Experimental Study on Flexural Behavior of Pre- Loaded RC T- Beam Strengthened with CFRP Laminate under NSM Technique

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Abstract -
The RC structures are subjected to several loads under adverse environmental conditions, which may cause the structures to deteriorate before their designed service life. In such circumstances, dismantling and rebuilding the structure is a time-consuming and costly operation. As a result, in order to increase the serviceability of the RC structure and satisfy design criteria, the structures are reinforced with CFRP composites. The current experimental effort attempts to study the flexural behavior of pre-loaded Reinforced concrete T-beams strengthened with CFRP strips under NSM Technique with different orientation of CFRP strips i.e., horizontal and vertical. In comparison with control beams, the working and ultimate loads of T-beams strengthened with NSMLV and NSMLH technique enhanced by up to 23.69% and 25.43% respectively. The load deflection behavior and failure mechanisms of all reinforced and control T-beams are also investigated. The percentage of quantity of CFRP laminates used in NSMLH technique was almost double than that in the NSMLV technique. Hence the NSMLV technique is more economically then NSMLH technique. The deflection at the failure load in the NSMLV reinforced beams was more than two to three times that at the working load, indicating that the requisite level of deflection ductility was reached.

Key Words: Reinforced concrete, T-Beams, CFRP Laminate, Flexural Strengthening, NSM, Experimental.

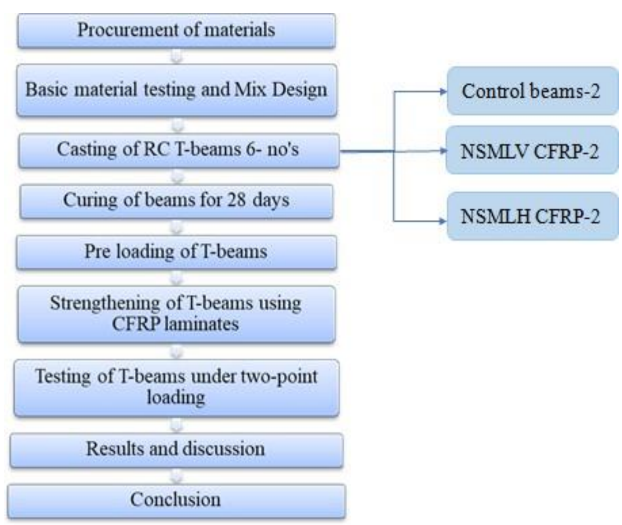
1. INTRODUCTION
Strengthening and retrofitting of existing and damaged reinforced concrete (RC) buildings has emerged as a critical construction activity in order to meet new design standards and strength specifications. Structures must be able to sustain a variety of loads under adverse environmental circumstances such as heavy traffic, intense explosions, debris flow, and a severely corrosive atmosphere. As a result, reinforcing RC structures is necessary to fulfill the appropriate required strength and to extend serviceability of the structures.

External reinforcement, Ferro cement and jacketing using steel plates and post tensioning or Surface treatments are prevalent procedures in the construction sector. Retrofitting or strengthening undamaged and damaged structures with Fiber Reinforced Polymer (FRP) composites, particularly Carbon FRP, has become popular in recent years due to their superior properties such as lightweight with high strength and stiffness, non-corrosiveness, high longitudinal tensile, higher durability, electromagnetic neutrality, lower transmissibility, ease of handling and ability to be implemented quickly with no or few skilled labors.

Near Surface Mounted Technique (NSM): The NSM approach involves inserting FRP strips into grooves, and installing at the stress zone of RC beam concrete cover. Epoxy resin is typical glue used to attach Carbon fiber reinforced polymer (CFRP) to the concrete surface. As an alternative to the external bonding (EB) approach, the NSM technique was created. Because both sides of the Carbon FRP strip are linked to the concrete substrate, it considerably increases the binding between CFRP-concrete and CFRP-epoxy. Carbon FRP reinforcements of various cross sections, such as circular, square, rectangular bars, and strips, are employed in the NSM-FRP strengthening procedure. The rehabilitation of deteriorated structures by using Near Surface Mounted CFRP Composites is gaining popularity in the construction sector owing to its high strength, optimum durability and compatibility with concrete structures during application.

