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REVIEW ARTICLE

Effect of Thickness of Reinforced Concrete Jacketing on Solid Reinforced Concrete Beam's Flexural Strength - A Critical Review

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ABSTRACT - Repairing and rehabilitating structures is a significant aspect of construction activities, and reinforced concrete is a widely used material worldwide. Nevertheless, structures constructed with reinforced concrete often undergo various forms of damage, including overloading, natural disasters such as earthquakes and floods, fire incidents, environmental impacts such as corrosion, and alterations in building functionality, before reaching their intended design lifespan. These damages can lead to structural elements failing to meet functional requirements within their designated service life. It was applied to strengthening to ensure the member could safely support its intended load. This study investigates the effect of various thicknesses of reinforced concrete jacketing on flexural strength resistance. Reinforced concrete jacketing is a widely used technique for structural rehabilitation and strengthening that involves applying additional layers of concrete to existing structures. The study investigates various jacketing thicknesses and their impact on the structure's flexural strength. In this study, the increase in load carrying capacity is between 1.5 and 3 times greater than the original samples. This difference is caused by differences in the material, the steel reinforcement, and the thickness of the jacketing. Reinforced concrete jacketing can increase stiffness by up to 173%.

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1. INTRODUCTION

Jacketing stands out as a highly favored and widely recognized approach for reinforcing poorly detailed or deficient reinforced concrete members and structures. Over time, it has become evident that RC jackets offer significant improvements in strength, stiffness, and overall structural performance [1]. Severe forces, such as sudden impacts or earthquakes, periodically expose concrete and steel-reinforced structures, potentially leading to devastating outcomes. Minimizing the vulnerability of existing buildings to earthquakes is a significant and common concern. Strengthening structural components, such as jacketing, presents an engaging solution [2]. Structural rehabilitation aims to achieve specific safety and performance standards for a structure or its parts. This process generally falls into two categories: repair and strengthening. Repair addresses damaged elements, while strengthening improves undamaged ones. A common method for strengthening structural elements involves jacketing, which comes in several types: concrete jacketing, steel jacketing, precast concrete jacketing, external prestressing, and fibre-reinforced polymer wrapping [3]. Researchers have conducted studies to determine the impact of applying bonding agents on the adhesive strength between concrete layers of varying ages, commonly using epoxy resin. They have also applied techniques before application to enhance the adhesive capacity and roughness of the substrate surface [4].

Epoxy is a thermosetting matrix or resin material that contains one or more epoxide groups in the molecule. The epoxide, also referred to as the oxirane or ethoxy-line group, is the representative unit of the epoxy polymer. Epoxy is used in various applications such as adhesives for general purposes, potting and encapsulating media, industrial painting, and coatings. Its distinct benefits include minimal shrinkage during curing, corrosion and impact resistance, and its ability to work well with a variety of substrates [5]. Concrete structures comprised of layers poured at different times necessitate a distinct approach compared to other concrete structures during both the design and construction phases. This specialized approach encompasses surface preparation, construction sequencing, curing methods, and load-bearing capabilities. Of utmost importance is the bond strength between two concrete layers, as it profoundly impacts durability and structural integrity. Along with material strength, carefully preparing existing concrete surfaces has a big impact on their ability to hold weight and last a long time. This is because the materials and interface parameters are not always distributed evenly across the contact surface [6].

Self-compacting concrete represents one of the most recent advancements in concrete technology. It boasts exceptional deformability, high fluidity, and improved durability potential, making it a prime example of a rheologically controlled mixture. SCC exhibits the ability to flow uniformly under its own weight, navigating through densely congested reinforcement without segregating or trapping air. Its exceptional workability, filling capacity, and passing ability make SCC an ideal material for repairing damaged concrete elements. More recently, SCC has found applications in jacketing, which serves to repair and strengthen existing or damaged reinforced concrete members [7]. Additionally, using UHPFRC

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in two different thicknesses (25mm and 35mm) for column jacketing is more effective than using NSC, especially in narrow sections, without any noticeable segregation or honeycombing issues [8].

