Adapting Infrastructure for Modern Needs

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ABSTRACT

The concept of retrofitting existing structures has gained significant traction in recent years as societies grapple with the challenges of aging infrastructure and evolving needs. This abstract delves into the critical aspects of retrofitting, emphasizing its importance in enhancing the functionality, sustainability, and resilience of infrastructure. Retrofitting involves the strategic modification of existing buildings, bridges, and other structures to meet contemporary standards, address safety concerns, and incorporate innovative technologies.One of the primary motivations behind retrofitting is the necessity to adapt infrastructure to changing environmental conditions and socio-economic demands. With climate change exerting unprecedented pressures on built environments, retrofitting offers a sustainable solution to mitigate risks and minimize environmental impacts. By incorporating energy-efficient systems, such as green roofs, solar panels, and advanced insulation, existing structures can significantly reduce their carbon footprint and contribute to the global effort towards sustainability.

Retrofitting plays a pivotal role in enhancing the resilience of infrastructure against natural disasters and other unforeseen events. Through structural reinforcements, seismic upgrades, and flood-proofing measures, existing buildings and bridges can better withstand extreme conditions, safeguarding lives and minimizing economic losses. Moreover, retrofitting offers an opportunity to improve accessibility and inclusivity, ensuring that infrastructure remains functional and accommodating for all members of society.In addition to addressing functional and environmental concerns, retrofitting also presents economic advantages. By prolonging the lifespan of existing structures and optimizing their performance, retrofitting projects can yield substantial cost savings compared to the construction of new facilities. Moreover, retrofitting initiatives create employment opportunities, stimulate local economies, and foster innovation within the construction industry.

Keyword: - *Retrofitting, Existing Structures, Infrastructure, Modern Needs, Sustainability.*

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1. Introduction

The construction industry has been an essential driver of societal development, shaping the way people live, work, and interact with their environments. As societies evolve, so do the needs and demands placed on infrastructure. In response to this evolution, the concept of retrofitting existing structures has emerged as a sustainable solution to adapt infrastructure to modern needs while minimizing environmental impact and maximizing resource efficiency.

Traditionally, when a structure needed to be transformed or repurposed, the common approach was to demolish and rebuild from scratch. However, this method not only generates significant amounts of waste but also consumes vast amounts of energy and resources. In an era where sustainability is paramount, such practices are no longer viable. Retrofitting, on the other hand, offers a more sustainable alternative by leveraging existing infrastructure and modifying it to meet contemporary requirements.The primary objective of retrofitting is to enhance the functionality, efficiency, and resilience of existing structures while minimizing environmental impact. This approach aligns with the overarching goal of sustainable development, which seeks to balance economic growth with environmental stewardship and social equity. Retrofitting enables the preservation of embodied energy in existing buildings and infrastructure, thereby reducing the carbon footprint associated with new construction and minimizing waste generation.

Retrofitting plays a crucial role in addressing the pressing challenge of climate change. By improving the energy efficiency of buildings and infrastructure, retrofitting projects contribute to the reduction of greenhouse gas emissions and help mitigate the adverse impacts of climate change. Energy-efficient retrofits, such as the installation of insulation, energy-efficient lighting, and HVAC systems, not only reduce operating costs for building owners but also contribute to broader efforts to combat climate change.Furthermore, retrofitting existing structures can enhance their resilience to natural disasters and other external shocks. With the increasing frequency and severity of extreme weather events, resilient infrastructure is more critical than ever. Retrofitting projects can include measures such as seismic upgrades, flood-proofing, and structural reinforcements, which help buildings and infrastructure withstand the forces of nature and minimize damage.

