction)

Story	Elevation	Location	X-Dir Existing	X-Dir Concrete	X-Dir Steel
	m		mm	mm	mm
First	10.9288	Top	12.032	9.021	9.179
Ground	5.5288	Top	5.594	3.8	3.922
Basement	1.8288	Top	1.162	0.679	0.718
Base	0	Top	0	0	0

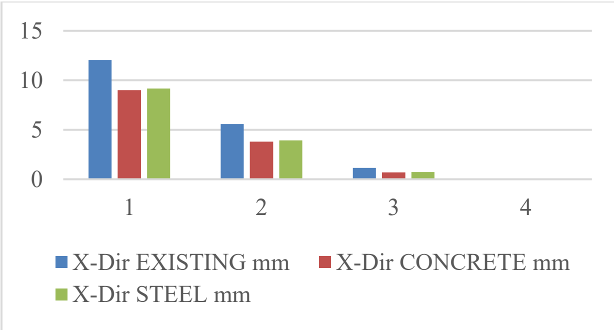

Fig. 8: Story response (story displacement X-direction)

Table 2: Story response (story displacement Y-Direction)

Story	Elevation	Location	Y-Dir Existing	Y-Dir Concrete	Y-Dir Steel
	m		mm	mm	mm
First	10.9288	Top	18.052	13.749	14.023
Ground	5.5288	Top	8.521	5.468	5.653
Basement	1.8288	Top	1.767	0.903	0.971
Base	0	Top	0	0	0

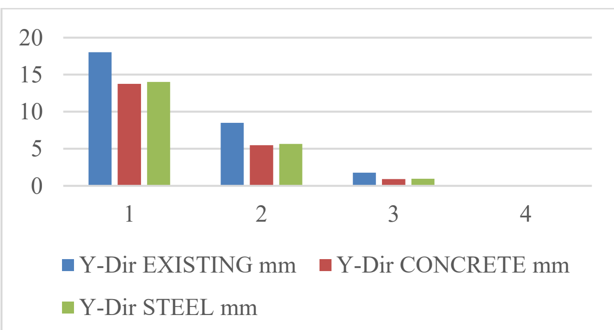

Fig. 9: Story response (story displacement Y-direction)

Table 1 and 2 shows the story displacement in X and Y direction of existing structure and after working with concrete jacketing and steel jacketing which is displayed in graph format in Figure 8 and 9.

Table 3: Story response (story drift X-Direction)

Story	Elevation	Location	X-Dir Existing	X-Dir Concrete	X-Dir Steel
	m				
First	10.9288	Top	0.00121	0.00097	0.000974
Ground	5.5288	Top	0.00124	0.00086	0.000884
Basement	1.8288	Top	0.00064	0.00037	0.000393
Base	0	Top	0	0	0

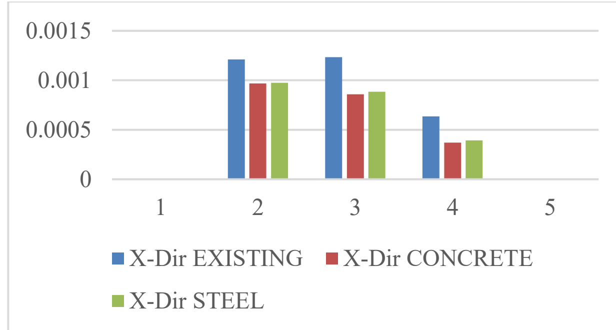

Fig. 10: Story Response (story drift X-direction)

Table 4: Story Response (Story drift Y-Direction)

Story	Elevation	Location	Y-Dir Existing	Y-Dir Concrete	Y-Dir Steel
	m				
First	10.9288	Top	0.001766	0.001536	0.001552
Ground	5.5288	Top	0.001883	0.00125	0.001289
Basement	1.8288	Top	0.000966	0.000494	0.000531
Base	0	Top	0	0	0

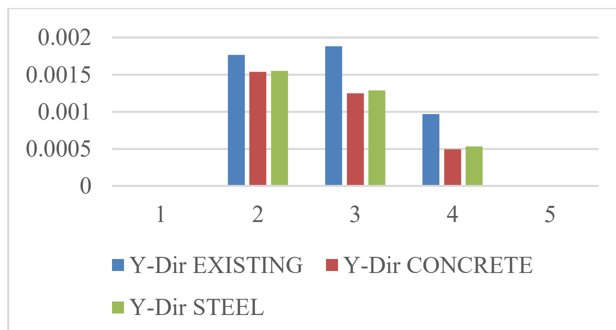

Fig. 11: Story Response (Story drift Y-direction)

Table 3 and 4 shows the story Drift in X and Y direction of existing structure and after working with concrete jacketing and steel jacketing which is displayed in graph format in Figure 10 and 11.