The demand for fibre-reinforced concrete has been increasing due to its premier compression, tensile, and flexural strength characteristics. Recently, experts have introduced a progress method to repair and strengthen beams subjected to static loads. The approach is based on utilising a thin jacketing of high-compressive strength concrete with high tensile strength in the hardening stage, such as high-performance fibre-reinforced concrete. Improvements in serviceability, load-carrying capacity, and fire resistance follow. Additionally, avoid corrosion that might occur when steel bars or steel plates are used [9–12]. Tests on reinforced concrete beams with wire mesh in various flexure zones revealed an improvement in flexural strength proportional to the number of wires. Increasing the number of wire meshes can control the sudden failure of the bonding system between the concrete and the wire mesh, thereby enhancing the flexure and energy absorption capacity [13]. Strengthening and enhancement of the structural elements is necessary due to various factors, including prolongation of design life, change in functionality, mechanical damage, environmental effects, updated design requirements, and errors due to design and construction. It's economically and environmentally preferable to rebuild the structures. This study aims to investigate the effect of various thicknesses of reinforced concrete jacketing on the flexural strength of solid beams.

2. LITERATURE REVIEW

Based on the information gathered from previous studies related to the strengthening of solid beams for the purpose of enhancing flexural strength, the materials used in jacketing can be classified into the following categories:

i. Jacketing with self-compacted concrete

Researchers conducted a study on self-consolidating concrete containing glass fiber and fiber-silica fume-composed gel of thickness 50 mm, and found that the amount of glass fiber increased the energy absorption capacity from 89 to 46% [14]. Based on the investigation of strengthening a beam to resist flexural surface operation, which occurs by roughening the surface with a motorized wire brush and cleaning it with a jet of water, the addition of reinforcement for the jacketing is 16 mm and 8 mm in diameter for longitudinal and transverse bars, respectively, and the compressive strength of the SCC used for jacketing is 25 and 33 MPa. It was observed that the strengthened specimen has a higher moment capacity compared to the reference beam, as shown in Figure 1 [15].

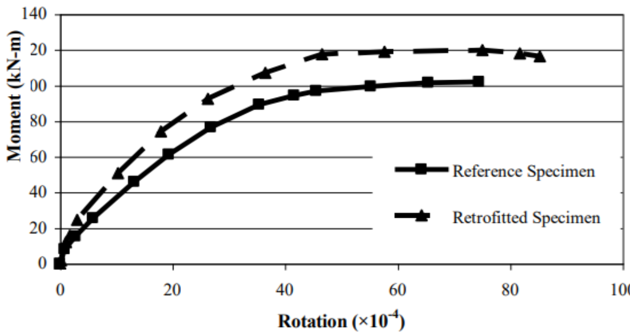


Figure 1. Moment required for rotating reference and retrofitted concrete samples [15]

Another investigation examines the U-shape SCC jacketing, which has a thickness of 30 mm on the vertical sides and 50 mm in the soffit. The jacketing is made of welded galvanized steel wire mesh, with diameters of 3.5 mm and 5.5 mm, and spacings of 25 mm and 50 mm respectively. The investigation focused on two types of shear connector surface roughness and used epoxy resin of type EPICHOR 1768 as the bonding agent. Researchers found that a higher reinforcement ratio greatly influences flexural strength [16].

ii. Jacketing with reinforced concrete of compressive strength ranges between 40 to 60 MPa