Its environmental and resilience benefits, retrofitting also offers economic advantages. By prolonging the lifespan of existing structures and optimizing their performance, retrofitting projects can generate cost savings over the long term. Moreover, retrofitting initiatives create employment opportunities, stimulate local economies, and foster innovation within the construction industry.Several research studies have explored various retrofitting techniques and their impacts on building performance and environmental sustainability. For example, studies have investigated the effectiveness of different energy conservation measures, such as insulation upgrades and renewable energy systems, in reducing greenhouse gas emissions and improving energy efficiency. Additionally, research has focused on innovative retrofitting solutions, such as carbon-fiber reinforced polymer (CFRP) external strengthening, to enhance the structural integrity of existing buildings and infrastructure.

2. Study Area

Literature Review:

Ali Q. (2009): Ali Q.'s "Seismic Retrofitting and Repair Manual for Buildings," published in 2009 by the NWFP University of Engineering and Technology in Peshawar, Pakistan, is a comprehensive resource for professionals involved in retrofitting existing buildings to enhance their seismic resilience. This manual addresses the urgent need for resilient infrastructure in earthquake-prone regions like Pakistan.The manual covers various aspects of seismic retrofitting, including structural assessment, strengthening techniques, and repair methodologies. It provides practical insights and guidelines drawn from both theoretical principles and real-world case studies. By offering a systematic approach to retrofitting, Ali Q. empowers engineers, architects, and policymakers to mitigate the impact of earthquakes on existing structures.

One of the strengths of Ali Q.'s manual is its emphasis on practical applicability. It not only discusses theoretical concepts but also provides step-by-step procedures and best practices for implementing retrofitting projects. This makes the manual a valuable resource for professionals working in the field, as it offers actionable guidance for assessing existing buildings, identifying vulnerabilities, and implementing appropriate retrofitting measures.Furthermore, the manual addresses the socio-economic implications of seismic retrofitting.

Plevri E. (2015): Anagnostopoulos et al.'s study, published in the journal Earthquakes and Structures in 2015, examines the role of accidental eccentricity in Eurocode 8, a set of European standards for seismic design. The authors, affiliated with the Department of Civil Engineering at the University of Patras in Greece, evaluate whether eliminating accidental eccentricity from Eurocode 8 would simplify seismic design procedures without compromising structural safety.The study involves a comprehensive analysis of structural behavior and design provisions, considering various scenarios and seismic loading conditions. Through rigorous analysis and simulation techniques, Anagnostopoulos et al. assess the implications of eliminating accidental eccentricity on the seismic performance of structures. They evaluate factors such as structural integrity, stability, and deformation under seismic loading, comparing different design approaches and criteria.

Astaneh, A.A. (2001): Astaneh's work on "Seismic Behavior and Design of Steel Shear Walls," published in 2001 by the Structural Steel Education Council's Technical Information and Product Service in Berkeley, California, USA, provides valuable insights into the seismic performance and design considerations of steel shear walls. This publication addresses the critical need for robust seismic design strategies in structural steel construction.The study delves into the behavior of steel shear walls under seismic loading conditions, examining factors such as lateral stiffness, strength, and ductility. Astaneh's research offers comprehensive guidance on the design and detailing of steel shear walls to enhance their seismic resistance and ensure structural integrity during earthquakes.

Bai J. (2003): Bai's study on "Seismic Retrofit for Reinforced Concrete Building Structures," presented in the Consequence-Based Engineering Institute Final Report at Texas A&M University in Texas in 2003, addresses the pressing need for retrofitting existing reinforced concrete buildings to enhance their seismic resilience. This report sheds light on the challenges and opportunities associated with retrofitting strategies for reinforced concrete structures.The study explores various retrofitting techniques and methodologies aimed at improving the seismic performance of reinforced concrete buildings. Bai discusses factors such as structural deficiencies, vulnerability assessments, and retrofitting measures, offering insights into the selection and implementation of appropriate retrofitting solutions. Through case studies and practical examples, Bai demonstrates the effectiveness of retrofitting in mitigating the seismic risk posed by existing reinforced concrete structures.