Objectives
The objectives of the current thesis are as listed below:
1. To study the flexural behavior of pre-loaded RC T-beams reinforced with Carbon fiber reinforced polymer utilizing a Near Surface Mounted method.
2. To investigate the effectiveness of reinforced T beams utilizing CFRP laminate in different orientations using the NSM approach i.e, horizontal and vertical.
3. To determine the working load, ultimate load, and deflections under working load of all strengthened and control beams.
4. To evaluate the change in load-deflection behavior of all strengthened and control beams.
5. To observe the debonding failure of CFRP strips in all reinforced RC T-beams.

Methodology
The experimental-methodology used for the thesis has been presented below:



2. SPECIMEN DETAILS

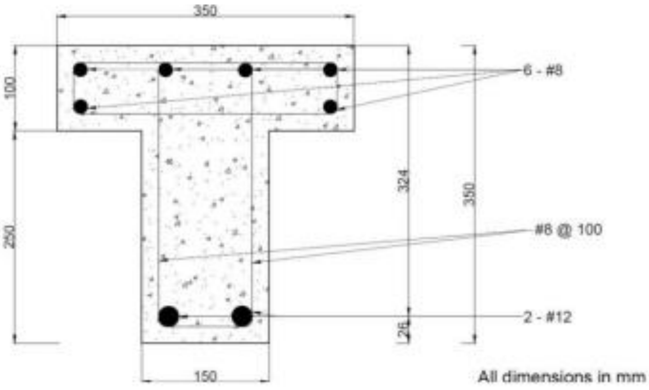


Fig.1 Reinforcement detailing of T-beam

All cross-sectional dimensions of the T- beam were taken as shown in fig.1. The longitudinal tension reinforcement for all T-beams consists of two 12mm diameter steel bars and four 8mm diameter hanger bars in the T-beam flange. There were also 8mm diameter two-legged the vertical stirrups at 100mm c/c along the span. Six T-beams had a clear span of L=2000mm, and Grade of concrete is M20.The formwork and reinforcement cage reinforced concrete T-beam is shown in fig2.

(a)

(b) (c)

(d)

Fig.2 (a)(b) Formwork of T-Beam, (c)(d) Reinforcement cage of T-Beam

3. MATERIALS

Three 150 x 150 x 150 mm concrete cubes were cast to test the compressive strength of concrete after seven, fourteen and twenty-eight days. The 28 days compressive strength of concrete was 24 Mpa. The water-cement ratio was 0.5 with a slump of 75mm. Tensile steel reinforcement for the T-beam was 12mm diameter while vertical stirrups and compression reinforcement were composed of 8mm diameter of HYSD Fe-550 grade bars.

The mentioned data were provided by the manufacturer. CFRP laminate of 1.4 mm thickness, independent of any hazardous contaminants, chemicals, salts, or any detrimental millimeter thickness, with tensile strength 2600 MPa and elasticity modulus 170 GPa, was utilized to reinforce T-beams.

The mentioned data were provided by the manufacturer. The laminates were bonded with concrete using Epoxy Nitobond PC40. The mix of Nitobond PC40 base and hardener epoxy results as adhesive in fig3. The colour of base is off white and hardener is black. We employed an epoxy resin with a compressive strength after 24 hours is > 60N/mm 2 and after 7 days is > 75N/mm2.The specific gravity is range from 1.8 to 1.9and the pot life is 30 min at 400 C.

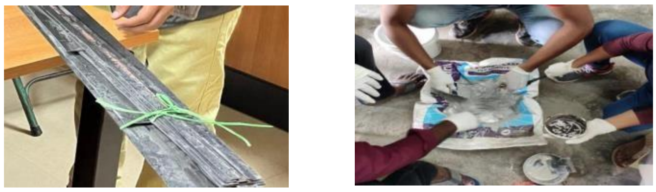


Fig.3 CFRP laminate and Epoxy Nitobond PC40

4. EXPERIMENTAL PROGRAM

Strengthening of beams

The RC T-beams were strengthened after curing for a period of twenty-eight days. CFRP laminates are used to strengthen 4 T-beams, out of which two were NSM with horizontal orientation of CFRP laminate and two were NSM with vertical orientation of CFRP laminates. The different strengthening configurations are shown in the Fig4.

