Experimental Study on Enhancing the Flexural Strengthening of Pre-loaded RC Beams using BFRP Bars

Nikhil V N [1], K.M. Kiran [2]
[1]*Student, Department of Civil Engineering, Bangalore Institute of Technology, Bangalore, Karnataka, India*
[2]*Assistant professor, Department of Civil Engineering, Bangalore Institute of Technology, Bangalore, Karnataka, India*

***Abstract*—Reinforced Concrete (RC) beams are critical load-carrying elements in structures, designed to ensure stability through the combined action of concrete and steel reinforcement. To further enhance their flexural capacity, Basalt Fiber Reinforced Polymer (BFRP) bars can be used with strengthening methods like Side Near-Surface Mounted (SNSM) and Bottom Near-Surface Mounted (BNSM)techniques.This study experimentally investigates the flexural performance of preloaded RC beams strengthened using SNSM and BNSM methods. The beams were preloaded and then retrofitted with longitudinal BFRP bars embedded in grooves along the sides (SNSM) and bottom (BNSM). Comparative analysis between strengthened and control beams was performed by evaluating ultimate load, service load, deflection, and crack behavior.**

***Index Terms*—Side Near-Surface Mounted (SNSM), Bottom Near-Surface Mounted (BNSM) preloaded, Load- Deflection, Ultimate load**

I. INTRODUCTION

Reinforced Concrete (RC) structures are widely used in construction due to their strength and durability. However, over time, they may suffer from cracking, corrosion, or overloading, which reduces their service life. To restore and enhance their performance, effective strengthening methods are required. Traditional techniques like steel jacketing are often heavy and prone to corrosion, leading to the adoption of modern materials such as Fiber Reinforced Polymers (FRP).

Among these, Basalt Fiber Reinforced Polymer (BFRP) offers high tensile strength, corrosion resistance, and light weight, making it ideal for structural rehabilitation. Strengthening methods such as Bottom Near-Surface Mounted (BNSM) and Side Near-Surface Mounted (SNSM) techniques are effective in improving the flexural capacity of RC beams.

This study focuses on evaluating the flexural performance of preloaded RC beams strengthened using BFRP bars through BNSM and SNSM techniques to assess their effectiveness in enhancing load capacity and crack control.

II MATERIALS USED

- Concrete: For this investigation, a pre-mixed concrete of grade M30 was utilized. The mix consisted of ordinary Portland cement (OPC), M sand, and gravel stones with coarse aggregates of 20 mm and 10 mm sizes.
- Reinforcement: Three Different Diameter of Bars were used in this experiment [12, 10, 8 mm], 12- & 10-mm bars are used as a primary reinforcement and 8mmforstirrups. All the Steel Bars are 550 grade Turbo steel TMT bars.
- Water: Water used for mixing and curing should be portable.
- Cement: OPC 53 grade cement was used in the entire project.
- Fine aggregates: The fine aggregates used to mix were Manufactured sand (M sand) with maximum particle size of 4.75 mm.
- Basalt fiber reinforced polymer bars: A basalt mesh composed of continuous basalt fibres interlaced into a grid formation. The fibre mesh was utilized in the same condition as provided by the local manufacturer.

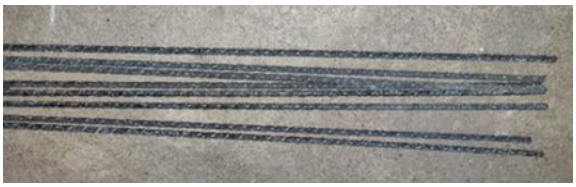


Fig 1. Basalt fiber reinforced polymer bars

Table I. Quantity of concrete [mix design-M30]

Grade of Concrete	M30
Mix Ratio	1:2.2:3.04
Materials	Mix
Cement	450 Kg/ m ^{3}
Fine aggregate	1200 Kg/ m^3
Coarse aggregate	180 Kg/m^3
Water	158 liter
Admixture	1.8 liter

Table II. Properties of Basalt fiber reinforced polymer bars
(Note: Properties as per the supplier)

salt fiber reinforced polymer bars	
Colour	Black
Form	Solid
Length of Rebar	2000mm
Diameter of Rebar	6mm
Cross-sectional area of design	28.26
Density	1.6 to 1.9 G/cm³
Tensile strength	3100 Mpa