3. Analysis 1 – (10 – Storey commercial building)

In the process of modeling and analyzing a building structure using the ETABS program, all the pertinent data utilized were sourced directly from field investigations and design documents provided by the consultant. This data primarily comprised the dimensions of each structural element, critical for accurately representing the building's geometry and load-bearing capacity within the software. Additionally, essential material properties such as the grade of concrete and grade of steel were extracted from the design document to ensure precise simulation of structural behavior. Subsequently, the building structure was meticulously modeled within the ETABS program, allowing for a comprehensive analysis of its response to various loads and conditions. Through this analysis, data on strip forces and potential failure modes were obtained, providing crucial insights into the structural behavior under gravity loads. By integrating field data and design specifications into the analysis process, the ETABS program facilitated a thorough examination of the building's structural integrity and performance, aiding in the identification of key factors influencing its behavior.

Data of Existing Structure:

For the study, a 10-storey commercial park was selected, featuring a well-designed top view layout and framing layout as depicted in figures 1 and 2. The structural system of the building comprises a moment-resisting reinforced concrete (RC) frame with a flat plate flooring system, 250mm thick. All structural members are constructed using reinforced concrete materials. The building has a floor height of 4 meters, with all columns uniformly sized at 800mm x 800mm, and perimeter beams having a cross-sectional dimension of 800mm x 600mm. Design strips were applied at the 4th storey along the y-axis (layer A) and the x-axis (layer B), further divided into column and middle strips. Additionally, the structure incorporates a core wall housing 6 lifts and a staircase, featuring a 300mm thick shear wall. Beam dimensions within the core region are 600mm x 450mm, while flat plates have a thickness of 200mm. The 3D model of the building structure was developed using the ETABS program, as illustrated in figures 3 and 4, with beam and column sections designed as frame elements. Subsequently, strip forces and moments generated were analyzed and presented in figure 5.

In analyzing the building for gravity loads, all design load combinations specified in the IS: 456 standard codes were considered. The RC frame structure was assessed in accordance with the guidelines outlined in the IS: 456 standard codes. Live and dead loads were determined as per IS: 875 (Part-I) standards. The compressive strength of concrete was assumed to be 25 MPa, while the yield strength of steel reinforcement bars was taken as 500 MPa for both longitudinal and transverse reinforcement components. This comprehensive approach ensured that the structural performance of the commercial park was evaluated under realistic loading conditions, adhering to established industry standards and guidelines.

