Structural Enhancement of RCC Beams Through Integrated External Prestressing and Concrete Jacketing Techniques

Swapnil G. Kamerkar[1], P. R. Barbude[2] and S. A. Rasal[3]
[1]*Post Graduate Student, Dept. of Civil Engineering, Datta Meghe College of Engineering, Airoli, Navi Mumbai 400708, Maharashtra, India*
[2] *Assistant Professor, Dept. 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*—The structural rehabilitation of reinforced cement concrete (RCC) beams has become increasingly vital due to aging infrastructure, evolving load demands, and environmental deterioration. This study investigates a hybrid strengthening technique that combines external prestressing and concrete jacketing to enhance the performance of single-span rectangular RCC beams. The objective is to evaluate the effectiveness of this integrated method in improving ultimate load capacity, stiffness, ductility, and crack control under peak stress conditions. External prestressing introduces favorable compressive stresses that counteract tensile forces, thereby reducing crack initiation and propagation. Concrete jacketing, on the other hand, increases the cross-sectional area and provides confinement, which enhances both flexural and shear strength. To assess the comparative performance, five beam specimens were analyzed using three-dimensional finite element analysis (FEA) in Midas Civil software. These included unstrengthened beams, beams strengthened with individual techniques, and beams strengthened using the combined method. The results demonstrate that the hybrid approach significantly outperforms the individual techniques. Beams retrofitted with both external prestressing and concrete jacketing exhibited higher ultimate load capacity, improved load deflection behavior enhanced crack resistance and energy absorption. This synergistic effect underscores the practical advantages of integrated strengthening strategies, especially for retrofitting deficient RCC beams in seismic zones, bridges, and industrial structures. The present study provides a framework for future applications and encourages the adoption of combined techniques for sustainable infrastructure rehabilitation.**

***Index Terms*—Structural Deterioration, Infrastructure Upgrading, Seismic Strengthening, Beam Rehabilitation, Aging Infrastructure, Integrated Strengthening, Synergistic Performance.**

I. INTRODUCTION

The structural integrity of reinforced cement concrete (RCC) beams is a critical concern in modern civil engineering, especially in the context of aging infrastructure, increased service loads, and exposure to adverse environmental conditions. Over time, these factors contribute to deterioration in strength, stiffness, and serviceability, necessitating effective strengthening strategies to restore and enhance performance. Among the various retrofit techniques available, external prestressing and concrete jacketing have emerged as two of the most promising solutions due to their complementary benefits.

External prestressing introduces controlled compressive forces into the beam, counteracting tensile stresses and mitigating crack formation. This active technique not only improves flexural capacity but also enhances serviceability by reducing deflections and extending fatigue life. Concrete jacketing, on the other hand, is a passive method that increases the cross-sectional area and provides confinement, thereby improving shear strength, ductility, and overall load resistance. When applied together, these methods offer a synergistic strengthening effect, combining the advantages of both active and passive systems.

This study investigates the combined application of external prestressing and concrete jacketing on single-span rectangular RCC beams using three-dimensional finite element analysis (FEA) in Midas Civil software. Five beam configurations including unstrengthened, individually strengthened, and hybrid-strengthened specimens are analyzed under ultimate load conditions to evaluate improvements in load-carrying capacity, stiffness, and failure behavior. The findings aim to provide a comprehensive understanding of the integrated technique's effectiveness and its potential for widespread use in the rehabilitation of deficient structural elements, particularly in seismic zones and high load environments.

Strengthening of the structure involves increasing the load-carrying capacity of a structure or member to meet the present or future demands. It often involves adding or modifying structural element. Strengthening is primarily concerned with improving the structural performance of a building. It is an effective alternative to rebuilding or reconstruction of existing structures. Strengthening of structural element of existing building created many challenges in civil engineering during recent years. There are many researches that studied different methods of strengthening. Strengthening is required due to Increase in a load over a time, such as load from additional floors or heavier equipment. Deterioration factors like corrosion, cracking, or exposure to harsh environments can weaken beams. Sometime seismic retrofitting is carried out to ensure the structural integrity during earthquakes. Upgradation in building codes may also necessitate strengthening of existing structures.