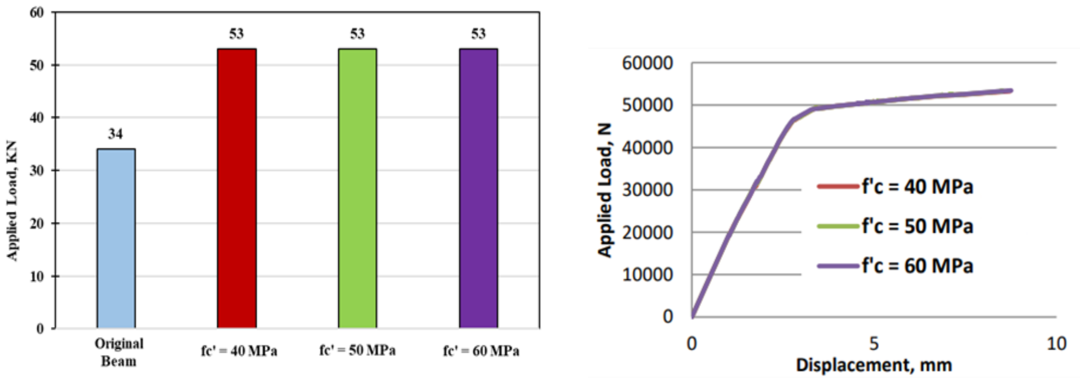
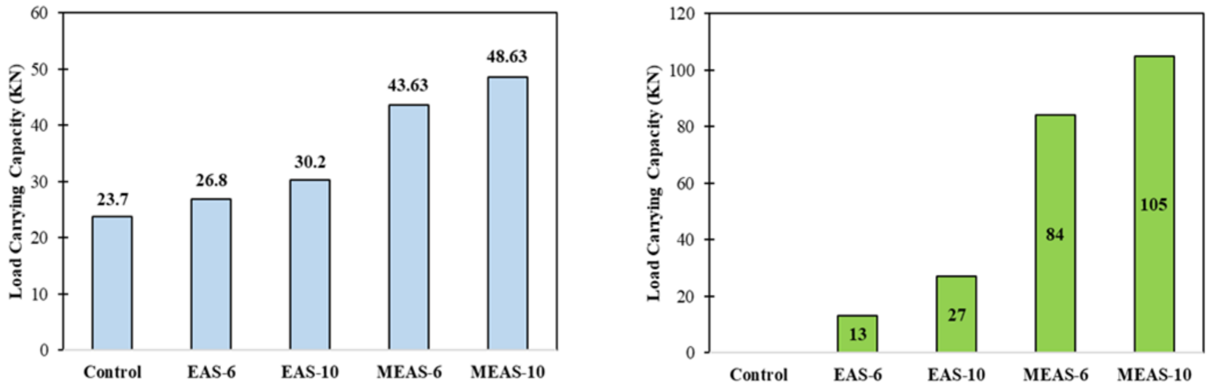


Figure 2. Load Carrying capacity of original and jacketed beam with different compressive strength [17]

It was examined a reinforced concrete beam with a compressive strength of 20 MPa under three distinct strengthening scenarios. In each case, jacketing concrete was utilized with compressive strengths of 40, 50, and 60 MPa, respectively. It was found that changes in concrete strength have no observed influence on load capacity, as shown in Figure 2 [17].

iii. Jacketing with non-shrink cement grout

An investigation into various anchoring systems to fix the steel bars to the beam—the epoxy anchorage system and mechanical expansion anchors—revealed that using non-shrink cement grout is the most effective method for increasing the ultimate load-carrying capacity of reinforced concrete beams, and both systems are applicable for attaching the external reinforcement 6 mm and 10 mm in diameter, as shown in Figure 3 [18].



Notes:
Control refers to original beam without jacketing, EAS-6 is epoxy anchorage system with bars 6 mm in diameter, EAS-10 epoxy anchorage system with 10 mm bar diameter, MEAS-6 mechanical expansion anchorage with 6 mm diameter and MEAS-10 stands for mechanical expansion anchoring with 10 mm diameter

Figure 3. Increasing in load carrying capacity for jacketed samples compared to original specimen

iv. Jacketing with different thickness

An investigation into reinforced concrete beams jacketed with steel bars 10 mm in diameter and concrete with 60 MPa compressive strength in various thicknesses of 2.5, 5, and 10 cm revealed that using 10 mm bar diameter with increasing jacketing thickness results in an improvement of 362% compared to the control specimen, where a 21% improvement occurs due to changing thickness, as shown in Figure 4 [17].

