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# Strengthening of Concrete Columns using NSM GFRP Bars

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## ABSTRACT

In recent times, there has been a significant surge in interest regarding the retrofitting of concrete columns utilizing Near Surface Mounted (NSM) Fiber Reinforced Polymer (FRP) bars due to their numerous benefits, such as more load carrying capacity, increased durability, and improved seismic performance. The purpose of this study is to determine that NSM GFRP bars can effectively strengthen circular, square, and rectangular concrete columns. Eight concrete columns of each shape (circular, square, and rectangle), Two control samples and six retrofitted Samples using various Retrofitting material and ratios were studied. Based on past research, it is projected that retrofitting with NSM GFRP increases the strength and ductility of columns, with the quantity and arrangement of NSM FRP bars being a key factor in overall performance. The report ends by highlighting the practical uses of research findings in construction sector and outlining potential directions for additional study in this area. In conclusion, this study's findings offer convincing proof that using NSM GFRP bars can increase concrete columns strength and durability when is compared to control columns.

**KEYWORDS:** NSM retrofitting, GFRP Bars, Concrete column, Stress Strain response, Ductility

## 1 INTRODUCTION

In construction industries, concrete columns are frequently constructed as load-bearing elements in structures that are subjected to a variety of loads. Increased loads, exposure to hostile conditions, material ageing, and poor design are some of the major causes for concrete columns deterioration with time. Previous methods including jacketing with reinforced concrete, steel plate bonding, and external post-tensioning have been used to strengthen and restore deteriorating concrete columns [1]. These techniques have been effective, but they are expensive, time-consuming, and sometimes impracticable. Concrete jackets expand column sections, add weight, demand more effort and quality control, are more expensive, and need a lot of time to construct while in case of steel jacketing the steel jackets degrade under corrosive environments [2].

Fiber Reinforced Polymer (FRP) composites have recently gained popularity as a substitute option for reinforcing concrete constructions, particularly for columns [3]. High-strength fiber polymers

like carbon, glass, or aramid have been placed in a polymer matrix make up FRP composites. One such material is GFRP bars in which glass fibers are embedded in polymer resin. In addition to this Near surface mounted FRP bar approach is gaining popularity. The NSM method involves embedding reinforcement into grooves that are carved into the surface of the member that must be strengthened. These grooves are then filled with the proper binding agent, like cement grout or epoxy paste [4].These near-surface mounted FRP bars efficiently increase the column's load-bearing capacity and ductility by adding tensile strength, shear resistance. In addition, the NSM approach requires less surface preparation than other methods, improves peak and post-peak behaviour, ductility, flexural strength, energy absorption capacity, and is excellent at enhancing the seismic performance of reinforced concrete frames [5].
The primary goal of this study is to determine whether near-surface mounted GFRP bars are useful in strengthening concrete columns by increasing their load-carrying capability. Through experimental testing, the project will evaluate the influence of near surface mounted GFRP bars on columns behavior particularly in terms of enhanced stiffness and load-carrying capability. The research aims to provide a quantitative understanding of how near-surface mounted GFRP (Glass Fiber Reinforced Polymer) bars enhance the strength and ductility of concrete columns. This is achieved by comparing the results obtained from retrofitting columns with those of control columns, allowing for a comprehensive evaluation of the FRP bars' impact on the overall performance of the concrete columns. To what extent near surface mounted GFRP bars may improve the load-carrying capacity of concrete columns will be determined through this assessment, which will be helpful information for structural engineers and practitioners working on column strengthening projects.