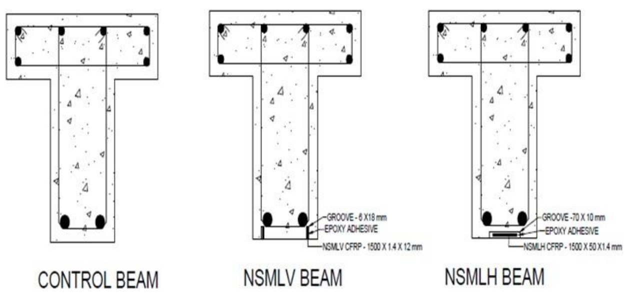


Fig.4 Strengthening Configurations

RC T beam strengthening with Near Surface Mounted Laminate in Vertical Orientation (NSMLV):

Concrete surface preparation using a machine grinder, two grooves of length 1500mm (length), 6mm (width), 18mm (depth) were formed on the cover section of the concrete bottom surface. The dust particles were removed using a blower and then cleaned with a brush to prepare the surface for reinforcement. CFRP laminates were cut to a length of 1.5 m using a reciprocating saw with a fine-tooth blade or a grinder. The epoxy adhesive was injected into grooves to a depth of 4 mm. The laminates were positioned vertically inside the grooves. Before the epoxy adhesive set, the leftover grooves were covered with epoxy adhesive. The epoxy adhesive was filled in all gaps between the laminate and the groove with attention. The surface was cured for 7 days after strengthening before being tested. Fig5 depicts the whole technique used in the NSMLV.


(a)


(b)


(c)


(d)


(e)

Fig.5 (a) Groove Cutting(b) Finished Grooves (6x18mm) (c) Laminate Cutting (d) Adhesive preparation (e) Application of adhesive

RC T beam strengthening with Near Surface Mounted Laminate in Horizontal Orientation (NSMLH)

Concrete surface preparation for strengthening T beam bottom surface was marked with the dimensions required for cutting the groove. The designated area was cut vertically using a fine-tooth blade or grinder, and then chipped with a chisel to create a groove 1500mm in length, 70mm in breadth, and 10mm in depth. The groove bottom surface should be even, with no undulations, gaps, or other irregularities. As a consequence, with a machine grinder, the bottom surface of the groove was ground. To prepare the surface for strengthening, the dust and chipped particles were wiped away after grinding. Carbon FRP laminates with a thickness of 1.4mm was cut to a length of 1500mm and a width of 50mm.The epoxy adhesive was carefully mixed in a 3:1 ratio of base and hardener until it became grey. The epoxy was placed into the groove to a level of 4mm before the laminate was put on top of it. The remaining section of the groove was filled with epoxy before it hardened. The epoxy was cured for at least 7 days after the laminate was applied for strengthening before testing. The NSMLH Technique is seen in Fig6.


(a)


(b)


(c)


(d)


(e)


(f)

Fig.6 (a) Groove Cutting (b) Concrete chipping (c) Finished grooves (70x10mm) (d)Laminate Cutting (e) Adhesive preparation (f) Application of adhesive

Test setup and data acquisition

All the six specimens were tested in the below arrangement, two specimens unstrengthen and four were strengthened with CFRP. The load is applied in gradual increment of 2 KN; the corresponding deflections in the dial gauge reading are recorded at each of these stages. When the load is applied on beams the corresponding load at which first crack appears is called cracking load, further the beams are loaded until failure which corresponds to ultimate load. As discussed, earlier dial gauge readings are recorded at three points namely at 1/3, 1/2 and 2/3 of effective length from the one end of support for each increment in loads. The test data recorded of the RC T-beams under two-point loading test are interpreted and discussed in detail further.