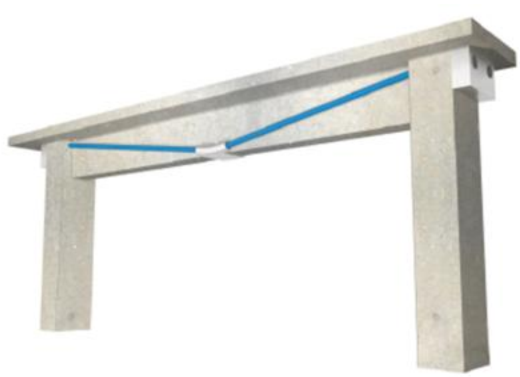

Fig 1: External Prestressed System of RCC beam

External prestressing is a specialized method used to strengthen existing reinforced concrete beams by applying tension through tendons placed outside the concrete section. Unlike traditional bonded prestressing, these external tendons often steel cables or fiber-reinforced polymers are not embedded within the concrete but are anchored externally and run along the beam's surface in straight or draped profiles. This system enhances the beam's flexural and torsional capacity, reduces deflections, and mitigates cracking, making it especially valuable for structures facing increased load demands or deterioration due to age or environment

II. REVIEW OF LITERATURE

The use of external prestressing tendons (EPT) for strengthening reinforced concrete (RC) and prestressed concrete members has evolved into a versatile and effective structural retrofitting method. This technique has been extensively explored over the last few decades, focusing on improving flexural strength, stiffness, crack control, and deflection recovery in deteriorated or underperforming structural members.

Early investigations, such as the work by M. Harajli et al. (1999), developed a nonlinear analytical model to predict the behavior of RC members strengthened with external tendons. This study highlighted the significant role of second-order effects and tendon eccentricity changes during deformation. It concluded that while external tendons generally result in lower nominal flexural resistance compared to bonded tendons, moderate levels of prestressing significantly improve deflection recovery, serviceability, and load-carrying capacity. Similarly, Hanaa I. El-Sayad and Karim M. El-Dash (2001) focused on externally confined concrete members using prestressed steel straps. Their findings demonstrated that confinement effectiveness varied with cross-sectional shape, strap spacing, and positioning, especially at the corners of rectangular elements.

Expanding on the design considerations, Arlyawardena and Ghali (2002) distinguished between bonded and unbonded systems, emphasizing friction losses and tendon behavior at deviators. They proposed a modification to the NU girder series for weight reduction while employing both pretensioned and externally post-tensioned tendons. In a comprehensive evaluation of strengthening parameters, Ahmed Ghallab (2005) assessed the ultimate stress in external tendons made from both steel and FRP (Parafil ropes). The study compared prediction equations from Eurocode, ACI318, and BS8110, concluding that tendon profile, depth, and deviator configuration critically influence tendon stress development.

T. Aravinthan (2005) explored tendon layout optimization for flexural enhancement of continuous beams. His findings suggested that while confinement improved ductility, it had little effect on ultimate strength. Also, moment redistribution was dependent on tendon profile and loading conditions. Hakan Nordin et al. (2005) provided a comprehensive review of external prestressing methods, evaluating performance differences between bonded FRP laminates and unbonded tendons. Key advantages included ease of inspection and maintenance, particularly for retrofitting existing structures.

In later developments, S. Saibabu *et al.* (2009) introduced an innovative anchoring method for external prestressing using end-block shear transfer. Experimental and finite element results showed ductile behavior and reduced deformation in retrofitted girder ends, affirming the method's practicality for bridge strengthening. Ali J. S. *et al.* (2013) proposed a novel analytical approach to account for beam-tendon interaction at deviators by modeling global deformation compatibility, offering reliable predictions up to the elastic limit.

Addressing torsional behavior, Hakim Khalil A. *et al*. (2015) examined RC box beams with and without web openings, strengthened using horizontally and vertically applied external tendons. Results showed torsional strength improvements up to 58%, with vertical tendon application proving more effective, especially in mitigating the weakening effects of web openings.

The benefits of external prestressing in bridge applications were outlined by Hanbing Zhu and Yaxun Yang (2015), who emphasized stiffness improvement, crack reduction, and minimal disruption during retrofitting. Tianlai Yu et al. (2016) focused on externally prestressed beams using CFRP tendons, showing significant gains in stiffness and flexural capacity. Their results indicated tendon angle, reinforcement ratio, and applied stress levels as key influencing factors, while concrete strength had a minor effect.

A broad literature review by Harpreet Kaur and Jaspal Singh (2017) summarized technical insights into design, construction, and mechanical behavior of EPT systems. The authors emphasized that although external prestressing avoids friction losses seen in bonded systems, its behavior deviates from conventional assumptions like plane sections remaining plane due to unbonded tendon action.

In terms of modeling and simulation, Li Jun (2018) used ANSYS to simulate external prestressing effects in bridge retrofitting. The model incorporated material and geometric nonlinearities, offering accurate predictions on tendon stress distribution and deformation. Similarly, Jinhua Zou *et al.* (2019) evaluated how deviator number, tendon shape, and tension method affect T-beams. Beams with V- and U-shaped tendons performed better, and deviator placement significantly improved serviceability and stiffness.