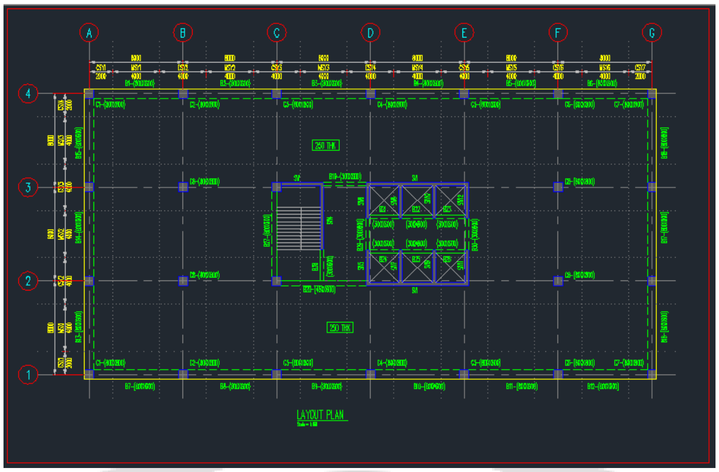

Fig. 1. The plan layout of the building

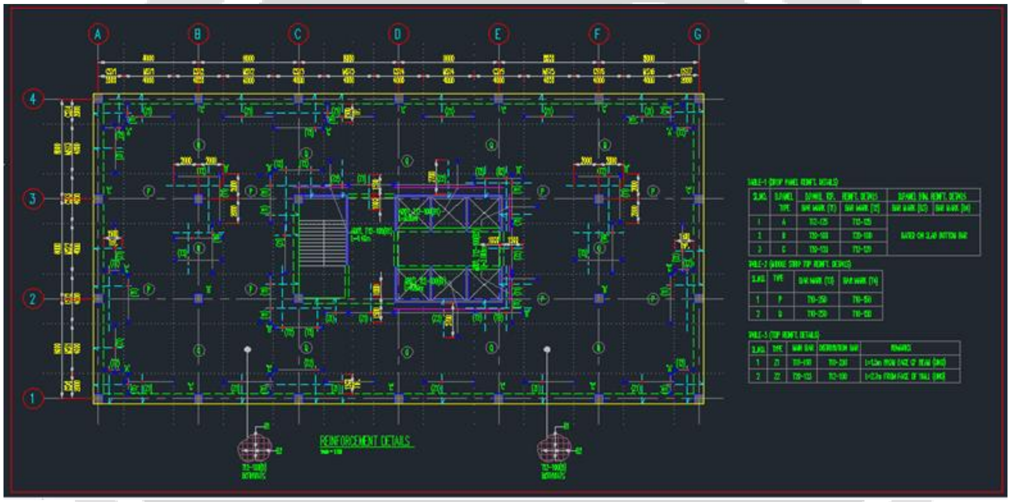

Fig. 2. The framing layout of the building

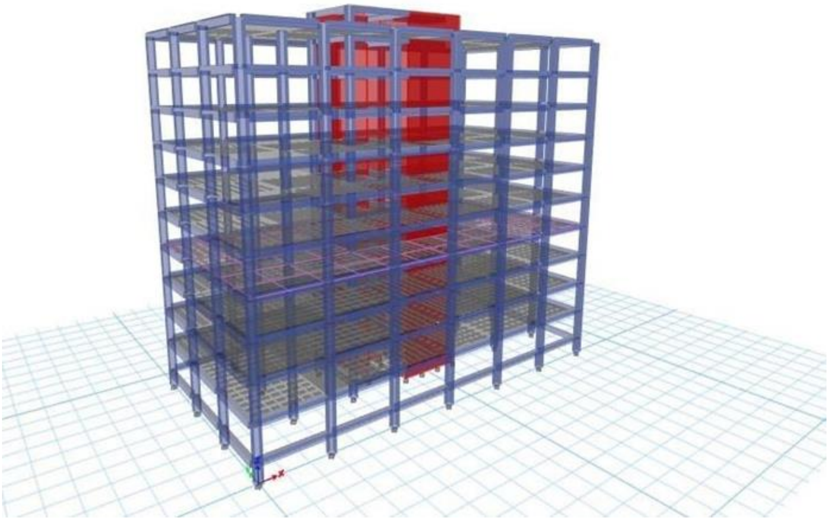

Fig. 3.The 3D model of the existing building by using ETABS.

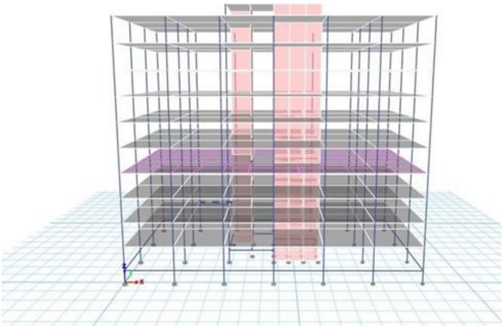

Fig. 4.The structural model of the existing building by using ETABS.