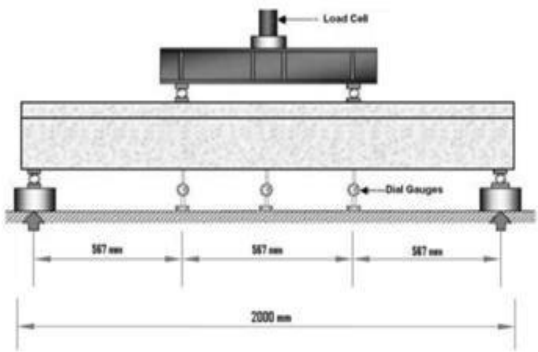


Fig.7 Test setup

5. RESULTS AND DISCUSSIONS

Behavior of Control T-Beams

Control Beam-1 (CB-1)

The beam was tested with the load being gradually increased in an increment of 2KN. First crack appeared in the web of the T-beam under the load of 76KN with deflection 1.07mm. The working load was observed at 120KN with deflection 2.94mm. The reversal of the proving ring needle signaled the beam's failure under the load of 166KN, which is the ultimate load of the beam. Fig8 represents the crack pattern of the CB-1.the graphical representation of Load vs Deflection Curve of CB-1 is provided in Fig9.

Fig.8 Crack pattern observed in CB-1

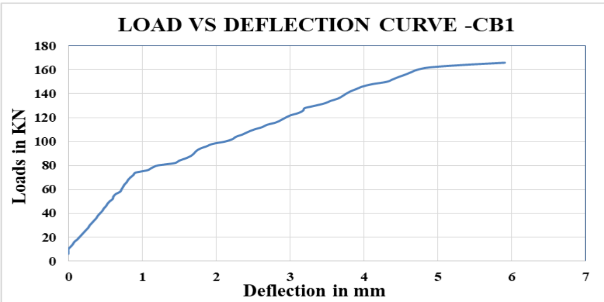


Fig.9 Load vs Deflection Curve of CB-1

Control Beam-2 (CB-2)

The beam was tested with the load being gradually increased in an increment of 2KN. First crack appeared in the web of the T-beam under the load of 90KN with deflection 1.54mm. The working load was observed at 126KN with deflection 3.7mm. The reversal of the proving ring needle signaled the beam's failure under the load of 180KN, which is the ultimate load of the beam. Fig10 represents the crack pattern of the CB-2.the graphical representation of Load vs Deflection Curve of CB-2 is provided in Fig11.

Fig.10 Crack pattern observed in CB-2

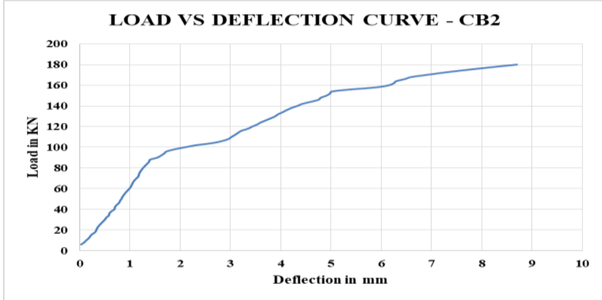


Fig.11 Load vs Deflection Curve of CB-2

PRELOADING

Two-point loading test was done for preloading the T beams. The four beams which have to strengthen with NSM technique using CFRP strips are preloaded with 64% of the ultimate load. Ultimate load of 173KN was obtained with reference to control beams testing. So, the beams are preloaded with the load of 110KN.

Behavior of Strengthened T-Beams

Near Surface Mounted in vertical orientation of laminate (NSMLV-1)

The beams which were preloaded were being tested after strengthened with CFRP laminates. First crack appeared in the web of the T-beam under the load of 36KN with deflection 0.93mm. The working load was observed at 138KN with deflection 4.01mm. The reversal of the proving ring needle signaled the beam's failure under the load of 208KN, which is the ultimate load of the beam. Fig12 represents the crack pattern of the NSMLV-1.the graphical representation of Load vs Deflection Curve of NSMLV-1is provided in Fig13.