In steel structures, Kamal Sh. Mahmoud et al. (2020) demonstrated that externally prestressed steel beams experienced improved yield load and stiffness, especially at higher tendon eccentricities. The yielding strain location shifted from the bottom flange to the top, reflecting the tendon's upward force. Sang-Hyun Kim *et al.* (2021) experimentally simulated aging by weakening concrete specimens and found that external prestressing restored over 200% of cracking load and improved load capacity, depending on reinforcement layout.

Addressing retrofitting for high-strength concrete beams, Ahmed M. El-Basiouny *et al.* (2021) evaluated beams with various opening dimensions. Numerical simulations of 70 beams led to a predictive formula for flexural capacity, with results indicating that opening height affected stiffness more than length. This study highlighted the critical influence of tendon layout and reinforcement coordination in achieving optimal retrofitting results.

Guo H. *et al.* (2024) provided a field-based analysis of long-term prestress loss in externally prestressed box girder bridges. Using advanced sensors and ABAQUS simulation, they found that most losses occurred immediately after tensioning and that longitudinal losses had the highest impact on mid-span deflection. External prestressing was shown to significantly reduce both sagging and reverse deflection, validating its efficacy in long-span structures.

Concrete jacketing is a widely adopted and effective technique for strengthening and retrofitting reinforced concrete (RC) structural members, especially in seismically vulnerable or aging buildings. It involves encasing existing members—columns, beams, or beam-column joints—with new concrete and additional reinforcement, thereby enhancing stiffness, strength, and ductility.

Md. Akhter Jamil *et al.* (2013) conducted one of the earlier studies focused on re-strengthening cracked RC beams using RCC jacketing. Through finite element analysis in ANSYS, the study evaluated both cracked and uncracked beams before and after jacketing. Results showed that jacketing reduces stress concentration at crack tips, significantly increases ultimate load capacity, and improves stiffness—affirming the viability of this method for retrofitting partially damaged components.

Further refinement in the analysis of jacketed RC beams was introduced by Alhadid *et al.* (2016), who emphasized the importance of accounting for interfacial slip between the existing concrete and the jacket. Most conventional models neglect this factor, resulting in inaccurate estimations of stiffness and strength. Their research developed a simplified analytical method incorporating nonlinear behavior of concrete and steel, and proposed an iterative algorithm to determine moment-curvature and load-deflection relationships. The study also derived slip modification factors to enhance the precision of capacity predictions.

Bandar F. Al Harbi *et al.* (2018) explored partial concrete jacketing, which is often necessitated by architectural constraints such as beams near building edges where full jacketing isn't feasible. Finite Element Modeling (FEM) using ANSYS software was used to study various configurations of partial jacketing. The study found that even partial jacketing significantly increased the load-bearing capacity and reduced reinforcement stress. These results align well with prior experimental findings, offering valuable insights for strengthening beams without altering their geometry drastically.

In strengthening beam-column junctions, Majumdar et al. (2019) demonstrated the widespread application of RC jacketing in high-rise structures. This study acknowledged the bond deterioration and reinforcement pull-out that occur during inelastic loading, especially in seismic zones. Numerical modeling in ABAQUS revealed that jacketed joints have greater energy dissipation and load-bearing capacity than their non-retrofitted counterparts. Due to practical constraints like drilling and placing joint confinement, the study also noted the incorporation of steel components within the jacket, adding complexity and effectiveness to the retrofitting process.

Expanding to column strengthening, Karim SH and Karim FR (2020) presented a critical review on RC column jacketing. They highlighted that although the technique has been extensively tested experimentally, there's still a need for more efficient methods and better design strategies. Key variables include dowel bar integration (through drilled holes), surface preparation, and concrete type selection. These measures improve bond strength, crack resistance, and structural capacity. The study also addressed challenges in applying the method to structures under sustained or increasing loads common in multi-story buildings.

Addressing the design code and practical modeling aspects, Meenakshi Krishnan *et al.* (2020) focused on the application of IS 15988:2013 for retrofitting columns using concrete jacketing. The study provided a detailed ETABS modeling procedure for jacketed sections, aligning closely with physical behavior. It emphasized improvements in column flexural capacity and ductility, while also acknowledging a lack of clear retrofitting guidelines in Indian codes, thus serving as a practical reference for engineers