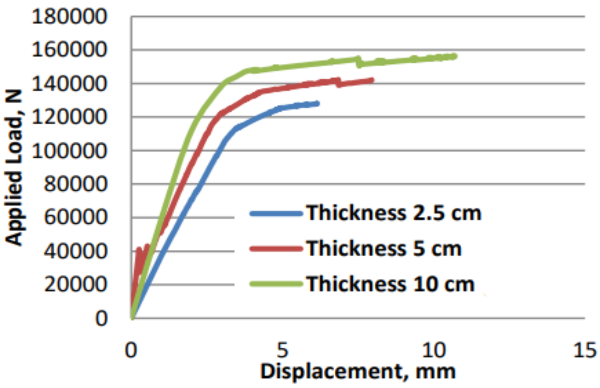
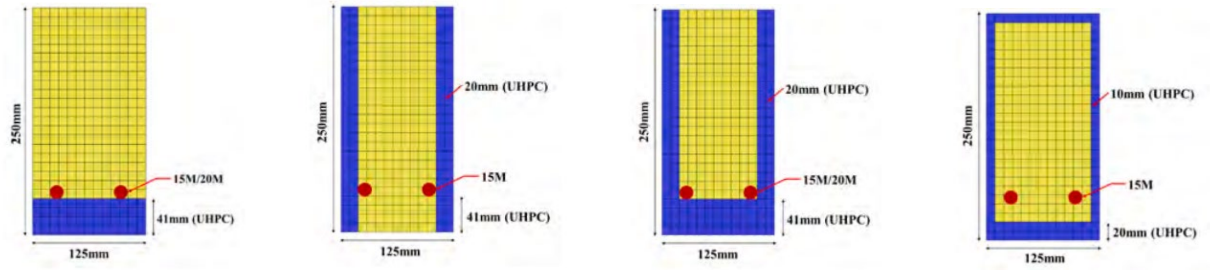


Figure 4. Effect of changing in jacketing thickness on load capacity [17]

Additionally, U-shaped jacketing for reinforced concrete uses steel fibers of 0, 1, and 2% to strengthen the beams. The original sample had a compressive strength of 20 MPa, and the result improved the absorption capacity by 1.88 times compared to the original beam [19]. Another study looked at how to improve the resistance and flexural capacity of a high-strength concrete beam using Ultra High-Performance Concrete (UHPC), with steel ratios of 1.6% and 2.4%. It found that the stiffness went from 80% to 85%, the flexural strength went from 20% to 35%, and the ductility went from 40% to 18% compared to the control sample. Figure 5 illustrates that UHPC has a thickness of 41 mm in T-side jacketing, 20 mm on both sides in 2-sided jacketing, 20 mm on both sides in U-jacketing, and 41 mm on the tension face. However, in the FJ, the thickness decreases to 20 mm in the tension face and 10 mm on all other sides, leading to the conclusion that the thin jacketing FJ is quite effective, offering benefits related to material cost and increased ductility in the failure mode [20].