## 2 EXPERIMENTAL PROGRAM AND METHODOLOGY

### 2.1 Experimental Program

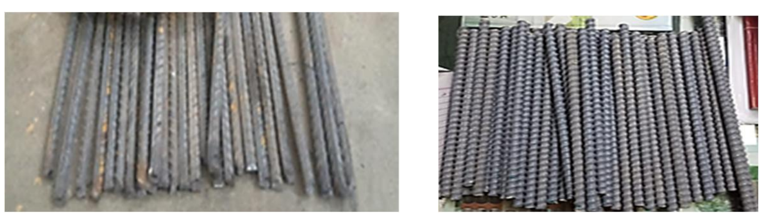
Total 24 samples were casted for experimental study, focusing on three different shapes: Circular, Square, and Rectangular for each shape two types of retrofitting material was used steel and GFRP bars. For each shape, 8 specimens were used as control, steel and GFRP bars retrofitted samples.
For each specimen, 2 identical samples were tested. Circular, square, and rectangular shapes, as shown in Table 1-A, were chosen for columns as they represent the most conventional shapes used in construction in real field conditions. Size of specimens was kept small due to the testing machine limitations. Number of bars were also chosen according to the cross-sectional sizes and to get the effects of using different amount of GFRP or steel bars to get the optimum value because it was predicted that strength might decrease by increasing bars due to less cross-sectional area after grooves. The effect of retrofitting material was studied by using steel and GFRP bar while the effect of cross-section was studied by using different shapes and the effect of extent of retrofitting was studied by using different number of GFRP retrofitted rebars.
In Table 1-A Sample designations are listed with sample notation as follow the first symbol “C, S, R” is used for shape circle, square and rectangle. The second symbol determines retrofitting with “CO” for control, “ST” for 4 NSM retrofitted Steel rebars, “GF1” for samples with 4 NSM retrofitted GFRP rebars and “GF2” for samples with 8 NSM retrofitted GFRP rebar.

Table 1-A: Sample 1-ADesignations and Descriptions

| Samples Designations | | | | | |
|---|---|---|---|---|---|
| Sr. No. | Shape | Dimensions (mm) | Retrofitting Material (#3 bar, 10mm diameter) | No of bars added | Designation |
| 1 | Circular | 150×300 | - | - | CCO |
| 2 | Circular | 150×300 | Steel | 4 | CST |
| 3 | Circular | 150×300 | GFRP Bars | 4 | CGF1 |
| 4 | Circular | 150×300 | GFRP Bars | 8 | CGF2 |
| 5 | Square | 150×150×300 | - | - | SCO |
| 6 | Square | 150×150×300 | Steel | 4 | SST |
| 7 | Square | 150×150×300 | GFRP Bars | 4 | SGF1 |
| 8 | Square | 150×150×300 | GFRP Bars | 8 | SGF2 |
| 9 | Rectangle | 103×203×300 | - | - | RCO |
| 10 | Rectangle | 103×203×301 | Steel | 4 | RST |
| 11 | Rectangle | 103×203×302 | GFRP Bars | 4 | RGF1 |
| 12 | Rectangle | 103×203×303 | GFRP Bars | 8 | RGF2 |

## 2.2 Material properties:

Concrete of M15 grade having a mix ratio of 1:2:4 (cement, sand, aggregates) was used for casting samples. For NSM Retrofitting of Steel, 60 Grade #3 Steel rebar were used. While for NSM Retrofitting of GFRP, #3 GFRP rebars were used, having a diameter of 10mm & length of 250mm each, attached axially along the specimen.



(a) (b)

Figure 1: (a) Steel Rebar, (b) GFRP Rebar

For ties Steel Binding wire was used, having a diameter of 1mm, about 36 turns of this steel wire were wounded in each tie so that cumulative area should become equivalent to that of #2 rebar. For filling the groves of retrofitting **Sika Grout®-114** was used. This selection was made because it is self-compacting and high-performance grout so easily flows beneath the ties & rebar, while filling. For making moulds plywood was used, for each specific shape the plywood panel was cut up to exact dimension and nailed together to form 150x150x300 mm square & 103x203x300 mm rectangular formworks.

## 2.3 Samples preparation:

Firstly, specimens were casted in exact dimensions using formwork and left for 28 days curing.

Figure 2 Casting of samples

Then for the axial installation of steel and GFRP groves were precisely cut in each sample, 20 mm deep for longitudinal bars and 10 mm deep for ties. The number of grooves changed depending on the sample, while the number of horizontal grooves for the stirrup stayed constant at 3.

