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STRENGTHENING OF REINFORCED CONCRETE BEAMS WITH STEEL REINFORCEMENTS BY NSM SYSTEM

R.Muthukumar, *N.Balasundaram, [3]Neeta.A

Karpagam Academy of Higher Education, Coimbatore and [1]Paavai Engineering College, Namakkal, India. Email: *balasundaram49@gmail.com

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ABSTRACT

To enhance the service loading requirement, imposed cyclic loading and errors in design, reinforces the re-construction of existing structural members to improve its strength. In the current scenario, two primary methods of strengthening were in usage which shows remarkable results. Active strengthening systems are EBR (Externally Bonded Reinforcement system) and NSM (Near Surface Mounted system). In this study, an experimental investigation was made for strengthening of reinforced RC beams in flexural behavior with NSM systems employing various proportions of steel bars. Beams were tested with two-point load test setup up to failure, on 4 RC beams of size 125 mm width, 200 mm depth and 1800 mm length which are strengthened with varied combinations of steel reinforcement. Yield strength and ultimate strengths of RC beams, failure modes, ductility behavior and cracking behavior was recorded and reviewed based on measured load and deflection. The final output of this project results in increasing of deflection, ductility nature and also flexural strength raised up to 54.82%.

Keywords: NSM system, Flexural Strengthening.

I. INTRODUCTION

India is second populated country in the world. There needs scarcity of residential build ings for the people. More residential area is required to meet the population demand. So, there is a very high demand for apartments. Moreover, due to the ongoing trend toward moving to the city or process of urbanization, there is an increase in city populations and therefore new residential areas are needed to meet this demand. Along with the population problems, the need for more public buildings, such as social facilities and schools, has arisen. If we want to use national resources economically and meet the needs, we want to repair and strengthen the existing and damaged buildings. There are various reasons we want to repair and strengthen the structure. They are mechanical defects, environmenttal action and faults in construction. (Almusallam, et al., 2013).

The enhancement of the strength properties of the existing structures has been done by enhancing the serviceability performance and improving the load carrying potential of the structures. There is extensive number of procedures for repairing and strengthening of existing structures. Among all those strengthening systems EBR (Externally Bonded Reinforcement system) and NSM (Near Surface Mounted system) is most popular in construction field (ACI, A., 440.2 R-0 2, 2002).

The EB R system comprises steel plates or fiber reinforced polymer (FRP) laminates by external attachment for strengthening purpose. (Kachlakev and McCurry, 2008) Yet, this system experiences the huge likelihood of readiness failures like delamination, separation of longitudinal laminates and other notations of readiness failure. This issue limits the strengthened members from delivering its ultimate flexural capacity. The original improvements of the system of strengthening concrete members with polymer sheets took place in Germany and Switzerland. FRP plates are defenseless against environmental, mechanical and thermal damage. Hence, the NSM strengthening system extends an adequate substitute to the EBR system. In the NSM system, the concrete guards the NSM bars against environmental, mechanical and thermal damage, and to prevent readiness failure (Hawileh, et al., 2014).

In 1940s the NSM system was used originally in Finland where grooved steel bars were used to strengthen the deck slab in bridge. Numerical analysis of flexural behavior in RC beams was strengthened by using NSM bars and FRP Materials. (Barros, et al., 2007) FRP reinforcement has various benefits such as large strength, less weight, protection against corrosion and possibly great durability. The only disadvantage was very costly (Kachlakev and McCurry, 2000).

In this study the performance of RC beams is strengthened with NSM steel bars constrained to bending was examined. Since its rare availability, steel is employed as the strengthening material. It provides a budgetary solution and also offers the efficient structural behavior. The experimental test variables are yield strength and strengthening reinforcement proportion (ACI-2002, Barros et al., 2007, Hawileh et al., 2014, Kachlakev et al., 2000. To determine the failure modes, cracking behavior, bending stiffness and ductility of the beams Load, deflection and strain data was analyzed (Onal, 2006).

II. MATERIALS USED

All beam samples were cast using M40 grade conventional concrete mix. Maximum size of coarse aggregate was chosen about 20mm crushed granite. For fine aggregates natural river sand was used. Normal tap water was used for concrete mixing and casting the specimens. Water-cement ratio adopted for this research work was 0.5.

Table 1: Mix design

Cement (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
478	902	910	239
1	1.89	1.90	0.5

Table 2: Properties of reinforcing steel

Properties of steel reinforcements used	HYSD bar			Mild steel bar	
	16mm	12mm	10mm	8mm	6mm
Yield strength (MPa)	596	550	532	324	318
Ultimate strength (MPa)	712	690	647	425	421
Modulus of Elasticity (GPa)	200				

Sikadur 30 is an epoxy adhesive which is employed to bond the strengthening materials to the concrete. Sikadur® 30 has two segments namely segment A (White) and segment B (Black). The two segments were mixed in a ratio of 3:1 until the grey color was obtained. The bond strength of steel is 21 MPa and with concrete is 4 MPa has been used. The density was 1.65 g/cm^3 at 23°C after mixing.