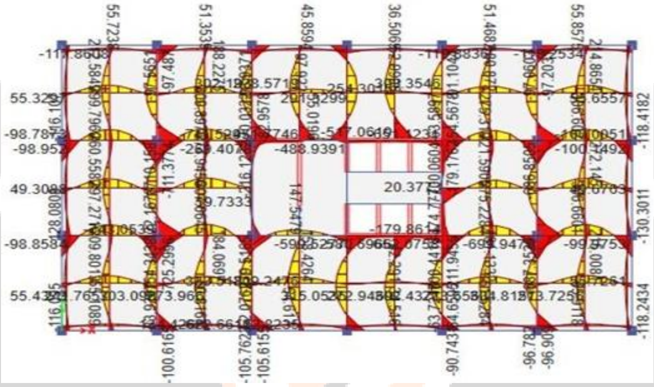

Fig. 5. The strip forces along the x and y axis and its structural moment reactions.

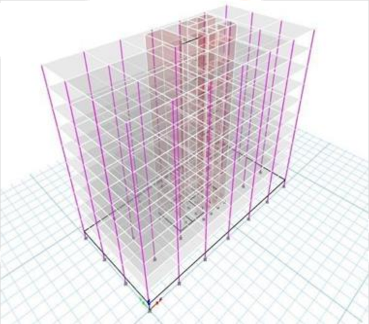

Fig. 6. The analyzed model shows no modes of failure occurring on the structural elements.

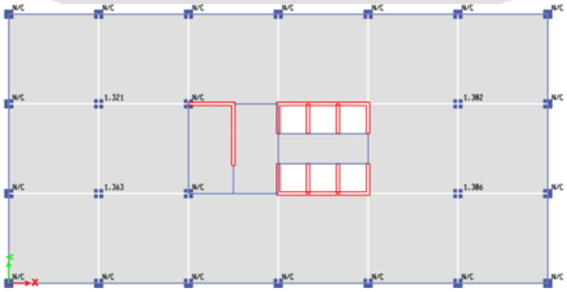

Fig. 7. The analyzed model shows the encompassed flat slab is stable against punching shear.

Load Bearing Capacity of the Existing Structure:

The structural analysis yielded critical insights into the capacity of various structural elements within the building system. Key parameters such as bending and shear capacities for beams, shear capacities for columns, and strip moments were meticulously assessed. By evaluating these results, the ability of structural elements to withstand the combination of loads imposed on them could be effectively determined. Remarkably, the analysis revealed no identifiable failure modes for columns and slabs, indicating their robustness and adequacy to withstand the applied loads. This outcome underscores the effectiveness of the structural design and reinforces confidence in the building's overall structural integrity. The absence of failure modes signifies that the structural elements possess sufficient strength and resilience to support the anticipated loads without compromising safety or performance. Consequently, the results of the structural analysis provide assurance regarding the structural stability and reliability of the building under various loading scenarios.

Beam Capacities:

A thorough review of beam capacities, considering various sections and positions, aimed to ascertain their flexural and shear nominal capacities relative to internal forces generated by applied loads. Notably, the 450mm x 600mm core beam demonstrated sufficient strength to withstand bending moments and shear forces, affirming its suitability for structural demands. This underscores the importance of thoughtful beam design and placement in ensuring optimal structural performance and safety.

Table 1. Beam family

Type	Beam name	Size
Beam	B1 - B18 Perimeter beam	
		800mm x 600mm
	B27, B20 Stair case	
		450mm x 600mm
	B19, B21-B26, B28-B30 Core wall	300mm x 600mm

Table 2. Properties of Steel

Property	Value
Density	7850 kg/m³
Young's Modulus	210000MPa
Poisson's Ratio	0.3

Table 3. Reinforcement details for beam

Reinforcement bars provided for commercial building			Bending Moment
Beam	**Topandbottomreinforcement**	**Distributionbars**	
B1 @450x 600 mmsupport	20mmΦbars.4Nos.	10mmΦ@100mmspacing	284kNm
B1 @450x 600 mmmidspan	20mmΦbars.4Nos.	10mmΦ@200mmspacing	284kNm