Figure 3 Grooved Samples

Then retrofitting of GFPR and steel was performed. After this precision grouting and structural repairs was done with Sika-114 grout before they were ready for further testing.

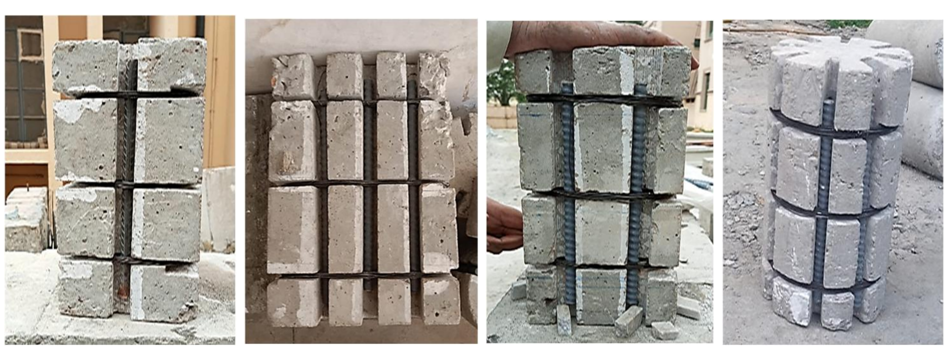


Figure 4 Retrofitted samples.

### 2.4 Testing setup:

Universal Testing Machine (UTM) was used for testing. We monitored and recorded the associated dial gauge strain readings as we incrementally raised the applied load with rate of 2.5kN/s on each sample. These strain readings were taken on a regular basis in increments of 25 KN of load. Stress-strain graphs for each specimen were plotted using the testing data.

## 3 EXPERIMENTAL RESULTS AND DISCUSSION:

### 3.1 Failure Mode

Specimens exhibited a distinct failure mode. Initially, as the load was applied, the bond between the grout and concrete degraded, leading to the spalling out of grout and resulted in reduction of load-resisting area the area that could resist the applied load, so increased effective stress cause cracking of side flanges further diminishing the load-resisting area. At peak, concrete core got cracked and the entire load was sifted on NSM retrofitting bars. Under the increasing stress clear cover (measuring 25 mm at the top and bottom) began to crack, and the bars themselves started to buckle, in some specimens under extreme stress, the steel wire stirrups also broken.

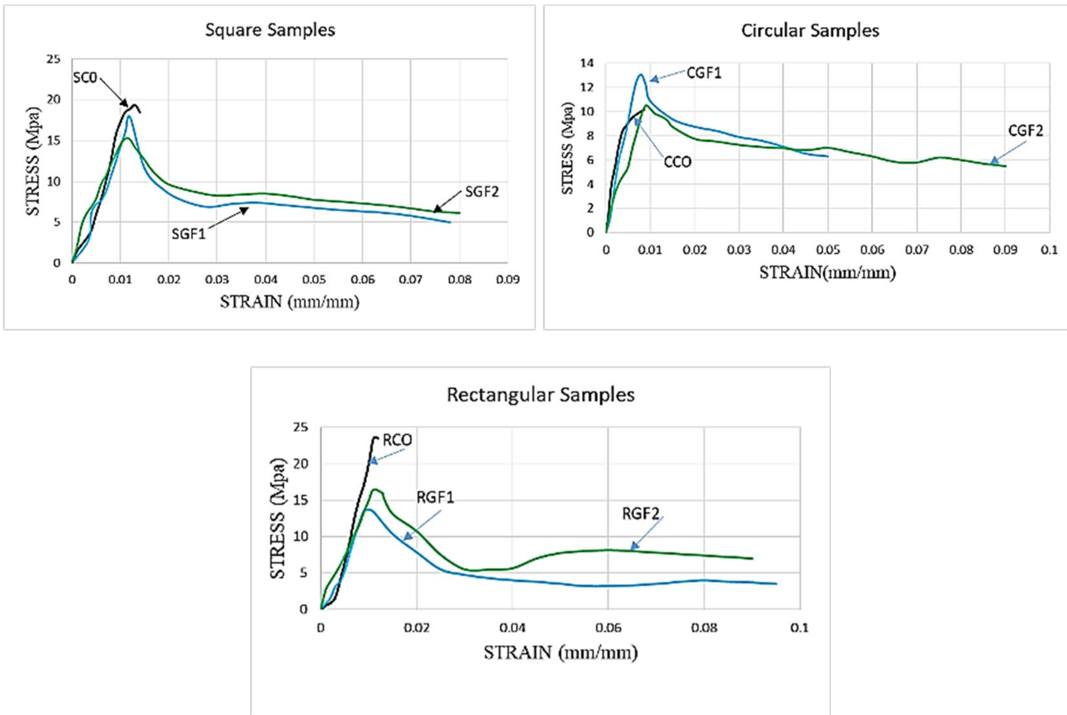
(a) (b) (c)