T-sided 2-sided UJ FJ (Thin)

Figure 5. Type of strengthening for high strength beam [20]

v. Jacketing with changing diameter of the steel reinforcement

For self-compacted concrete with tight spacing and square openings of 3.5 mm in diameter and 25 × 25 mm in size, as well as 5.5 mm in diameter and 50 × 50 mm in size, epoxy resin was used to attach shear connectors to the surface of the concrete. It was found that the flexural load carrying capacity for the jacketed samples with a diameter of 3.5 mm and a size of 25 × 25 mm increased by 110.24% on average. Meanwhile, the apparent improvement in jacketed specimens with a diameter of 5.5 mm and an opening of 50 × 50 mm is 162.96% compared to the beam sample without jacketing [16]. In a different study that used the U-shaped beam and changed the rebar diameter in the RC jacket, the original beam's compressive strength was found to be 28.2 MPa and the jacketing's to be 42.8 MPa. Increasing the bar diameter by 173.5% for 8 mm and 276.5% for 10 mm will make the beam 173.5% and 276.5% stronger, as shown in Figure 6 [17].

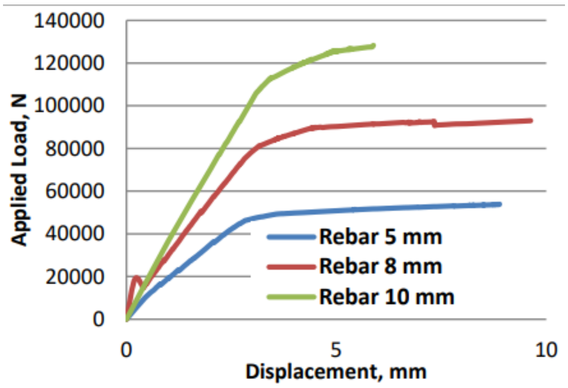


Figure 6. Influence of changing rebar diameter on load capacity of jacketed beam

3. RESULTS AND DISCUSSION

The literature review and studies on beam jacketing, which aim to enhance the ultimate load capacity by employing diverse materials of varying thicknesses, have yielded the following results.

3.1 Load Carrying Capacity

The increase in flexural load-carrying capacity for the jacketed samples compared to the original ones is due to a strengthening approach that includes cross-sectional enlargement, resulting in a change in the thickness of the retrofitted beam. Jacketing will cause a notable enhancement in the load-carrying capacity that occurs in various approaches, such as the material used in jacketing, reinforcement ratio, and several thicknesses, as it’s demonstrated in Figure 7. The load capacity goes up when the thickness of reinforced concrete is changed. For example, the load capacity goes up when the thickness is 100 mm compared to 25 and 50 mm. Changing the diameter of the galvanised wire mesh used as a reinforcement in self-consolidating concrete can also make the load capacity go up. A steel wire mesh with a diameter of 5.5 mm and a length of 50 mm results in a greater improvement than a mesh with a diameter of 2.5 mm and a length of 25 mm.

If the concrete used in the jacketing system is changed, like SCC changed with glass fibre (GF) and fiber-silica fume composite gel (FSCG), it works better than SCC changed with only GF for the same thickness. Moreover, changes in the shape of the jacketing can significantly influence the flexural strength, as is obvious in Figures 7-11. Full jacketing can greatly improve the load capacity of the jacketed beam specimens compared to U jacketing and T-side jacketing. Similarly, an increase in the steel ratio for previous jacketing shapes will lead to an improvement in the flexural capacity, following the same trend but at a higher ratio. Based on the data gathered from the literature review, T-sided jacketing with a thickness of 41 mm yields the lowest load capacity, with the highest load carrying capacity enhancement occurring when the reinforced concrete jacketing thickness reaches 100 mm.

3.2 Stiffness of the Beam after Reinforced Jacketing

It gets stiffer in a way that is similar to the flexural load capacity percentage of modified self-compacted concrete with GF. FSCG gets stiffer more than concrete that has only been modified with GF. However, enhancement occurs with SCC with SWM 3.5 mm diameter and 25×25 mm 1.5 times, while SCC with 5.5 mm 50×50 mm increases 1.96 times compared to the original beam.