Fig.12 Crack pattern observed in NSMLV-1

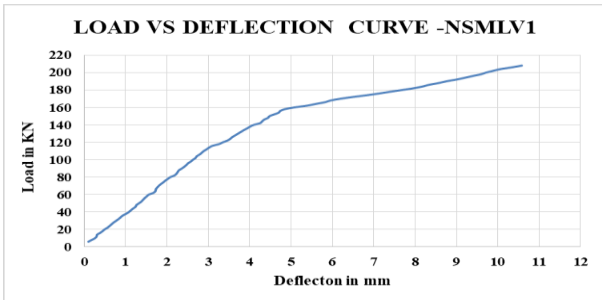


Fig.13 Load vs Deflection Curve of NSMLV-1

Near Surface Mounted in Vertical Orientation of Laminate (NSMLV-2)

The beams which were preloaded were being tested after strengthened with CFRP laminates. First crack appeared in the web of the T-beam under the load of 32KN with deflection 0.85mm. The working load was observed at 146KN with deflection 4.82mm. The reversal of the proving ring needle signaled the beam's failure under the load of 220KN, which is the ultimate load of the beam. Fig14 represents the crack pattern of the NSMLV-2.the graphical representation of Load vs Deflection Curve of NSMLV-2 is provided in Fig15.

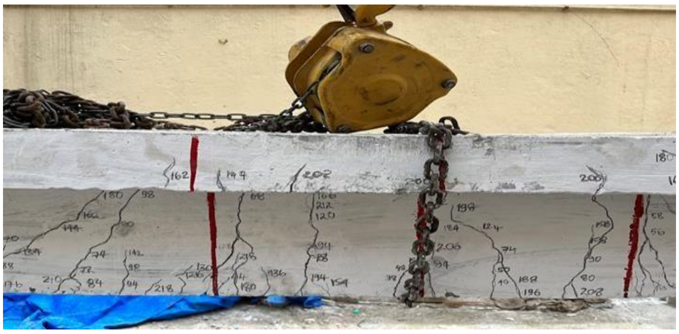


Fig.14 Crack pattern observed in NSMLV-2

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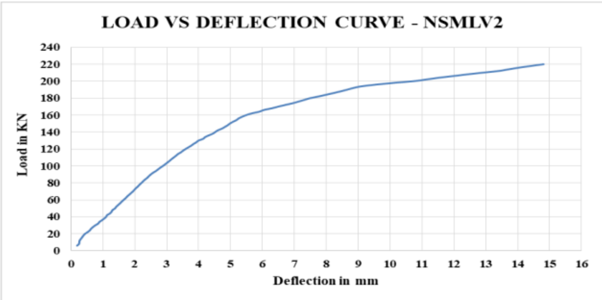

Fig.15 Load vs Deflection Curve of NSMLV-2

Near Surface Mounted Laminate in Horizontal Orientation (NSMLH-1)

The beams which were preloaded were being tested after strengthened with CFRP laminates. First crack appeared in the web of the T-beam under the load of 30KN with deflection 0.41mm. The working load was observed at 144KN with deflection 3.65mm. The reversal of the proving ring needle signaled the beam's failure under the load of 216KN, which is the ultimate load of the beam. Fig16 represents the crack pattern of the NSMLH-1.the graphical representation of Load vs Deflection Curve of NSMLH-1 is provided in Fig17.

Fig.16 Crack pattern observed in NSMLH-1

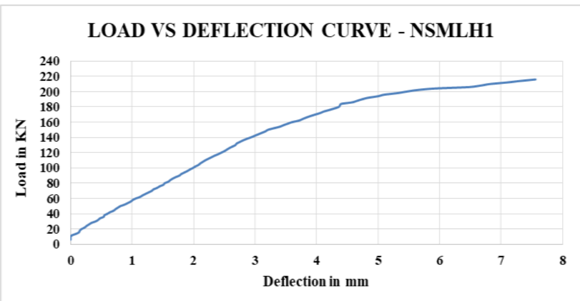

Fig.17 Load vs Deflection Curve of NSMLH-1

Near Surface Mounted Laminate in Horizontal Orientation (NSMLH-2)

The beams which were preloaded were being tested after strengthened with CFRP laminates. First crack appeared in the web of the T-beam under the load of 30KN with deflection 0.54mm. The working load was observed at 146KN with deflection 3.11mm. The reversal of the proving ring needle signaled the beam's failure under the load of 218KN, which is the ultimate load of the beam. Fig18 represents the crack pattern of the NSMLH-2.the graphical representation of Load vs Deflection Curve of NSMLH-2 is provided in Fig19.