Despite the proven effectiveness of external prestressing combined with concrete jacketing for strengthening reinforced concrete (RC) beams, several critical research gaps remain. One major concern is the long-term durability of external tendons, particularly their susceptibility to corrosion under varying environmental conditions. Additionally, the bond behavior between old concrete, newly added jacketed concrete, and external tendons over time remains insufficiently understood. Fatigue performance under cyclic loading, especially in relation to tendon stress levels, bond conditions, and concrete properties, also warrants further study. Accurate nonlinear material models are needed to capture the complex behavior of both old and new concrete, steel reinforcement, and tendon-concrete interaction, especially under high stress and geometric nonlinearity. Seismic performance is another key area requiring evaluation through dynamic testing under diverse earthquake scenarios. Moreover, life-cycle cost analysis comparing this method with alternative strengthening techniques is essential for understanding long-term economic feasibility. Lastly, current design codes and standards must be updated to incorporate modern insights and provide comprehensive guidelines for using external prestressing in combination with concrete jacketing.

The primary aim of this study is to assess the effectiveness of combining external prestressing with reinforced concrete (RC) jacketing to significantly improve the flexural and shear capacity of existing RC beams. Six beams five strengthened and one control are evaluated with the following objectives: to enhance load-carrying capacity without altering beam geometry, maintain cost-efficiency through minimal material and labor use, preserve existing structural headroom, and conduct a comparative performance assessment to identify the most technically and economically optimal strengthening approach.

III. METHODOLOGY

The present work involves testing six beam specimens (five strengthened, one control) to evaluate the effectiveness of combining external prestressing with reinforced concrete jacketing in enhancing flexural and shear capacity. This study explores a less-common hybrid solution that aims to balance performance enhancement, constructability, and dimensional constraints. By avoiding significant enlargement of the beam section, it presents a potentially more efficient and application-friendly retrofitting option, particularly in low-clearance or weight-sensitive structures.

The experimental program comprised six beam configurations designed to investigate the effectiveness of various strengthening techniques for reinforced concrete (RC) beams. The first beam, RB, served as the control specimen with minimum reinforcement and no strengthening, providing a baseline for evaluating both shear and flexural (moment) capacities. Beam B1 was strengthened through concrete jacketing with minimum reinforcement, aiming to assess the improvement in strength compared to the unstrengthened RB beam. Beam B2 also utilized concrete jacketing but included maximum reinforcement, allowing for analysis of the influence of reinforcement density within the jacket on the overall capacity enhancement.

Beam B3 explored the effects of external prestressing alone, without any change in cross-sectional geometry or additional reinforcement, to isolate and quantify the contribution of prestressing to shear and flexural performance. Beam B4 combined concrete jacketing (with minimum reinforcement) and external prestressing, targeting an understanding of how the two methods interact and whether their synergy results in improved structural behavior beyond individual effects. Lastly, Beam B5 employed a hybrid approach with both maximum reinforcement in the concrete jacket and external prestressing, aiming to evaluate the maximum achievable strength and performance through combined techniques. This configuration represented the most robust strengthening scenario and was used to determine the upper performance bounds of the hybrid method.

The experimental study involved six reinforced concrete (RC) beams configured under different strengthening schemes to assess the combined effects of external prestressing and concrete jacketing. The first beam, labeled RB, served as the reference specimen and was constructed with minimum reinforcement using M25 grade concrete, a cross-sectional size of 230 mm × 450 mm, and a 6-meter span. Beam B1 was strengthened by concrete jacketing using M45 grade concrete and minimum reinforcement, increasing its cross-section to 530 mm × 450 mm. Similarly, Beam B2 featured the same jacketing dimensions and concrete grade but with maximum reinforcement to examine reinforcement density effects. Beam B3 was enhanced solely through external prestressing using high-strength steel strands (1860 MPa tensile strength, 12.9 mm diameter, and 100 mm² cross-sectional area) while retaining the original beam dimensions and concrete grade (M25). Beam B4 combined concrete jacketing with minimum reinforcement and external prestressing, maintaining the upgraded cross-section of 530 mm × 450 mm. Finally, Beam B5 incorporated both maximum reinforcement and external prestressing within the same jacketing configuration. All beams had a uniform span of 6 meters and used Fe500 grade reinforcement, allowing for consistent comparison of structural performance under different strengthening techniques

IV. STRUCTURAL MODELLING

The six beam configurations were modeled in Midas Civil software to evaluate different strengthening techniques under self-weight loading. *Case 1 (RB)* served as the reference beam with minimum reinforcement and no strengthening. *Case 2 (B1)* added concrete jacketing with M45 grade concrete and minimum reinforcement, showing improved capacity. *Case 3 (B2)* used maximum reinforcement in the jacket, further enhancing strength. *Case 4 (B3)* applied external prestressing (75% of ultimate strength), increasing flexural and shear capacity. *Case 5 (B4)* combined concrete jacketing (minimum reinforcement) with external prestressing, demonstrating synergistic improvements. *Case 6 (B5)* used maximum reinforcement with external prestressing, achieving the highest performance among all cases. Construction stage analysis and prestress losses were considered in applicable cases.