Table III. Adhesive Performance Parameters

salt fiber reinforced polymer bars	
Colour	Pale yellow to amber
Application thickness	90 -100 microns dft in 2 coats
Viscosity	Thixotropic
Density	1.25 – 1.26 g/cc
Mixed density	1.3 g/cc
Curing time after application	5 days at 30 c

Table IV provides the details of the test specimens along with the naming convention adopted

Specimen ID	Description
BNSMB - 1	Bottom near surface mounted Beam
BNSMB - 2	Bottom near surface mounted Beam
SNSMB - 1	Side near surface mounted Beam
SNSMB - 2	Side near surface mounted Beam

II OBJECTIVES

1. To comprehend the flexural behavior of BFRP-stirred preloaded RC beams through the application of NSM and SNSM.
2. To determine the essential properties of the strengthening materials.
3. To observe the variations of deflections and failure patterns of the beam strengthened using both NSM and SNSM technique.
4. To compare the experimental results of strengthened beams such as ultimate load, deflection, working load and Width of cracks with conventional beams.

III BEAM SPECIMENS

A. Details of Beam Specimens: The experiment involved casting a total of six reinforced concrete (RC) beams. As illustrated in Figure 4.9, the setup included the following:

1. Two beams acted as control specimens with no additional reinforcement.
2. Two beam was retrofitted with BFRP bars using Bottom NSM technique.
3. Two beam was retrofitted with BFRP bars with Side NSM technique

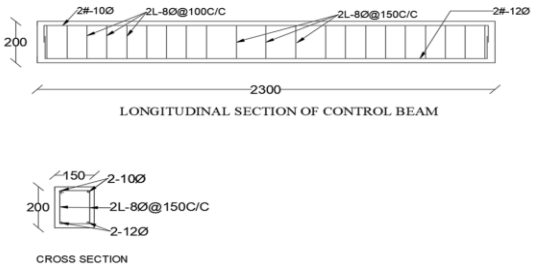


Fig 2. Longitudinal and sectional view of Control Beams

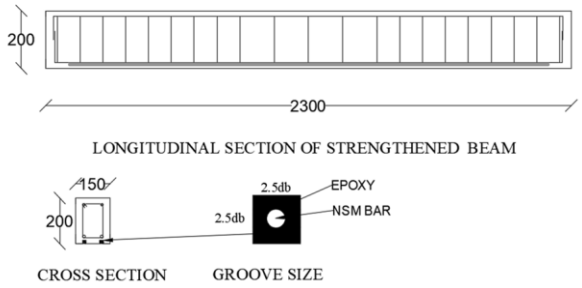


Fig 3. Longitudinal and sectional view of BNSM BFRP Beams

TableV. Specifications of the beam specimens

Type of test	Flexure
Overall length (L) mm	2300
Effective length (l) mm	2100
Overall depth (D) mm	200
Width(B) mm	150

B. Details of Reinforcement

Steel reinforcement design of all the six beams was performed as per IS 456:2000.

Table VI. Reinforcement details

Grade of Concrete	M30
Grade of Steel	Fe550
Reinforcement	2-10mm Φ + 2-16mm Φ
Effective depth (d) mm	167
Areaof steel (Ast) mm2	201.06

C. Casting of Beam Specimens

The steel reinforcements were cut to the required lengths as per the design specifications. Steel shuttering molds with dimensions of 150 mm × 200 mm × 2300 mm (width × depth × length) were prepared, and their inner surfaces were coated with oil to facilitate easy removal of the beams after 24 hours. The reinforcement cage, along with 25 mm spacers, was then positioned inside the molds. Material batching was carried out by weight in accordance with standard procedures to ensure precise measurements and correct use of equipment. A tilting drum mixer was employed to achieve a consistent and thoroughly blended concrete mix, which was then poured into the molds.

Concrete compaction was carefully carried out using a needle vibrator to eliminate any voids that could weaken the structural integrity. Particular attention was given to preventing air pockets and ensuring complete consolidation. The top surfaces of the beams were finished smoothly using a trowel. All six beams were cast on the same day. After a period of 24 hours, the beams were gently demolded. Post-demolding, they were wrapped in gunny bags and cured by watering three times a day for a period of 28 days to ensure proper hydration and strength development.