Fig.18 Crack pattern observed in NSMLH-2

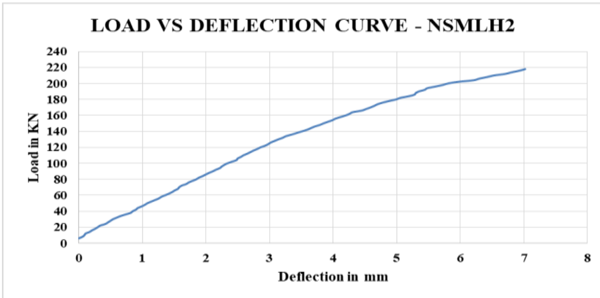

Fig.19 Load vs Deflection Curve of CB-1

COMPARATIVE STUDY ON THE BEHAVIOUR OF CONTROL AND STRENGTHENED T-BEAMS

Combined Load vs Deflection curve for the Control Beams and Strengthened T-beams using NSMLV Technique and NSMLH Technique is shown in fig20 and fig21.As demonstrated in below graphs, all strengthened beams behaved similar to the control beam up to cracking load. Following the cracking load, from Table1 it is clear that the working and ultimate loads for both NSMLV and NSMLH beams increased as compared to the control beams, with percentage increases of 23.69% and 25.43%, respectively can be seen. From Table2 the deflection at the failure load in the NSMLV reinforced beams was more than two to three times at the working load; where as in NSMLH is more than two times at the working load indicating that the requisite level of deflection ductility was reached. Furthermore, the deflections of the NSMLV beams at ultimate load were larger than those of the NSMLH and control beams, showing that the required level of ductility was attained. From Table2 we can say all of the beam's deflections under working loads met the IS 456:2000 standard of span/250 =8. Fig.22 shows average working load of control and strengthened T-beams and Fig.23 shows average ultimate load of control and strengthened t-beams

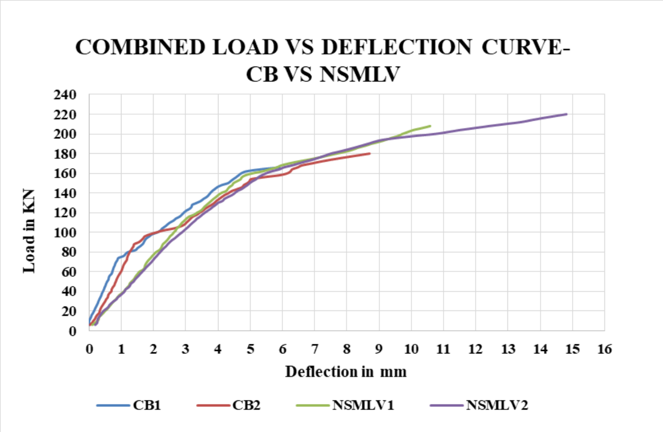

Fig.20 Combined Load vs Deflection Curve for the Control Beams and Strengthened T-beams using NSMLV Technique

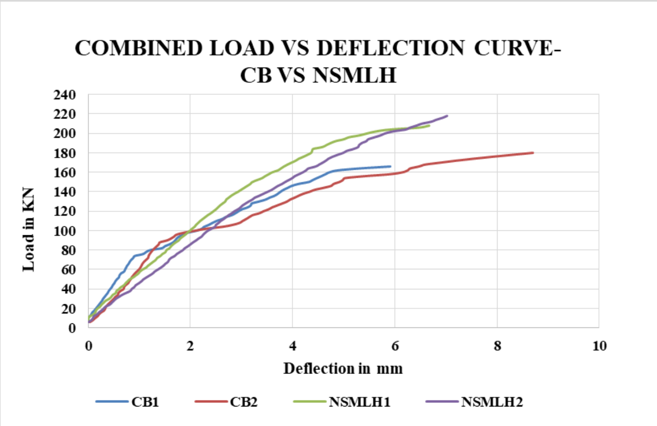

Fig.21 Combined Load vs Deflection Curve for the Control Beams and Strengthened T-beams using NSMLH Technique