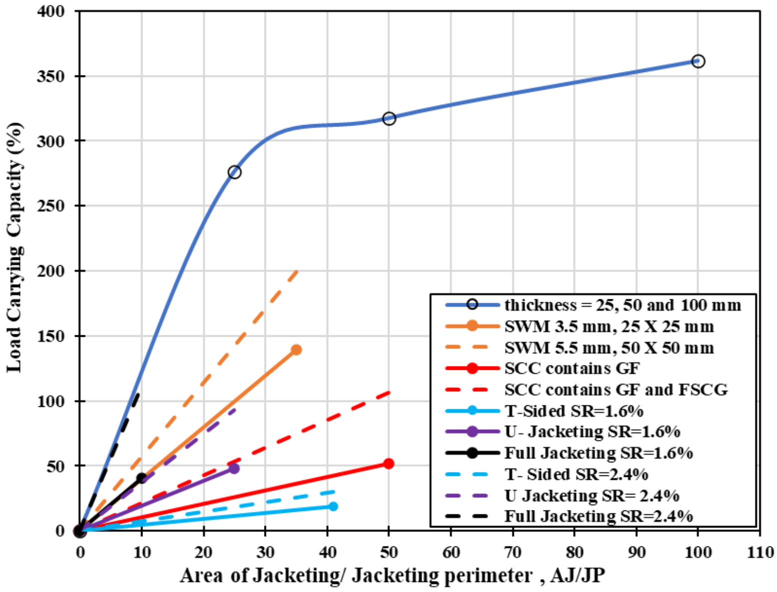


Figure 7. Improvement in load capacity of jacketed beam

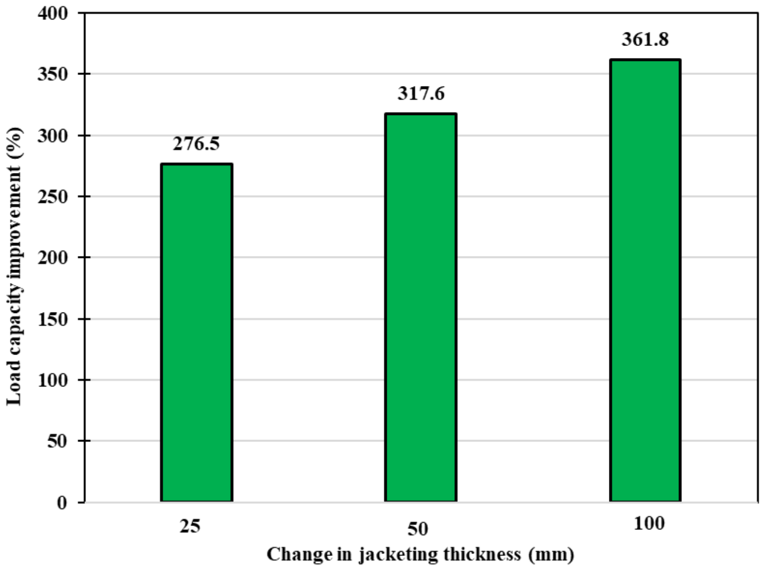


Figure 8. Load carry capacity versus thickness of jacketing

The effective thickness changes with the shape of the jacket, resulting in stiffness, as shown in Figure 12. A change in jacket shape will lead to stiffness improvements. Full jacketing with a steel ratio performs better than other jacketing shapes like T-Sided and U jacketing. Furthermore, increasing the steel ratio results in the same performance, which in turn leads to a higher stiffness of the jacketed beam, as shown in the bar chart in Figure 13. Stiffness obtained by the full jacketing of the beam has a steel ratio equal to 2.4%, with an effective thickness of 10 mm of 110%. However, the minimum value of stiffness is obtained when the T-sided jacketing approach is applied for the purpose of increasing flexural resistance.