Fig 3. Steel Reinforcement

Fig 4. Placing Steel Reinforcement and Concrete Cover Blocks into the Formwork

Fig 5. Pouring of Concrete

Fig 6. Curing of the beams

D. Strengthening of Beam Specimens

This study used two strengthening techniques for RC beams — Bottom Near-Surface Mounted (BNSM) and Side Near-Surface Mounted (SNSM) methods — with Basalt Fiber Reinforced Polymer (BFRP) bars to improve flexural performance. After 28 days of curing, four beams were strengthened using the Near-Surface Mounted (NSM) technique: two along the bottom and two along the side faces.Grooves were cut on the concrete surface using a diamond saw and cleaned to remove dust. A primer coat was applied, followed by epoxy adhesive filling. The BFRP bars were then placed into the grooves and properly aligned to ensure full bonding. After installation, the beams were cured under controlled conditions, protected from moisture and temperature variations to achieve strong adhesion between the bars and concrete.

Fig 7.: Groove Cutting

Fig 8. Surface Cleaning after groove Cutting

Fig 9. Adhesive application

IV TEST SETUP AND INSTRUMENTATION

The beams were tested at the Bangalore Institute of Technology laboratory using a loading frame with a capacity of 50 tons, following their casting and a 28-day curing period. To aid in crack pattern analysis, lime wash was applied to the specimens, and lines were marked at 700 mm, 1000 mm, and 1300 mm from one support along the effective span.

The testing utilized a four-point bending arrangement, which creates a central region of pure bending where the moment is nearly uniform and shear forces are minimal. A hydraulic jack was used to apply the load, which was transmitted to the specimen via a spreader beam (I-Section). Deflections were measured by placing the dial gauge at the mid span of the beam.

Load was incrementally applied using the hydraulic jack and a hand-held lever, in uniform 2 KN increments, until the beam failed. For each increment, deflection readings were recorded. The load at which the first crack appeared was noted, and as cracks developed, they were marked with a pen and the width of each crack was measured. The ultimate load at which the beam failed and the mode of failure were carefully documented. After reaching the ultimate load, the load was gradually removed from the beam.

A. Testing of beams

All six specimens were tested using the specified setup: two beams were strengthened with BFRP bars using the Bottom Near-Surface Mounted (NSM) technique, another two with the Side NSM method, while the remaining two acted as control

specimens. During testing, dial gauges were employed to record deflections corresponding to each increment in load. The load corresponding to the appearance of the first visible crack was noted as the cracking load. Loading was then continued until the beams reached failure, with the maximum load recorded as the ultimate load. A dial gauge was positioned at the mid-span of each beam, and readings of deflection were noted for every 2 kN increase in applied load.

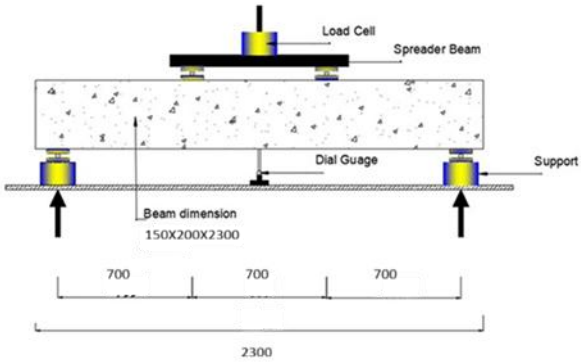
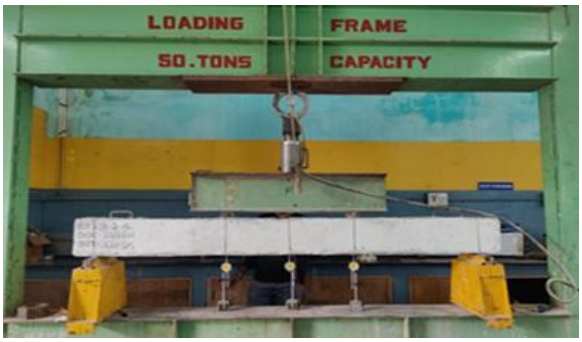


Fig 10. Experimental Test Setup



V. RESULTS AND DISCUSSION

A. Results of tested control beams

- Control Beam 1

The control beam (CB-1) was initially tested following the standard experimental procedure previously described. A load was applied incrementally in steps of 2 kN, with deflection measurements taken using a dial gauge positioned near the mid-span. In the early loading phase, the concrete demonstrated adequate strength and resistance. The initial visible crack was observed in the pure bending zone at a load of 24 kN, where as the designated working load was 37.77 kN. At this load, the observed crack width was 0.2 mm, and the corresponding deflection was 9 mm remaining within the permissible limit of 9.2 mm. As the load increased, the beam began to show signs of reduced stiffness, leading to the formation of additional flexural cracks. These cracks propagated upward, transitioning from micro-cracks into larger macro-cracks that eventually defined clear failure paths. The beam ultimately failed at a peak load of 56 kN due to pure tensile failure. At failure, the deflection measured 16.4 mm, and crack widths had expanded considerably.