Table-1 Loads of Control and Strengthened T-Beams

Beam designation	Pcr (KN)	Pw (KN)	AvgPw (KN)	Pu (KN)	AvgPu (KN)	%Increase compare to CB (%)
CB-1	76	120	**123**	166	**173**	-
CB-2	90	126		180		
NSMVB-1	36	138.6	**142.67**	208	**214**	**23.699**
NSMVB-2	32	146.6		220		
NSMHB-1	30	144	**144.66**	216	**217**	**25.43**
NSMHB-2	30	145.3		218		

Table-2 Deflections of Control and Strengthened T-Beams

Beam designation	Δcr (mm)	Δw (mm)	Avg Δw (mm)	Δu (mm)	Avg Δu (mm)	Requirement as per IS456:2000
CB-1	1.07	2.94	**3.32**	5.9	**5.45**	**Δw<8**
CB-2	1.54	3.7		5		
NSMVB-1	0.93	4.01	**4.415**	10.58	**12.965**	**Δw<8**
NSMVB-2	0.85	4.82		14.81		
NSMHB-1	0.41	3.65	**3.38**	7.65	**7.335**	**Δw<8**
NSMHB-2	0.54	3.11		7.02		

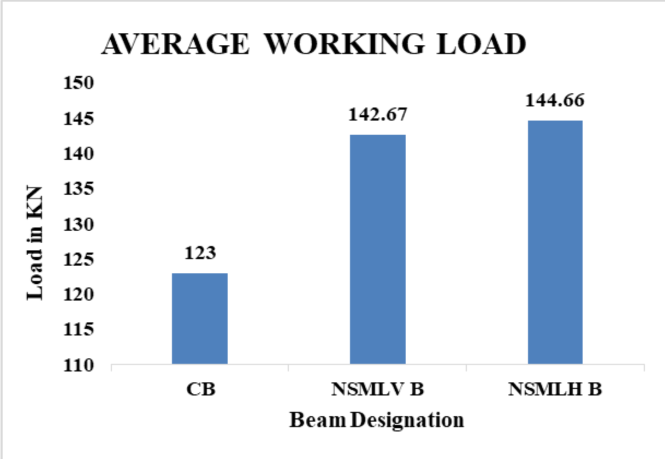

Fig.22 Average Working Load of Control and Strengthened T-Beams

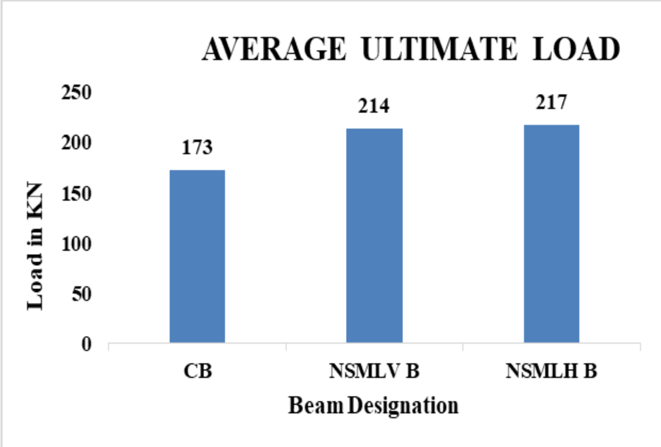

Fig.23 Average Ultimate Load of Control and Strengthened T-Beams

FAILURE MODES OF RC T-BEAMS STRENGTHENED BY NSMLV TECHNIQUE

From the experimental investigation it was observed that, the specimen NSMLV1 and NSMLV2 was failed due to widening of cracks and spalling of the concrete cover which is shown fig24(a)(b). After the failure, the beam bottom portion was examined in order to identify whether the laminate has ruptured there was no rupture of laminate found.

(a) (b)

Fig.24(a)(b) Failure Modes of Strengthened Beams under NSMLV Technique

FAILURE MODES OF RC T-BEAMS STRENGTHENED BY NSMLH TECHNIQUE

The strengthened beams using NSMLH1 Technique failed due to concrete cover separation which was initiated at the end of CFRP laminate shown in fig 25(a). In case of NSMLH2 the beam failed due to debonding of laminate with epoxy which further led to concrete cover separation shown in fig 25(b).