Table 5: Story Response (overturning movement X-direction)

Story	Elevation	Location	Y-Dir Existing	Y-Dir Concrete	Y-Dir Steel
	m		kN-m	kN-m	kN-m
First	10.9288	Top	0	0	0
Ground	5.5288	Top	-2182.41	-2936.74	-2802.14
Basement	1.8288	Top	-4196.51	-5634.42	-5381.29
Base	0	Top	-5192.01	-6967.8	-6656.09

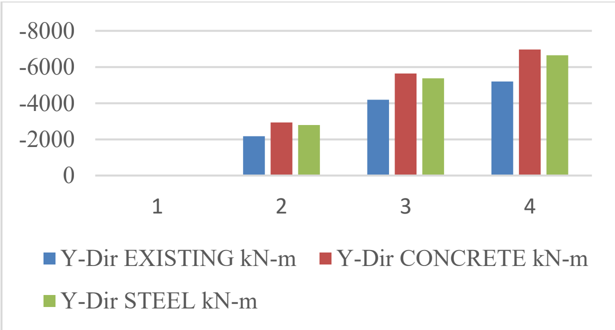

Fig. 12: Story Response (overturning movement X-direction)

Table 6. Story Response (Overturning Movement Y-Direction)

Story	Elevation	Location	X-Dir Existing	X-Dir Concrete	X-Dir Steel
	M		kN-m	kN-m	kN-m
First	10.9288	Top	0	0	0
Ground	5.5288	Top	1495.148	2350.408	2196.889
Basement	1.8288	Top	2874.985	4509.48	4218.955
Base	0	Top	3556.998	5576.645	5218.403

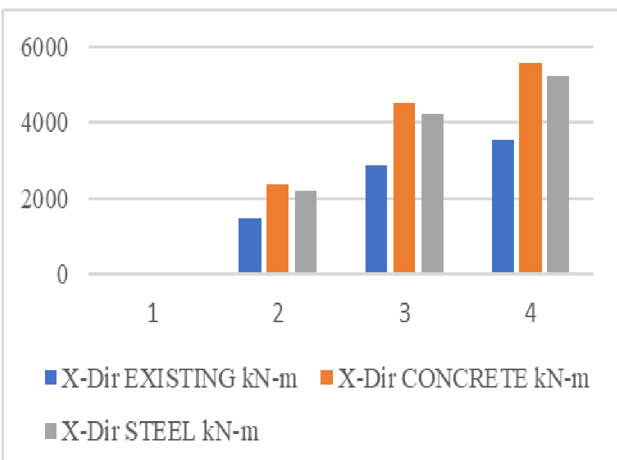

Fig. 13: Story Response (Overturning Movement Y-direction)

Table 5 and 6 shows the Overturning Movement in X and Y direction of existing structure and after working with concrete jacketing and steel jacketing which is displayed in graph format in Figure 12 and 13.

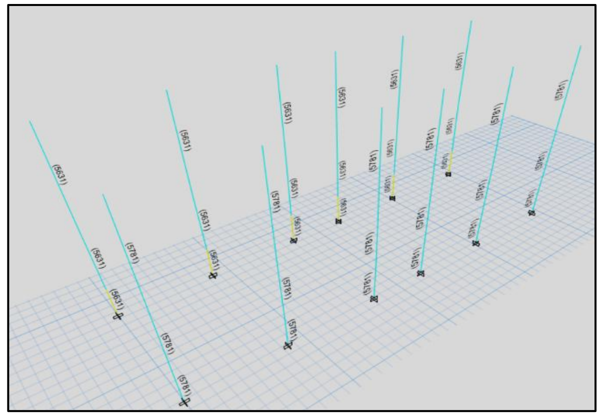

Fig. 14. Result of analysis on the ETABS of the structure plan after using concrete jacketing method.

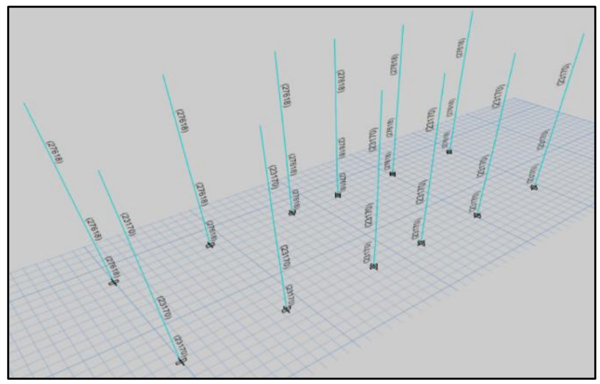

Fig. 15: Result of analysis on the ETABS of the structure plan after using steel jacketing method.

VII. CONCLUSION

The structural analysis of the original building revealed significant failures in the columns when subjected to design loads, indicating critical weaknesses that could compromise the overall stability and safety of the structure. These failures necessitated the implementation of strengthening techniques to restore and enhance the structural integrity. Two primary retrofitting methods—concrete jacketing and steel jacketing—were applied and thoroughly evaluated for their effectiveness in improving the building's performance.

Concrete jacketing significantly enhanced both the strength and stiffness of the affected columns. By increasing the cross-sectional area and providing additional confinement, this method improved the columns' load-carrying capacity, resulting in a notable reduction in displacement, lateral drift, and overturning moments during load application. The added rigidity from concrete jacketing contributed to a more robust structural response, effectively mitigating potential failure mechanisms.

Steel jacketing, while slightly less effective than concrete jacketing in reducing displacement and improving stiffness, offered distinct practical advantages. Its installation process was simpler, quicker, and less labor-intensive, making it a preferred option in scenarios where minimizing construction time and disruption is critical. The steel jackets also provided effective confinement to the columns, enhancing their ductility and overall seismic performance.

Both retrofitting techniques demonstrated their capability to significantly enhance the safety and durability of the structure. By addressing the weaknesses identified in the original design, these methods not only prevented further deterioration but also extended the building's service life. The choice between concrete and steel jacketing can thus be guided by project-specific considerations such as required performance levels, time constraints, and budget.

The study confirms that strategic application of concrete and steel jacketing are reliable and effective solutions for column strengthening, contributing to improved structural resilience against applied loads and ensuring long-term safety and serviceability of buildings.

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