Table VII. Experimental test Results of CB-1

Identification of Beam	CB - 1
Casting Date	26/06/25
Testing Date	13/08/25
Initial crack load (Pcr)	24 kN
Working Load	37.77 kN
Center deflection at working load	9 mm
Ultimate load (Pu)	56 kN
Central deflection at ultimate load	16.4 mm
Total number of cracks	4

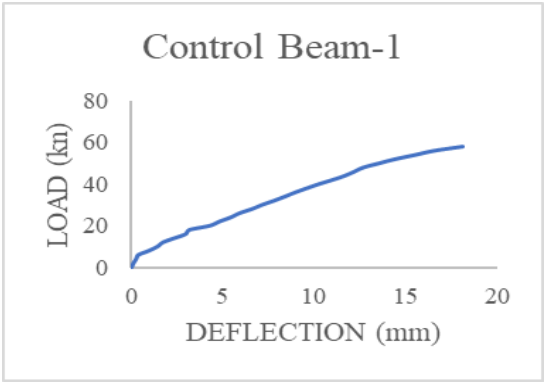


Fig 11. Load vs Deflection Curve of CB-1

Fig 12. CB - 1 Crack Patterns

- Control Beam 2

The control beam (CB-2) was the first to undergo testing, following the standard experimental procedure outlined earlier. The applied load was in

2 kN increments, and Deflection was recorded at the mid-span of the beam using a dial gauge. During the beginning stages, the concrete exhibited considerable strength and durability under loading. The first visible crack emerged in the pure bending zone at 22 kN, while the designated working load was 36 kN. At this load level, a crack width of 0.25 mm was observed, and the corresponding deflection was 8.4 mm well within the acceptable limit of 9.5 mm. As loading increased, a gradual reduction in stiffness was noted, accompanied by the formation of additional flexural cracks. These cracks progressed upward, evolving from micro-cracks into macro-cracks that eventually defined prominent failure zones. The beam ultimately reached its peak load capacity at 54 kN, failing due to pure tensile action. At the point of failure, the deflection reached 15.22 mm, and the cracks had widened considerably.

Table VIII. Experimental test Results of CB-2

Identification of Beam	CB - 2
Casting Date	26/06/25
Testing Date	13/08/25
Initial crack load (Pcr)	22 kN
Working Load	36 kN
Center deflection at working load	8.4 mm
Ultimate load (Pu)	54 kN
Central deflection at ultimate load	15.22 mm
Total number of cracks	5

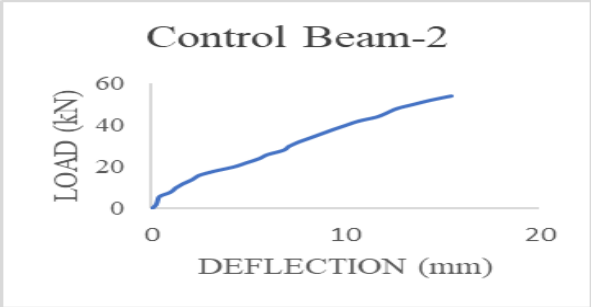


Fig 13. Load vs Deflection Curve of CB-2Fig

Fig 14. CB - 2 Crack Patterns

B. Beam specimen preloading procedure

Prior to the application of Basalt Fiber Reinforced Polymer (BFRP) bars using the BNSM (Bottom Near Surface Mounted) and SNSM (Side Near Surface Mounted) strengthening techniques, the beams were subjected to preloading via a two-point loading setup. This method reflects real-world scenarios, as many existing structures require retrofitting due to insufficient load capacity or to comply with updated design codes. Evaluating beams under preloaded conditions is essential, since pre-existing damage can affect the performance of strengthening interventions. The experimental findings revealed that beams tested without preloading exhibited greater stiffness and higher ultimate load capacity compared to preloaded beams, highlighting the considerable influence of preloading on the structural behavior of reinforced members.