(a) (b)

Fig.25(a)(b) Failure Modes of Strengthened Beams under NSMLH Technique

6. CONCLUSION

- In comparison to the control beams, the working and ultimate loads of T-beams strengthened using NSMLV technique with CFRP enhanced by up to 23.69%.
- In comparison to the control beams, the working and ultimate loads of T-beams strengthened using NSMLH technique with CFRP enhanced by up to 25.43%.
- The beams strengthened with NSMLH CFRP failed by end cover separation along with the laminate, which occurred at single the ends of laminate, while the NSMLV beams failed by concrete cover separation which occurred due to widening of cracks at flexure zone.
- The percentage of quantity of CFRP laminates and epoxy adhesive used in NSMLH technique was almost double than that in the NSMLV technique. Hence the NSMLV technique is more economically then NSMLH technique.
- The deflection at the failure load in the NSMLV reinforced beams was more than two to three times that at the working load, indicating that the requisite level of deflection ductility was reached.
- As a result, both the NSMLV and NSMLH procedures employing CFRP are shown to be successful in increasing the flexural strength of RC T-beams, however the NSMLV technique is more effective than the NSMLH technique due to its higher strength.

REFERENCES

[1] Yanuar Haryanto, Hsuan-Teh Hu, Ay Lie Han, Fu-Pei Hsiao, Charng-Jen Teng, Banu Ardi Hidayat.(2021), "Negative Moment Region Flexural Strengthening System Of RC T-Beams With Half-Embedded NSM FRP Rods", JOURNAL OF THE CHINESE INSTITUTE OF ENGINEERS. https://doi.org/10.1080/02533839.2021.1936646

[2] Mohammed A. Zakia , Hayder A. Rasheedb, Reza R. , Mustafa Raheem .(2020), "Performance of Reinforced Concrete T Beams Strengthened with Flexural CFRP Sheets and Secured Using CFRP Splay Anchors", @ ELSEVIER https://doi.org/10.1016/j.engstruct.2020.110304

[3] Al-Abbas B. Hussein , Abbas A. Ghanim and Al-Fendawy D. Mohsin. (2018) "Experimental Study on the Flexural Strengthening of Reinforced Concrete Beams Using NSM CFRP Bars",5th national and 1st international conference on modern materials & structural engineering Tehran, @ Research gate.

[4] Pedro Fernandes , José Sena-Cruza , José Xavierb,c , Patrícia Silvaa , Eduardo Pereiraa (2017) "Durability Of Bond In NSM CFRP-Concrete Systems Under Different Environmental Conditions", https://doi.org/10.1016/j.compositesb.2017.11.022

[5] J.G. Teng, S.S. Zhang and J.F. Chen. "Strength model for end cover separation failure in RC beams strengthened with near-surface mounted (NSM) FRP strips", Engineering Structures, 110, 2016, 222–232.

[6] Dr. AbdulMuttalib Issa Said ,Dr. Ali Hussein Ali Al-Ahmed, Dhafer Mohsin Al-Fendawy .(2015) "Strengthening of Reinforced Concrete T- Section Beams Using External Post-Tensioning Technique",@ Journal of Engineering, Volume 21.

[7] Renata Kotynia, Krzysztof Lasek, Michał Staśkiewicz. (2012) "Preloading Effect on Load capacity and ductility of RC Beams Strengthened with Prestressed CFRP Strips ", https://www.researchgate.net/publication/289610767

[8] Joaquim A.O. , Barros, Débora, R.S.M., Ferreira , Adriano S.Fortes ,Salvador J.E.Dias(2006) "Assessing the Effectiveness Of Embedding CFRP Laminates in the Near Surface For Structura Strengthening",https://doi.org/10.1016/j.conbuildmat.2005.01.030

[9] IS: 456-2000, "Plain and Reinforced Concrete –code of practice", Bureau of Indian standards, New Delhi.

[10] SP 34:1987 "handbook for concrete reinforcement and detailing", Bureau of Indian standards, New Delhi.

[11] IS:10262-2009" guidelines for concrete mix design proportioning", Bureau of Indian standards, New Delhi.

[12] ACI Committee 440.2 R-08 (2008). "Guide for the design and construction of externally bonded FRP systems for strengthening concrete structures" , Reported by ACI Committee 440.