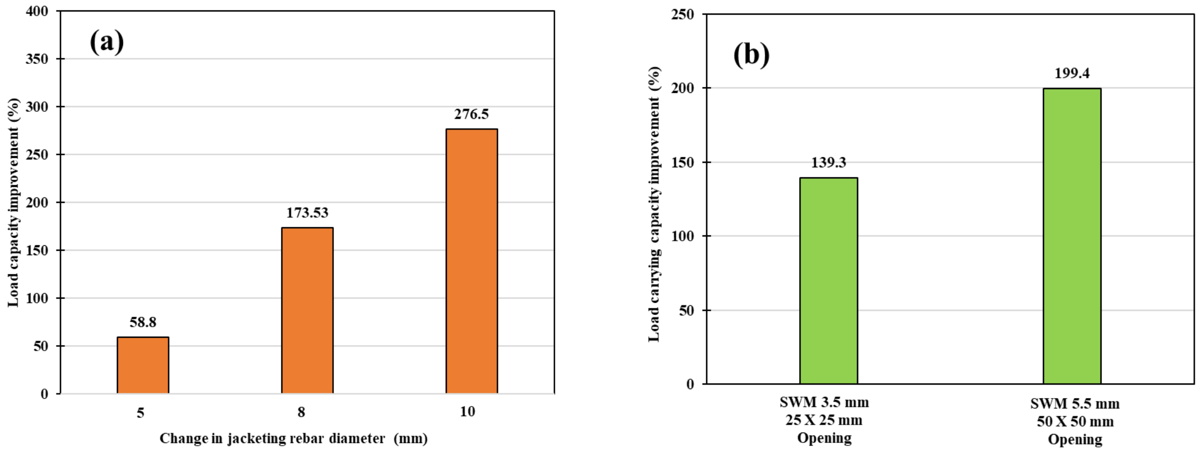


Figure 9. Improvement of load capacity corresponding to (a) change in rebar diameter; (b) change in the SWM diameter and opening

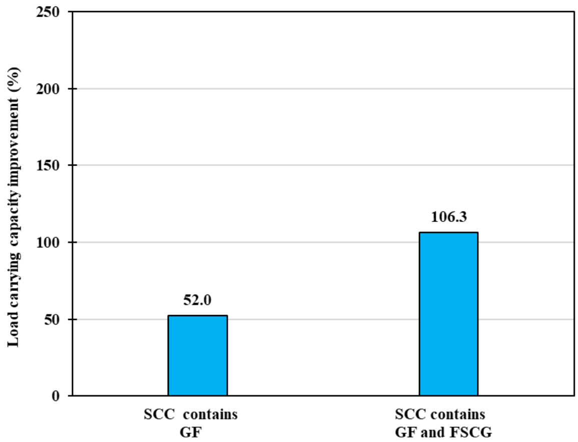


Figure 10. Enhancement in flexural load capacity due to changing in material of jacketing

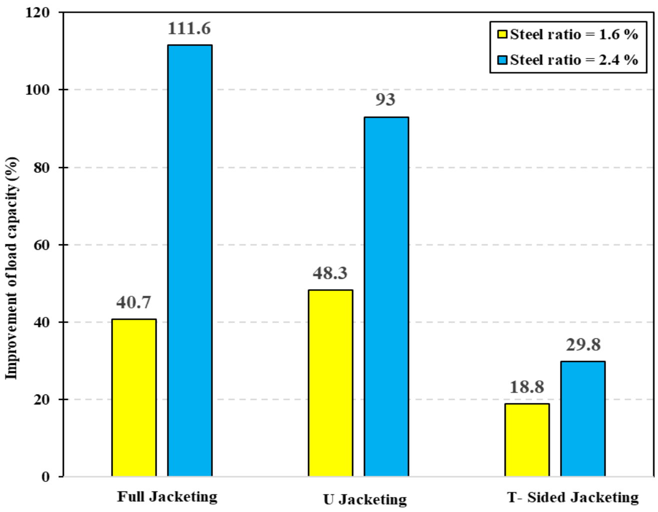


Figure 11. Enhancement of load capacity according to change in shape and steel ratio of the jacketing