The Effective preloading depends on the consideration of the following variables:

- The self-weight of the beam alone, which corresponds to the stresses exerted on the internal longitudinal reinforcement.
- The additional load, corresponding to load

= Yield capacity of the control beam /1.5

- According to the ACS code , it is 40-60% of ultimate load.
- Preload the beam until the initial crack appears.

Fig 15. Preloaded Beams Crack Patterns

C. Results of tested strengthened beams

- Strengthened beam using bottom NSM (BNSMB-1)

The beam, initially preloaded and then strengthened on its bottom face using BFRP (Basalt Fiber Reinforced Polymer) bars through the NSM (Near-

Surface Mounted) technique was subjected to a series of tests following the standard experimental procedures.

Table IX. Results of BNSMB-1

Identification of Beam	BNSMB - 1
Casting Date	26/06/25
Testing Date	30/08/25
Initial crack load (Pcr)	22 kN
Working Load	58.66 kN
Center deflection at working load	8.12 mm
Ultimate load (Pu)	88 kN
Central deflection at ultimate load	19.2 mm
Total number of cracks	9
Maximum crack width	2.0 mm

a) BNSMB-1 failure mode

b) Propagation of crack patterns

Fig 16. BNSMB-1 Failure Mode and Crack Patterns

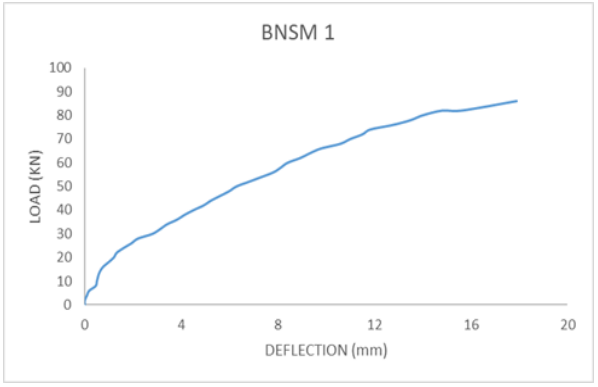


Fig 17. Load vs Deflection Curve of BNSMB-1

- Strengthened beam using bottom NSM (BNSMB-2)

The preloaded beam underwent strengthening with CFRP bars on its bottom side using the NSM technique, followed by a series of tests conducted as per the standard experimental procedure.

Table X. Results of BNSMB-2

Identification of Beam	BNSMB - 1
Casting Date	26/06/25
Testing Date	30/08/25
Initial crack load (Pcr)	22 kN
Working Load	58.66 kN
Center deflection at working load	8.12 mm
Ultimate load (Pu)	88 kN
Central deflection at ultimate load	19.2 mm
Total number of cracks	9
Maximum crack width	2.0 mm

a) BNSMB-1 failure mode

b) Propagation of crack patterns

Fig 18. BNSMB-2 Failure Mode and Crack Patterns

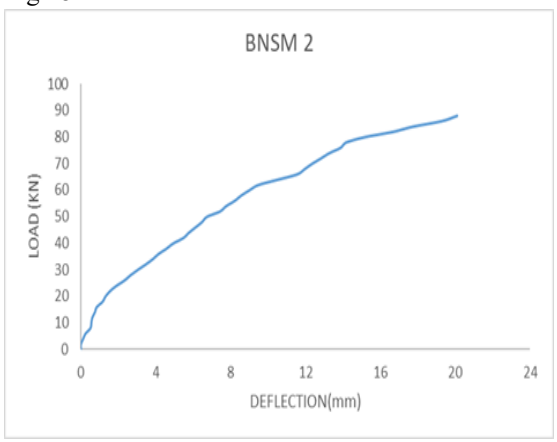


Fig 19. Load vs Deflection Curve of BNSMB-2

- Strengthened beam using side NSM (SNSMB-1)

The preloaded beam was strengthened on its side face using BFRP bars via the NSM technique, followed by testing in accordance with the standard experimental procedures

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Table XI. Results of SNSMB-1