1. Case 1-RB: Reference Beam with Minimum reinforcement

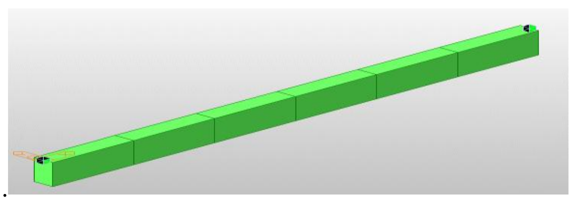

Fig 2: MIDAS model for Reference Beam with Minimum reinforcement

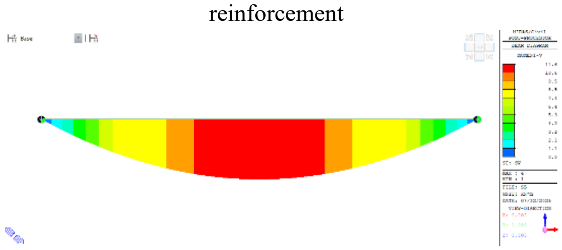

Fig 3: Bending Moment for Case 1-RB with Self Weight (kN.m)

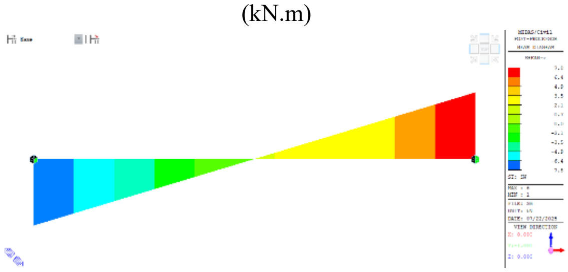

Fig 4: Shear Force for Case 1-RB with Self Weight. (kN)

2. Case 2-B1: Beam with Concrete Jacketing and Minimum Reinforcement

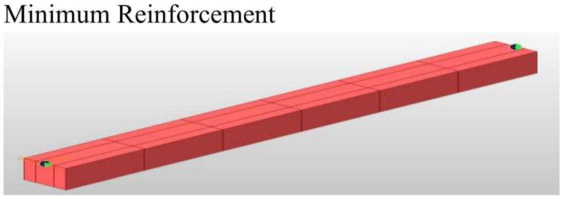

Fig 5: MIDAS model for Beam with Concrete Jacketing and Minimum Reinforcement

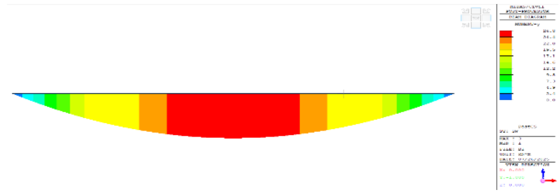

Fig 6: Bending Moment for Case 2-B1 Beam with Concrete Jacketing and Minimum Reinforcement for Self-weight. (kN)

Fig 7: Shear Bending Moment Diagram for Case 2-B1 Beam with Concrete Jacketing and Minimum Reinforcement for Self-weight. (kN)

3. Case 3-B2: Beam with Concrete Jacketing and Maximum Reinforcement

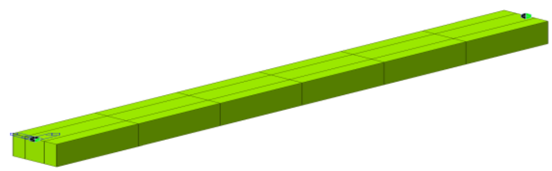

Fig 8: MIDAS model Beam with Concrete Jacketing and Maximum Reinforcement

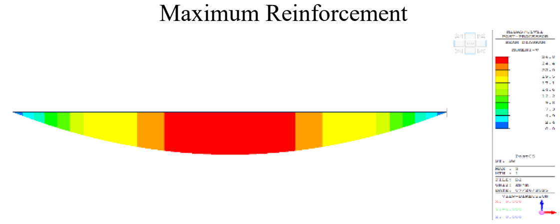

Fig 9: Bending Moment for Case 3-B2 Beam with Concrete Jacketing and Maximum Reinforcement for Self-weight. (kN.m)

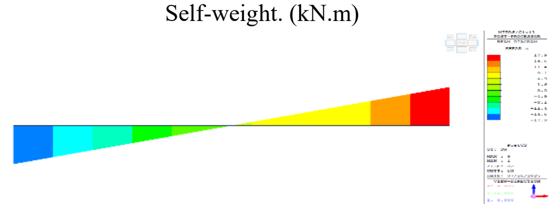

Fig 10: Shear Force for Case 3-B2 Beam with Concrete Jacketing and Maximum Reinforcement for Self-weight (kN)