Table 3: Properties of Adhesive material (Sikadur 30)

Strength	Curing time	Amount (MPa)
Compressive strength	7days	92.00
Tensile strength		35.00
Shear strength		21.00

Strengthening plan: In this research paper, four RCC beams were tested. Here first beam is control beam, and they are not strengthened, and the remaining beams were strengthened by NSM using steel bars systems.

Table 4: Strengthening plan

Specimen description	Comment
CB	Control beam (Unstrengthen)
SB1	Strengthened by NSM system with 1# 6mm dia bar
SB2	Strengthened by NSM system with 1# 8mm dia bar
SB3	Strengthened by NSM system with 1# 10mm dia bar

Specimen Configurations: In this study, simply supported reinforced concrete beams were subjected to pure bending by subjecting them to two-point loading test. The beams were casted with 2 numbers of 16mm diameter HYSD bars at bottom and 2 numbers of 12mm diameter HYSD bars at top. 8mm diameter mild steel bars were used as stirrups which are spaced at 150 mm centers.

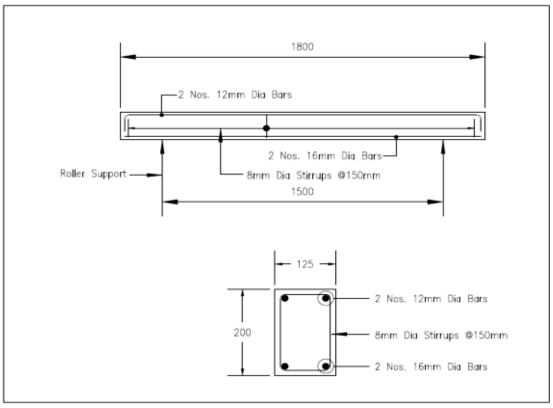

Fig. 1: Typical beam reinforcement details

Strengthening Procedure: Strengthening bars are placed in separate channels which were made by a cut on the concrete cover. Epoxy adhesive groove fillers are used to make perfect bond between the concrete surface and strengthening bars. Special concrete saw mounted with diamond blade was used as a primary cutting equipment in the formation of grooves. Secondary cutting equipment's like hammer and chisel were adopted to smoothen the surface of groove. Grooves were cleaned and half filled with adhesive material, then the strengthening bars were pressed inside the adhesive material. The beam was left undisturbed for 1 week, to achieve better bonding by the adhesive material.

Experimental setup

Fig. 2: Experimental test setup

All beams were examined as simply supported beams under two-point loading over a sufficient span of 1500mm. These beams were examined in a loading frame of 500kN capacity. Mid span and L/3 deflections were marked using displacement sensor with least count of 0.001mm. The parameters such as initial cracking load, ultimate load and surface change in length of the specimens were noted.

Experimental Results: The cracking load, crack width, yield load, ultimate load and modes of failure aspects are considered.

Table 5: Summary of Beam Test Results

Specimen Description	P_{cr}		P_y		P_u		Δ_{max}	Failure mode
	kN	%	kN	%	kN	%	(mm)	
CB	17	-	68	-	73	-	30.25	Flexural
SB1	18	5.88	78	14.71	81	10.96	37.51	Flexural
SB2	21	23.53	94	38,24	99	35.61	36.21	Flexural
SB3	23	35.29	104	52.94	112	53.42	35.22	Flexural

Load deflection curve: The curves defined by elastic, concrete cracking and steel yielding to failure stages as tri linear behavior. The first cracking load, yield load and ultimate loads were increased 35.29%, 52.94% and 53.42% respectively than conventional beam. The beams were fails by flexural mode of failure. Typical readings taken from experimental investigation were shown in table 6 and table 7.

Table 6: Load deflection curve readings for CB

S. No	Load (kN)	Deflection(mm)		
		L/3 Left	L/2	L/3 Right
1	0	0.00	0.00	0.00
2	3	0.30	0.36	0.28
3	13	1.82	1.91	1.52
4	18	2.48	2.48	2.18
5	23	3.40	3.91	3.02
6	29	4.26	5.02	3.90
7	35	5.24	6.17	4.84
8	42	6.42	9.56	5.98
9	49	7.52	9.00	7.12
10	58	9.30	11.15	8.82
11	61	9.98	11.91	9.46
12	63	11.02	13.17	10.40
13	65	14.08	17.17	12.94
14	66	16.58	20.57	15.36
15	68	18.66	23.72	17.80
16	69	20.94	26.87	20.10
17	73	23.54	30.25	22.64