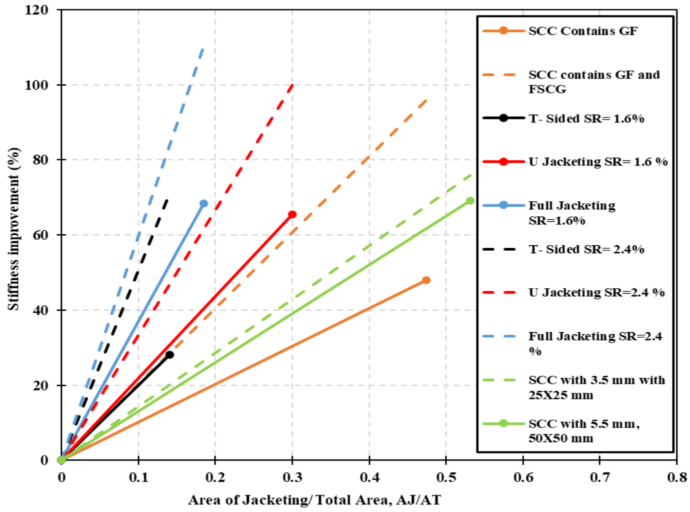


Figure 12. Relationship between stiffness improvement and area of jacketing to total area ratio

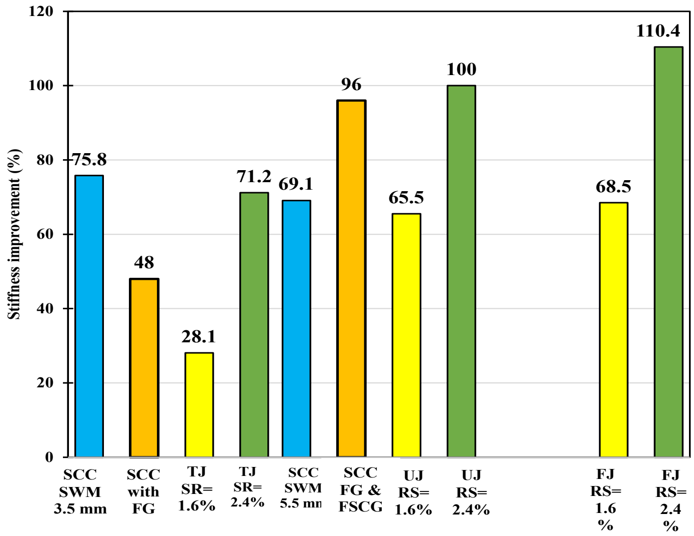


Figure 13. Bar chart demonstrate the improvement of stiffness

4. CONCLUSION

The conclusions drawn are based on data derived from previous studies concerning enlargement techniques (jacketing) and how varying jacket thicknesses affect the flexural capacity of a solid beam:

- Reinforced concrete jacketing can utilize different materials, including ultra-high-performance concrete (UHPC) or regular concrete with a compressive strength below 40 MPa. It may also include self-compacting concrete (SCC) with fibers or mineral additives like silica fume. Additionally, the process can employ non-shrinkable cement grout; the most appropriate approach is to increase the thickness of the jacketing.
- By using different materials in the jacketing method, the initial increase in load capacity that comes from making the beam three times thicker can be increased by 1.8 and 2.7 times, respectively. This is because the steel rebar is changed and modified concrete is used.
- The strengthened beam with reinforced concrete jacketing has an enhanced load carry capacity due to the increased thickness of the jacketing.
- Due to the increase in the area covered with reinforced concrete jacketing of up to 27.5%, the stiffness of the strengthened beam increased by up to 173%.
- Full jacketing with an effective thickness of 10 mm could be the most effective feature for flexural strengthening of the reinforced concrete beam.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Maryam Basil Ishaq: Conceptualization, Methodology, Data curation, Writing- Original draft preparation
Ferhad Rahim Karim: Writing- Reviewing and Editing

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