Table 4. Reinforcement details for slab

Slab	Reinforcementbarsforcommercialbuilding.(Topandbottombars)	BendingMoment
250 mm thickness column strip @ support	200 mm Φ @ 100 mm spacing	744 kNm
Column strip @ middle span	12 mm Φ @ 100 mm spacing	305 kNm
Middle strip @ support	10 mm Φ @ 200 mm spacing	211 kNm
Middle strip @ mid span	12 mm Φ @ 100 mm spacing	80 kNm

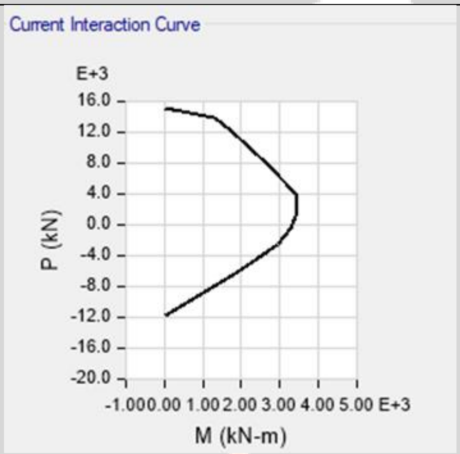

Fig. 8.The P-M interaction graph for columns (Commercial Building).

Column capacities:

The P-M interaction diagrams provide a graphical representation of a column's capacity to withstand axial and bending moments resulting from applied loads, as depicted in Figure 8. Each point on the diagram illustrates a specific combination of axial force and bending moment acting on the column. For instance, in column C1, the internal forces remain within the nominal moment and axial reduction limits, indicating the column's ability to effectively resist the imposed loads. Furthermore, the analysis of shear force capacity reveals that all columns are capable of withstanding the shear forces exerted on the structure. Consequently, during the identification of potential failures, it was determined that the columns remained stable and operated within permissible limits. This assessment underscores the structural integrity of the columns, affirming their capacity to safely support the applied loads without experiencing failure.

Flat plate against punching shear:

The flat plate integrated into the structure exhibited safety against punching shear, as demonstrated in Figure 7. With a punching shear ratio of 1.36, well below the permissible limit of 1.5, and a nominal shear stress (tv) of 1.69 N/mm², falling within the range of the calculated maximum permissible shear stress of 1.88 N/mm² and the permissible shear stress for M25 grade concrete of 1.25 N/mm², the section was deemed safe. Thus, with the addition of shear reinforcement, the flat plate section was confirmed to be structurally sound.

Upon evaluating the strength and performance of the existing commercial building structure, it can be inferred that the structure is capable of withstanding a combination of loads. Subsequently, to adapt the building's functionality from a commercial establishment to a data center storage facility, the imposed live load was revised from 5 kN/m² to 10 kN/m² in accordance with IS code (875 Part-II). This adjustment ensures that the structure can accommodate the increased load requirements associated with its new intended use, maintaining structural integrity and safety standards as per regulatory guidelines.

4. Analysis of retrofitted model

Retrofitting entails the incorporation of enhancements or modifications into an existing segment of a structure with the aim of bolstering its strength or load-bearing capacity. In recognition of the structural vulnerability characterized by significant column failure, the implementation of column jacketing emerges as a recommended course of action. This intervention involves the application of additional material, such as reinforced concrete or steel, around the existing columns to augment their structural integrity and resistance to loading forces. By fortifying the columns through jacketing, the overall stability and performance of the structure can be significantly improved, mitigating the risk of catastrophic failure and ensuring the safety and longevity of the building. Thus, column jacketing stands as a proactive measure to address existing structural deficiencies and enhance the resilience of the building against potential hazards.

Retrofit - Column Jacketing:

Column jacketing involves augmenting the size of a column by applying additional jackets around its perimeter. These jackets can be fabricated from various materials such as Fiber Reinforced Polymer, steel, or concrete. Concrete jacketing is a prevalent retrofitting method due to its compatibility with existing reinforced concrete (RC) column design and construction techniques. Through concrete jacketing, the column's axial and flexural strength can be enhanced by reinforcing the confinement and adding supplementary steel reinforcement. In the process of modeling columns and beams with jackets in software like ETABS, the cross-sectional dimensions are enlarged, and additional reinforcement is incorporated according to the planned enhancements for both columns and reinforcing beams.