Identification of Beam	SNSMB - 1
Casting Date	26/06/25
Testing Date	30/08/25
Initial crack load (Pcr)	24 kN
Working Load	52 kN
Center deflection at working load	9 mm
Ultimate load (Pu)	78 kN
Central deflection at ultimate load	21.26 mm
Total number of cracks	11
Maximum crack width	2.7 mm

a) SNSMB-1 failure mode

b) Propagation of crack patterns

Fig 20. SNSMB-1 Failure Mode and Crack Patterns

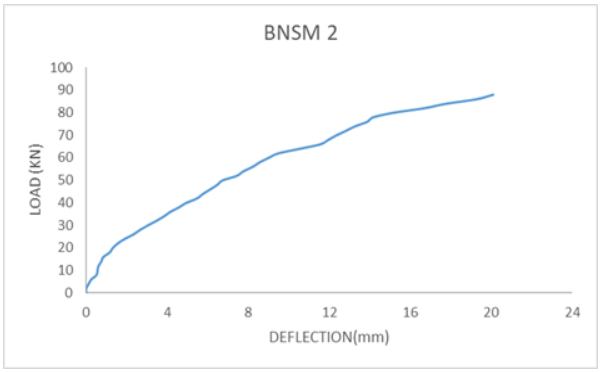

Fig 21. Load vs Deflection Curve of SNSMB-1

- Strengthened beam using side NSM (SNSMB-2)

The preloaded beam was strengthened on its side face using BFRP bars via the NSM technique, followed by testing in accordance with the standard experimental procedures.

Table XII. Results of SNSMB-2

Identification of Beam	SNSMB - 2
Casting Date	26/06/25
Testing Date	30/08/25
Initial crack load (Pcr)	24 kN
Working Load	48 kN
Center deflection at working load	8.86 mm
Ultimate load (Pu)	72 kN
Central deflection at ultimate load	20.46 mm
Total number of cracks	12
Maximum crack width	2.8 mm

a) SNSMB-2 failure mode

b) Propagation of crack patterns

Fig 22. SNSMB-2 Failure Mode and Crack Patterns

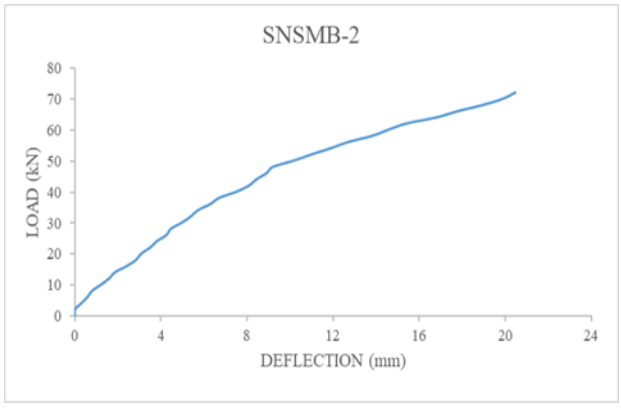

Fig 23. Load vs Deflection Curve of SNSMB-2

D. Comparative study on behaviour of control and strengthened beam : A comparison between the control beams and those reinforced using the NSM method reveals considerable advantages and marked improvements in structural behavior. The NSM technique significantly strengthens the structure, reducing the risk of early failure and increasing the beam's ability to carry greater loads. Consequently, this method enhances safety factors and contributes to a longer service life for the structure, offering lasting benefits. Additionally, the beams reinforced using strengthening techniques exhibit a significantly higher ultimate load significantly higher ultimate load capacity compared to the control beams. Specifically, beams strengthened using the BNSM method exhibited an 88.24% increase in ultimate load, while those reinforced with the SNSM method showed a 52.94% improvement. This significant enhancement in structural strength is especially important in scenarios where structures are subjected to heavy or dynamic loading. The marked increase in ultimate load capacity demonstrates that the strengthened beams can withstand much greater forces before failure, providing enhanced durability and dependability under challenging conditions.