Figure 5 Tested samples (a) cracked flanges, (b) Bulked and ruptured GFRP bar, (c) broken Stirrup

However, the post-peak behaviour of the retrofitted specimens showed a substantial improvement compared to the samples without retrofitted bars, despite the failure of some components. The addition of NSM bars was crucial in improving the specimens' structural integrity and load-bearing capacity, proving the efficiency of this retrofitting technique for fortifying, and enhancing concrete columns' performance.

### 3.2 Effect of Retrofitting Ratio (4 bars vs 8 bars in each specimen)

The graph labelled in Figure 6 are stress –strain curves showing the effect of retrofitting ratio on the peak stress of shaped samples.




(a) (b) (c)

Figure 6 Specimen with GFRP NSM retrofitting, (a) Square samples, (b) Circular samples, (c) Rectangular samples

**CONTROL VS GFRP RETROFITING:** Based on the results, it is concluded that the strength of the control specimens (without retrofitting) is greater than that of the GFRP NSM retrofitted specimens for all the shapes considered (square, circular, and rectangular). This conclusion is due to the process of NSM retrofitting, which involves cutting grooves in the initial samples to embed the GFRP bars. As a result, the effective load-bearing area of the samples is reduced, leading to a decrease in the peak stress that can be resisted by the specimens. The reduction in effective load-bearing area due to the grooves' presence results in a weaker mechanical behaviour of the retrofitted specimens compared to the control specimens.

**GF1 VS GF2:** Upon further evaluation, it is evident that the strength of the sample does not increase simply by increasing the ratio of GFRP NSM retrofitting. Instead, the strength follows a critical optimal ratio, which is dependent on the geometry of the grooves cut and the shape of the sample. It is crucial to maintain this optimal ratio because adding each new NSM bar requires cutting grooves in the sample, which decreases the initial load-resisting area.

On the other hand, rectangular samples, with an aspect ratio of 2, demonstrate a different trend. In this case, the strength of RGF2 is greater than RGF1. The aspect ratio of the rectangular samples plays a role in determining the optimal retrofitting ratio, which leads to variations in strength between RGF1 and RGF2. Properly considering the aspect ratio and the retrofitting ratio is essential to achieve the desired strengthening effect without compromising the load-resisting capacity of the samples.

### 3.3 **Effect of Retrofitting Material (Steel bars vs GFRP bars)**

The graph labelled in Figure 7 are stress –strain curves showing the effect of retrofitting material on the peak stress of different shaped samples.