4. Case 4-B3: Beam with External Prestressing

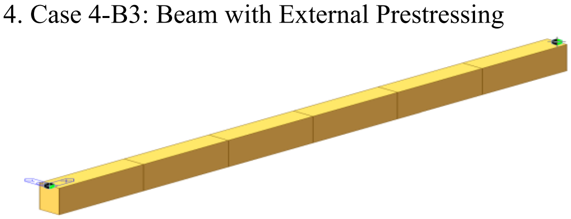

Fig 4.11: MIDAS Model Case 4-B3: Beam with External Prestressing

Fig 12: Bending Moment for Case 4-B3 Beam with External Prestressing for Self-weight (kN)

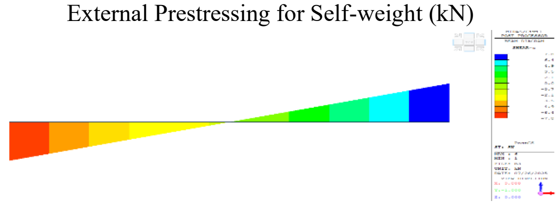

Fig 13: Shear Force for Case 4-B3 Beam with External Prestressing for Self-weight (kN)

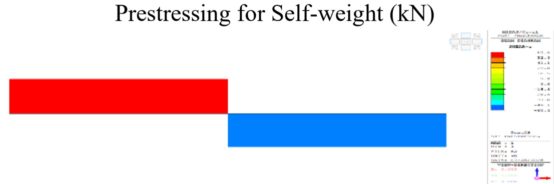

Fig 14: Shear Force for Case 4-B3 Beam with External Prestressing for Prestress. (kN)

5. Case 5-B4: Beam with Concrete Jacketing, External Prestressing and Minimum Reinforcement

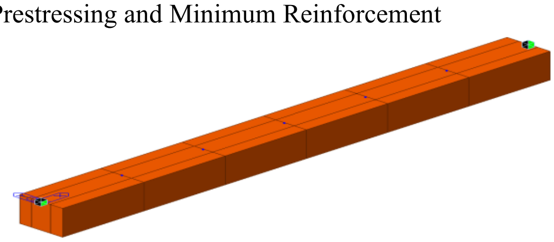

Fig 15: MIDAS model for Case 5-B4: Beam with Concrete Jacketing, External Prestressing and Minimum Reinforcement

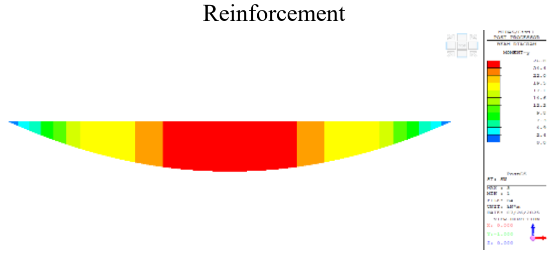

Fig 16: Bending Moment Diagram for Case 5-B4 Beam with Concrete Jacketing, External Prestressing and Minimum Reinforcement for Self-weight. (kN.m)

Fig 17: Shear force Diagram for Case 5-B4 Beam with Concrete Jacketing, External Prestressing and Minimum Reinforcement for Self-weight. (kN)

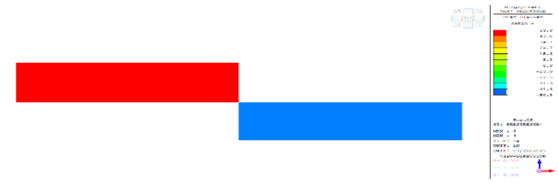

Fig 18: Shear Force Diagram for Case 5-B4 Beam with Concrete Jacketing, External Prestressing and Minimum Reinforcement for Prestress. (kN)

6. Case 6-B5: Beam with Concrete Jacketing, External Prestressing and Maximum Reinforcement

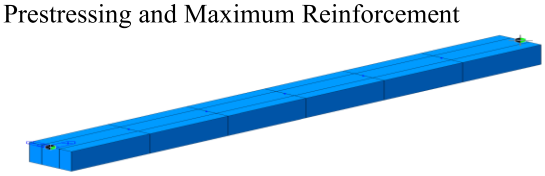

Fig 19: MIDAS Model of Beam with Concrete Jacketing, External Prestressing and Maximum Reinforcement

Fig 20: Bending Moment Diagram for Case 6-B5 Beam with Concrete Jacketing, External Prestressing and Maximum Reinforcement for Self-weight (kN.m)