Table XIII. Comparison of Load and Deflection Values of all the Beams

Beam designation	Ultimate Load Pu (in kN)	Deflection at Ultimate Load Δu (in mm)	Working Load Pw (in kN)	Deflection at Working Load Δw (in mm)	Allowable Deflection
CB-1	54	16.40	37.33	9	9.12
CB-2	58	15.22	36	8.4	9.12
BNSMB-1	88	19.20	58.66	8.12	9.12
BNSMB-2	90	21.50	60	9.02	9.12
SNSMB-1	78	21.26	52	9	9.12
SNSMB-2	72	20.46	48	8.86	9.12

Table XIV. Ultimate Load Comparison of All Beams

Designation of beams	Ultimate Load Pu (in kN)	Average (kN)	Proportion of Strength Gained
CB-1	54	56	
CB-2	58		
BNSMB-1	88	89	58.92%
BNSMB-2	90		
SNSMB-1	78	75	33.92%
SNSMB-2	72		

The reinforced beam's load-deflection curve shows enhanced performance, characterized by greater stiffness, a delayed onset of the first crack, and a higher ultimate load capacity when compared to the observed behavior of the reference beam. The application of BFRP strengthening materials leads to a significant decrease in deflection at the ultimate load, reflecting an overall increase in the beam's stiffness and rigidity.The ultimate loads displayed by the control beams (CB1 and CB2) were 54 kN and 58 kN, respectively.

The bottom NSM-strengthened beams (BNSMB1 and BNSMB2) achieved a marked enhancement in strength, as indicated by ultimate loads of 88 kN and 90 kN. Similarly, the ultimate loads of SNSMB1 and SNSMB2, the beams with side NSM reinforcement, were 78 kN and 72 kN, respectively. The results indicate that NSM strengthening methods significantly improve the load-bearing performance of beams.

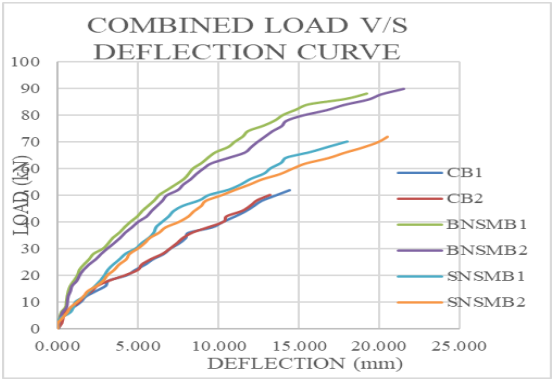

Fig 24. Combined load v/s deflection curve of all beams

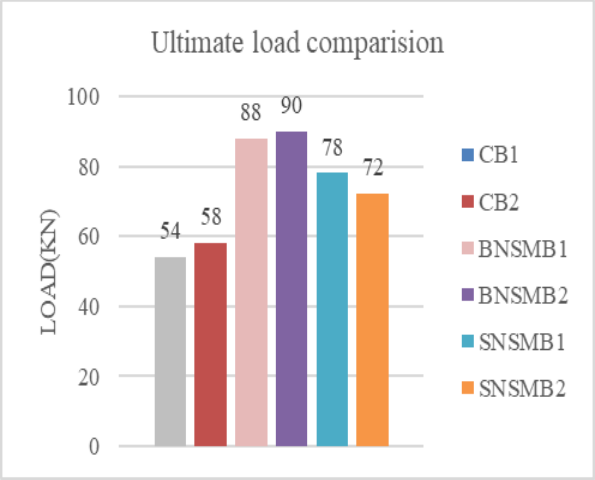

Fig 25. Ultimate Load Comparison Between Control and Strengthened Beams

The control beams, CB1 and CB2, exhibited crack widths of 0.2 mm and 0.25 mm, respectively at the working load, showcasing the limitations of traditional reinforcement methods in controlling cracks. In contrast, the strengthened beams displayed enhanced performance. BNSMB1 showed a crack width of 0.11 mm at a working load of 58.66 kN, while BNSMB2 had a crack width of 0.14 mm at 60.00 kN. Similarly, SNSMB1 and SNSMB2 had crack widths of 0.10 mm and 0.12 mm at working loads of 52.00 kN and 48.00 kN, respectively. The decreased crack widths in the strengthened beams highlight the effectiveness of the NSM (Near-Surface Mounted) technique in enhancing crack control under service loads.