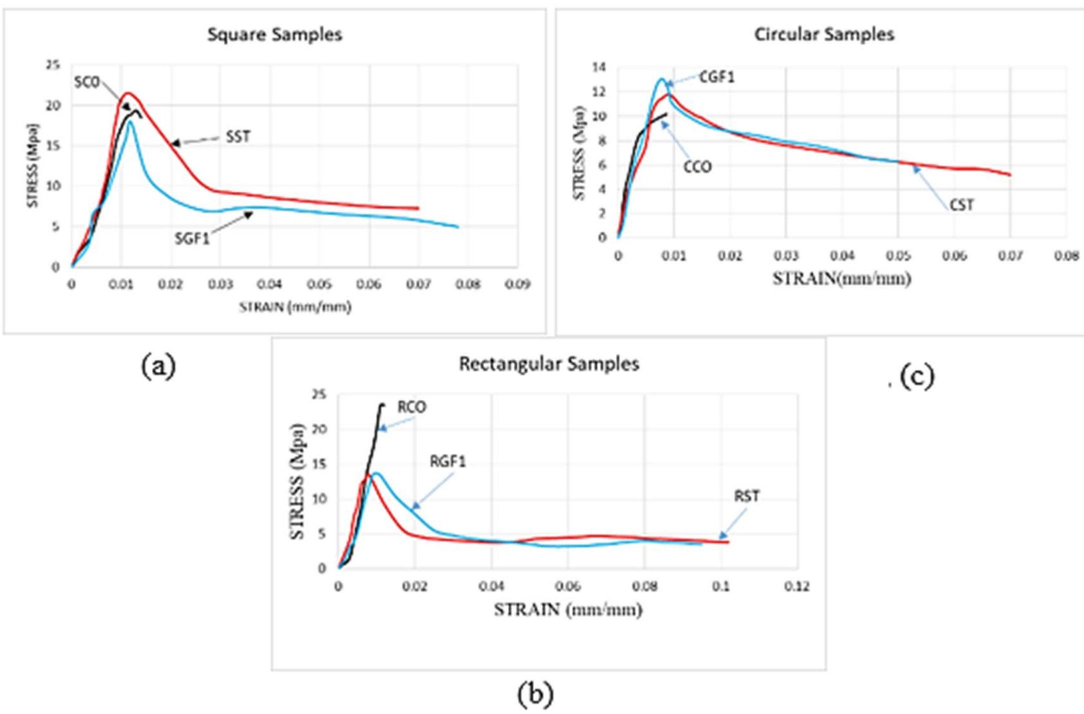



Figure 7 Specimen with Steel & GFRP NSM Retrofitting, (a) Square samples, (b) Rectangular samples, (c) Circular samples

The results indicate that the strength of the NSM retrofitted sample is influenced by the material used for retrofitting. Both steel and GFRP NSM retrofitting demonstrated similar behavior in the stress-strain curve, showing almost comparable results. However, it is evident that the strength of GFRP retrofitted specimens surpasses the strength of steel retrofitted specimens. This observation leads to the conclusion that GFRP is a more durable material for retrofitting compared to conventional material steel, as its non-corrosive and lightweight so minimizes the additional dead load on the structure added by retrofitting.