In the specific scenario described, a concrete jacket with dimensions of 100 mm on each side was applied, effectively increasing the column size from 800 x 800 mm to 1000 x 1000 mm. Given the heightened steel percentage requirement for the data center application, a composite section for the column was adopted to accommodate the necessary reinforcement bars. The resulting configuration of the column post-jacketing is illustrated in Figure 9, demonstrating how this retrofitting technique can be employed to strengthen and enhance the structural capacity of existing columns in the building.

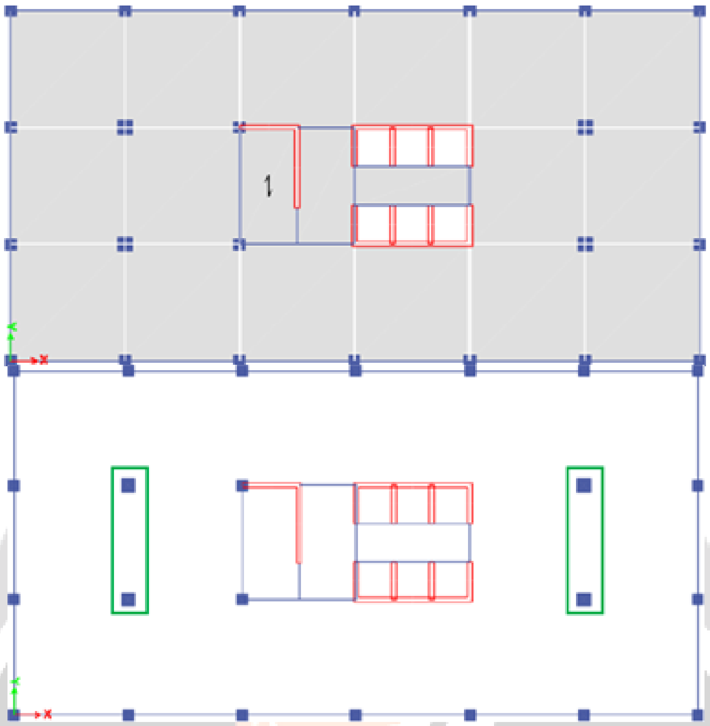

Fig. 9.Position of column after column jacketing.

Table 4. Column table

Condition	CommercialUtility	ColumnJacketing
Section %Ofsteel	800x800mm4.2%	1000x1000mm2.954%
Flexural reinforcementBars	34Nos.,32Φmm	36 Nos.,32Φmm

The implementation of the concrete jacketing method effectively enhances the load-bearing capacity of the columns, enabling the structure to efficiently carry both axial and bending moments. Post-jacketing analysis reveals that the columns exhibit increased capacity to withstand the working loads, particularly in terms of moment capacity. This improvement is evidenced by a decrease in the percentage of steel reinforcement from 6.43% to 2.954%, aligning with the prescribed limits outlined in IS: 456 standards. Consequently, this reduction in steel percentage allows for the accommodation of 32mm diameter bars within the column, which proves adequate to address concerns arising from the ground floor and 1st-floor columns not being subjected to significant bending moments from working loads. As such, the application of concrete jacketing successfully mitigates structural deficiencies and ensures that the columns are suitably equipped to handle the imposed loads, thus enhancing the overall stability and performance of the building.