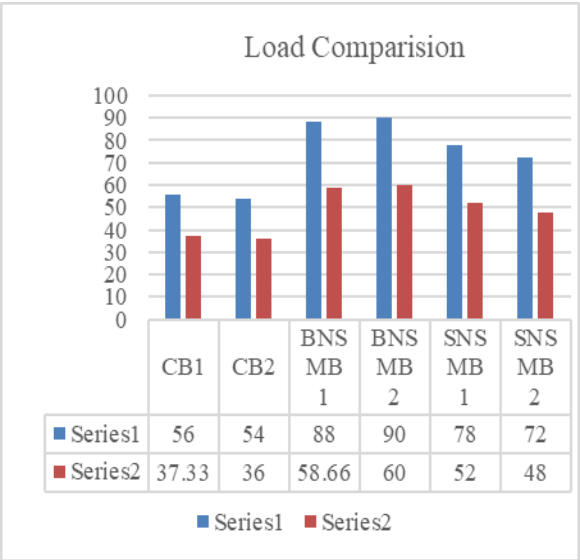

Fig 26. Ultimate Load Versus Working Load

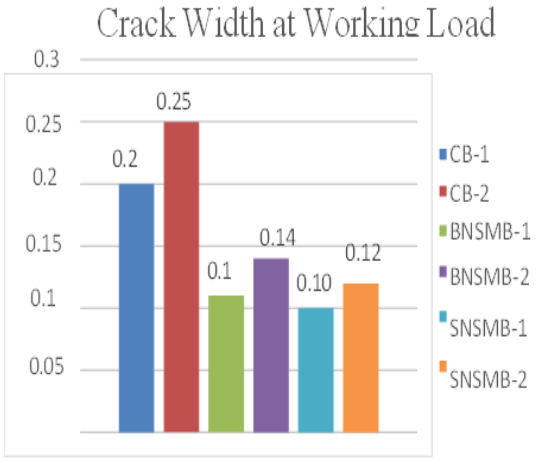

Fig 27. Crack Width at Working Load

Deflection measurements further highlight the advantages of strengthening. CB1 and CB2 had deflections of 6.7 mm and 5.2 mm, respectively, both within the allowable limit of 9.12mm. However, the strengthened beams displayed varying deflection behaviors. BNSMB1 possessed a diversion of 8.65 mm, within the allowable limit, while BNSMB2 possessed a diversion of 8.26 mm, staying within the limit. Side NSM beams, such as SNSMB1 and SNSMB2, showed deflections of 7.66 mm and 8.24 mm, respectively, also within the allowable range. This suggests that while both strengthening methods enhanced load capacity, the side NSM beams provided better deflection control compared to the bottom NSM beams.

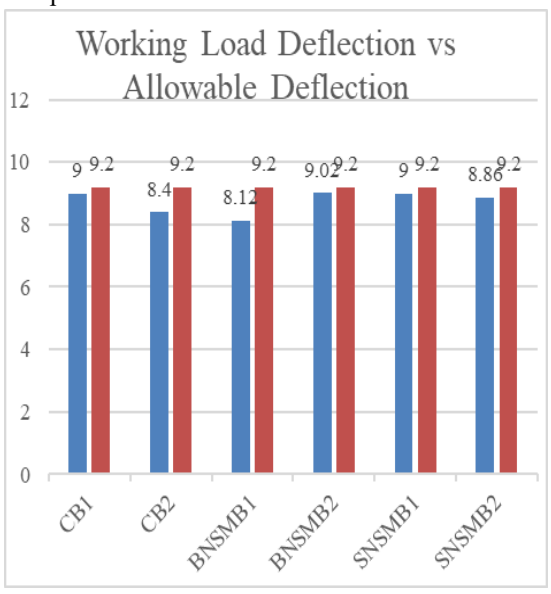

Fig 28. Working Load Deflection Versus Allowable Deflection

VI CONCLUSION

1. The use of BFRP bars as reinforcement considerably enhanced the ultimate load capacity of the strengthened beams relative to the control beams. Strengthened beams exhibited reduced crack widths compared to the control beams.
2. The ultimate load of beams reinforced with BFRP bars using the Bottom NSM technique increased by 58.92%, while those using the Side NSM technique showed a 33.92% increase.
3. The application of BFRP bars significantly increased the deflection of strengthened beams by 40% compared to control beams, indicating improved overall stiffness and rigidity.
4. Beams strengthened using the Bottom NSM technique exhibited a marginally higher ultimate load compared to those reinforced with the Side NSM technique.
5. Both strengthening methods (BNSM and SNSM) effectively enhanced the flexural strength of Preloaded RC beams. However, the Bottom NSM technique demonstrated higher efficiency, making it a more favorable choice for reinforcement purposes.

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