### 3.4 Post Peak effect:

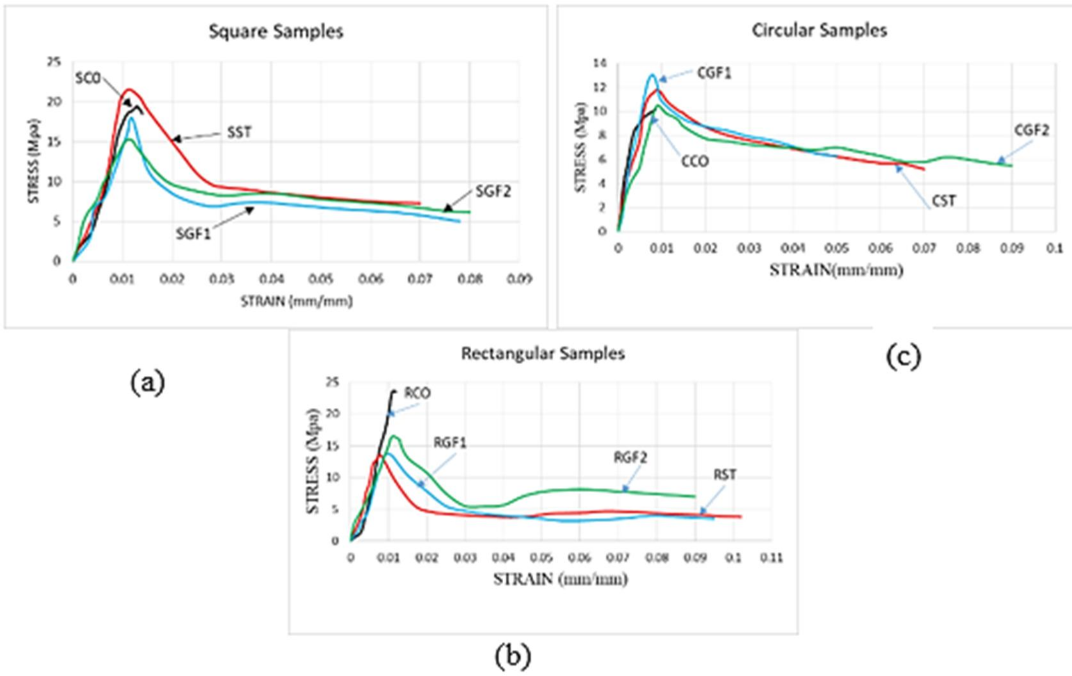



Figure 8 Post peak behavior of, (a) Square samples, (b) Rectangular samples, (c) Circular samples

As from data in figure 8, it is seen that unlike the original brittle behavior, retrofitted samples demonstrated a more ductile response during testing. And did not experience sudden failure, but instead, they underwent progressive failure, like reinforced structures. Retrofitted samples even resisted a considerable stress even after failure. This transition from brittle to ductile behavior and the progressive failure mechanism indicate that the NSM retrofitting process has effectively improved the structural performance and durability of the samples. The ability to absorb more strain energy and undergo deformation before failure is a desirable characteristic for enhanced safety and resilience in structures.

The addition of NSM GFRP bars has significantly enhanced the ductility characteristics of the retrofitted specimens, leading to a significant improvement in their post-peak behavior compared to the control specimens. While there is reduction in peak strength relative to the control specimens, the enhanced post-peak behavior underscores the effectiveness of the retrofitting strategy. In addition, the inclusion of double GFRP bars, as illustrated by the graphical data, demonstrates a further enhancement in post-peak behavior compared to specimens retrofitted with single GFRP bars on each side, as well as the control specimens. This indicates the progressive improvement in structural performance with the inclusion of NSM GFRP bars.

The NSM retrofitting process enhances the material's ability to withstand deformation and redistribute stresses, leading to a more gradual failure mode. The strengthening effect provided by NSM retrofitting improves the load-carrying capacity of the sample and allows it to sustain higher loads before reaching failure. This progressive failure behavior can further be increased by using reinforced structures, where the presence of reinforcing elements allows the material to continue carrying loads even after the initiation of cracks or damage. Thus, increasing the overall load caring capacity even after failure of concrete.

## 4 CONCLUSION

The study aimed was to investigate the effect of NSM GFRP retrofitting on axial compressive behaviour of different shaped concrete columns.

It is observed that the NSM retrofitting shifted behaviour of specimens to a more ductile and controlled response exhibiting enhanced plastic deformation beyond the peak stress point, indicating a greater ability to absorb strain energy and undergo controlled yielding suggesting improved structural integrity and resilience. NSM GFRP outperforms NSM steel in retrofitting by providing greater ductility and high peak stress and reduced additional dead weight, making it better choice due to its corrosion resistant properties.

The study highlights the need to use optimal ratio of NSM GFRP retrofitting, as increased NSM bars will require more grooving, resulting in a reduction of the effective load-resisting area. Which is responsible for decrease in the peak stress is experienced. The introduction of grooves led to stress concentrations, localize resulting in plastic deformation and fracture initiation resulting in a lower peak stress value compared to the control specimens. However, despite the decrease in peak stress, the overall performance of the modified specimens remained unaffected, as post-peak behavior exhibited significant improvements in other crucial aspects, compensating for the reduction in peak stress.

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