2nd Retrofit – Column Capital:

The second retrofitting strategy implemented is the introduction of a Column Capital, as depicted in Figure 10. A column capital serves as the crowning member of the column, providing essential structural support and serving as a mediator between the column and the load applied to it. This feature is introduced with the aim of preventing slab failure resulting from punching shear. Prior to the addition of the column capital, the punching shear ratio was calculated to be 1.577, exceeding the allowable ratio of 1.5. The nominal shear stress (tv) was determined to be 2.28 N/mm², surpassing the permissible shear stress for M25 grade concrete of 1.25 N/mm², and the calculated maximum permissible shear stress of 1.88 N/mm². Consequently, the condition tcmax<tv>tc is met.To address this issue and enhance load-bearing capacity, the column capital is introduced. Adopting a dimension of 100 x 100 mm on each side of the column, the column capital effectively reinforces the column and redistributes the applied loads, thereby mitigating the risk of punching shear failure. This retrofitting solution ensures the structural integrity of the building by strengthening critical components and optimizing their performance under loading conditions, contributing to the overall safety and stability of the structure.

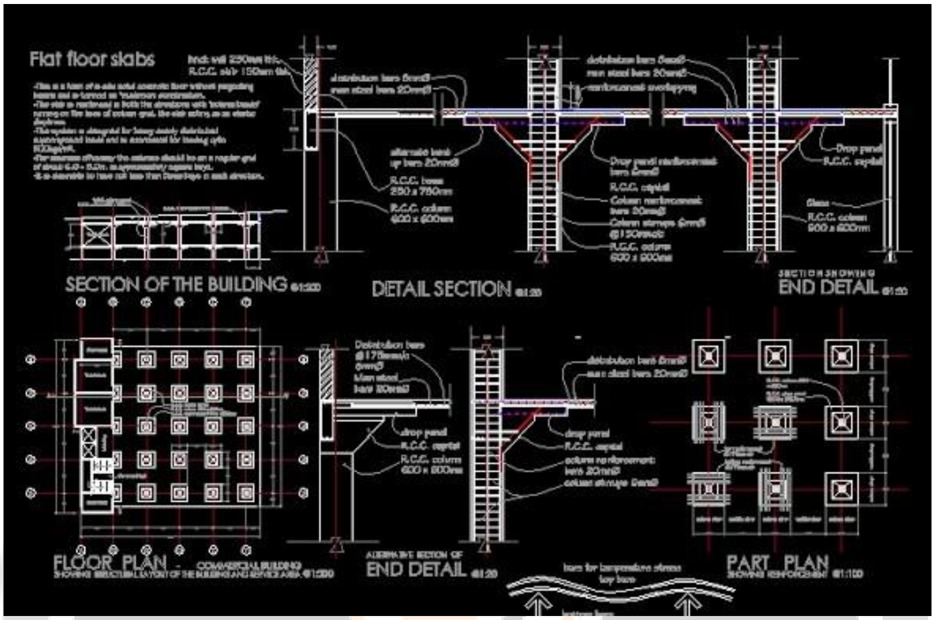

Fig 10.A typical section of a steel column capital.

5. Conclusion

The research aimed to convert a commercial building into a data center using retrofitting techniques, yielding several crucial findings. Initially, the structure was deemed safe for commercial use, with loading parameters well within permissible limits. However, upon analysis for data center functionality, severe issues emerged, including column loads surpassing safe limits, slab punching shear failures, and core wall beam failures. Column jacketing was implemented to bolster load-bearing capacity, though punching shear failures persisted due to flat slabs lacking drop panels. To address this, column capitals were introduced, effectively resolving all structural deficiencies. This analysis highlights the efficacy of retrofitting in enhancing structural functionality while ensuring safety and efficiency.

In conclusion, retrofitting presents a cost-effective and sustainable approach to adapt existing structures to contemporary requirements. By refurbishing rather than reconstructing, retrofitting minimizes costs, time, and energy consumption, aligning with the construction industry's shift towards sustainability. Thus, retrofitting stands as a pivotal strategy for future infrastructure endeavors, catering to evolving demands while prioritizing environmental conservation and resource efficiency.

6. References:

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