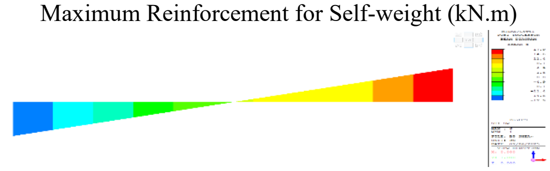

Fig 21: Shear force for Case 6-B5 Beam with Concrete Jacketing, External Prestressing and Maximum Reinforcement for Self-weight (kN)

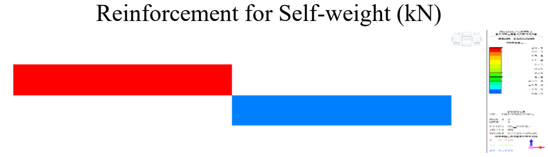

Fig 22: Shear Force for Case 6-B5 Beam with Concrete Jacketing, External Prestressing and Maximum Reinforcement for Prestress (kN)

V. RESULTS AND DISCUSSION

The table 1 summarizes the structural performance improvements achieved through various strengthening techniques applied to a reference reinforced concrete (RCC) beam.

Structural Performance Improvements

The table 2 (a) summarizes the structural performance improvements achieved through various strengthening techniques applied to a reference reinforced concrete (RCC) beam. In Case 1 (RB), the original beam with minimum reinforcement serves as the baseline, offering a moment capacity of 25.15 kN·m and a shear capacity of 118.9 kN. Case 2 (B1) introduces concrete jacketing with reinforcement, resulting in a modest increase in moment capacity to 453.23 kN·m and shear capacity to 397.2 kN roughly 18 and 3.34 times higher than the baseline, respectively. Case 3 (B2) applies external prestressing alone, raising moment capacity to 482 kN·m and shear capacity to 219.9 kN, showing significant gains of 19.16 and 1.84 times over the reference. Finally, Case 4 (B3) integrates external prestressing with jacketing and reinforcement, yielding the highest performance with a moment capacity of 486 kN·m and shear capacity of 909 kN, representing 19.32- and 7.64-times improvement over the original beam.

Table 1: Structural Enhancement Summary

Case	Intervention Type	Reinforcement Level	Prestressing Applied	Expected Capacity Gain
1-RB	Baseline (No retrofit)	Min. (IS 456)	No	Reference capacity
2-B1	Concrete Jacketing	Min. (IS 456)	No	Moderate increase
3-B2	Concrete Jacketing	Max. (IS 456)	No	Higher than B1
4-B3	External Prestressing	N/A	75% of ultimate	Significant increase
5-B4	Jacketing + Prestress	Min. (IS 456)	75% of ultimate	Higher than B3 and B1
6-B5	Jacketing + Prestress	Max. (IS 456)	75% of ultimate	Highest overall capacity

Overall, the data clearly demonstrates that combining concrete jacketing with external prestressing especially when maximum reinforcement is used results in the most effective enhancement of both flexural and shear capacities.

Table 2: The structural performance improvements achieved through various strengthening techniques applied to a reference reinforced concrete (RCC) beam

A. For Moment Capacity

Beam No	Description	Moment Capacity kN-m	Moment Capacity Increament
RB	Reference RCC Beam with minimum reinforcement	25.15	-
B1	RB with concrete jacketing and reinforcement	453.23	18
B2	RB with External Prestressing	482	19.16
B3	RB with External Prestressing, concrete jacketing and reinforcement	486	19.32

B. For Shear Capacity

Beam No	Description	Max Shear Capacity kN	Shear Capacity Increament
RB	Reference RCC Beam with minimum reinforcement	118.9	-
B1	RB with concrete jacketing and reinforcement	397.2	3.34
B2	RB with External Prestressing	219.9	1.84
B3	RB with External Prestressing, concrete jacketing and reinforcement	909	7.64

(b) Flexural Performance

Figure 23, compares four retrofit scenarios for a simply supported beam under self-weight. The baseline (Case RB) shows a utilization ratio of 0.89. Concrete jacketing with reinforcement (Case B1) and external prestressing (Case B2) significantly increase capacity, reducing utilization ratios to 0.96 and 0.86, respectively. Combining jacketing and prestressing with reinforcement (Case B3) delivers the highest capacity and with utilization ratio same as B2 ie 0.89. The results highlight that minimum reinforcement and prestressing lead to greater capacity and improved safety margins.