Table 7: Load deflection curve readings for SB1

S.No	Load (kN)	Deflection(mm)		
		L/3 Left	L/2	L/3 Right
1	0	0	0	0
2	4	0.4	0.63	0.38
3	8	1.02	1.34	0.98
4	13	1.84	2.61	1.86
5	21	3.18	4.68	3.36
6	28	4.6	6.83	4.94
7	36	6.14	8.98	6.62
8	43	7.42	10.82	8
9	49	8.3	12.16	9
10	56	9.5	13.91	10.26
11	60	10.74	15.64	11.48
12	62	12.7	18.03	12.82
13	68	16.28	22.98	15.62
14	71	19.08	26.77	17.92
15	77	21.86	32.46	20.24
16	81	23.96	37.51	22.22

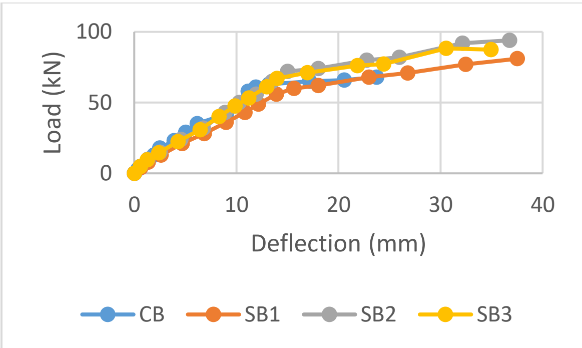

Fig. 3: Load vs Mid span deflection of RC beams

Mode of Failure: There are two modes of failure experienced in RC beams, which are crushing of concrete at top fiber and yielding of steel reinforcement at bottom fiber. Same crack pattern occurs in all tested beams. Initially fine flexural cracks produced at bottom, further increase in load additional cracks were formed up to the neutral axis with considerable increase in deflection. But the NSM strengthened beams shows only finer and narrow cracks.

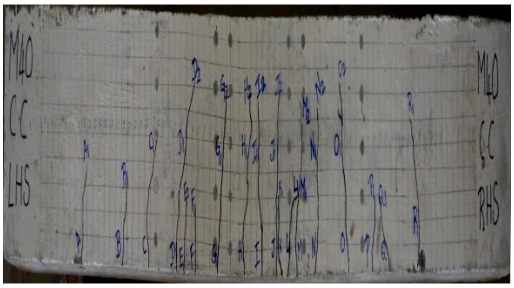

Fig. 4: Crack pattern and crack width profile in CB

From figure 5, the crack loads observed are 17kN, 19kN, 21kN and 23kN for CB, NSM1, NSM2 and NSM3 respectively. First crack load in CB was much lower than all strengthened beams.

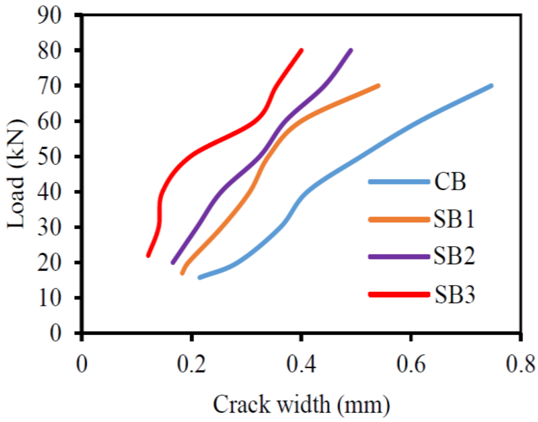

Fig. 5: Load vs Crack width curve Ductility

In this study, two ductility indexes were studied. The ductility index on deflection was decreased by 62.96%, 35.35%, and 34.68% for SB1, SB2 and SB3 respectively over the CB. The ductility index on energy was reduced by 81.43%, 57.30%, and 55.87% for SB1, SB2 and SB3 respectively over the CB.

Table 8: Ductility behavior of RC beams

Specimen Descriptio	Deflection ductility			Energy ductility		
	Δ_y (mm)	Δ_u (mm)	μ_d	E_y (kNmm)	E_u kNmm)	μ_E
CB	9.30	27.09	2.97	327.05	1694.48	6.30
SB1	11.97	12.99	1.10	498.02	571.20	1.17
SB2	10.89	20.58	1.92	568.72	1504.08	2.69
SB3	12.38	23.52	1.94	692.78	1896.14	2.78

CONCLUSION

The final conclusions are:

- NSM system results as excellent strengthening system.
- The flexural rigidity of the strengthened beams was powerful than the un-strengthened control beams. This development, nevertheless, reduced in cases where horizontal cracks and delamination were witnessed to occur.
- The increase in flexural potential was reliant on the amount of extra reinforcement and maintenance of full composite action until failure.
- Raising the amount of steel reinforcement employed will result in a loss of energy and ductility indexes and increase in ultimate load carried by the specimen.
- The appearance of the first crack was delayed by adding NSM steel bars at the bottom of the RC beam.

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