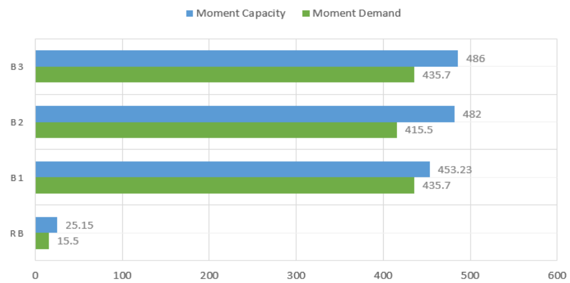

Fig 23: Summary of Flexural Performance

Shear Performance

Figure 24, compares shear performance across four strengthening strategies. The baseline (Case RB) shows a low utilization ratio of 0.086. Jacketing with maximum reinforcement (Case B1) improve capacity and lower utilization ratios to around 0.56. External prestressing alone (Case B2) increases shear demand and raises utilization to 0.36, indicating higher stress. Combining jacketing and prestressing (Case B3) greatly boosts capacity and reduces utilization to 0.14, demonstrating excellent shear resistance and structural resilience.

Overall, the data illustrates that hybrid strengthening methods especially those combining jacketing and prestressing deliver superior shear performance, dramatically improving capacity while keeping utilization ratios impressively low. The present study focuses on the combined strengthening of reinforced concrete (RCC) beams using external prestressing and concrete jacketing, aimed at enhancing load-carrying capacity and serviceability of existing structures. With aging infrastructure and increased design demands, there is a growing need for effective retrofitting solutions.

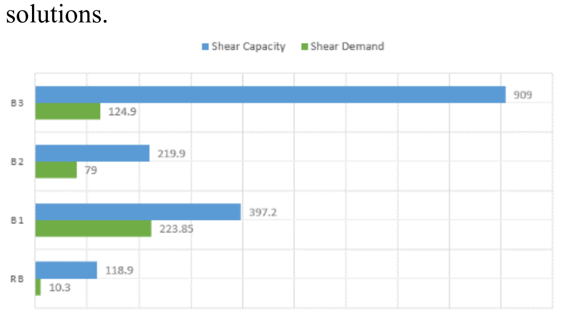

Fig 24: Summary of Shear Performance

In the present study, RCC beams were subjected to two strengthening techniques: (1) External prestressing, which introduces beneficial compressive forces to counteract tensile stresses, and (2) Concrete jacketing, which increases cross-sectional area and confinement. The study involved [mention number] beam specimens tested under two-point loading, including control (unstrengthen) beams.

Results showed a significant improvement in load-carrying capacity, flexural strength, and ductility in beams strengthened with the combined method compared to either method alone. Crack propagation was delayed, and stiffness increased. This proves that combining both methods leads to synergistic benefits, providing a viable retrofitting technique for deteriorated or under- designed concrete structures. The experimental investigation demonstrated that the combined use of external prestressing and concrete jacketing significantly enhances the structural performance of RCC beams. The externally prestressed tendons improved the flexural capacity and reduced deflections, while the concrete jacketing increased the cross-sectional area and confinement, resulting in improved ductility and stiffness.

Compared to beams strengthened by either technique alone, the combination yielded superior structural behavior, including higher load-carrying capacity, delayed crack formation, and better energy absorption. This dual technique provides an efficient and economical solution for retrofitting aging or deficient concrete beams, especially in structures where downtime and invasive techniques must be minimized. However, practical implementation requires careful consideration of tendon anchorage, bond strength, and compatibility of materials. Future studies may explore long-term behavior under fatigue and environmental exposure, as well as full-scale field applications.

Overall, the combined strengthening approach shows great potential for structural rehabilitation in both seismic and non-seismic regions.

VI. CONCLUSION

The structural integrity of reinforced concrete (RC) beams is crucial for infrastructure safety and durability. Aging, increased loads, environmental effects, and design limits necessitate effective strengthening methods. Concrete jacketing and external prestressing are proven techniques to enhance flexural and shear performance. This study evaluates six retrofit scenarios, from baseline to advanced jacketing and prestressing combinations using Midas

Civil software and IRC112 standards under self-weight loading. Results show a clear improvement in structural capacity, validating these methods for future design and rehabilitation.

Major Contributions from the present work:

- The baseline beam (Case RB) safely supported self-weight with moderate flexural and low shear utilization.
- Jacketing with reinforcement (Case B1) improved capacity and reduced utilization.
- External prestressing alone (Case B2) enhanced flexural strength and ductility with safe shear demands.
- Combined jacketing and prestressing (Cases B3) showed superior performance, with highest efficiency and lowest demand-to-capacity ratios.
- These improvements reflect enhanced capacity, ductility, safety margins, and design flexibility, confirming the reliability of combined retrofit strategies, especially in seismic or critical structures.

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