RESEARCH ARTICLE OPEN ACCESS

Strengthening of RC Beam with Web Bonded Steel Plates

Swetha K S[1], Rona Maria James[2]

1(*Dept. Of Civil Engineering, Vimal Jyothi Engineering College, Chemperi, Kannur, Kerala, India*

2(*Dept. Of Civil Engineering, Vimal Jyothi Engineering College, Chemperi, Kannur, Kerala, India*

Abstract:

Structures may be required to improve the structural behaviour and repair of damaged structures to restore structural performance for economical reasons. Steel plates are one of the most common materials for strengthening of reinforced concrete beams; it is very effective for increasing the flexural and shear capacity of reinforced concrete beam. From various studies it was understood that web bonded steel plates affects the crack patterns of the beams significantly and the position of web bonded steel plates significantly influences the stiffness and flexural capacity of plated beams. The critical gap in research is to study the flexural capacity of RC beam with web bonded steel plates by varying the plate thickness and to find the effective thickness of steel plate based on flexural capacity and crack pattern and to study the flexural capacity and crack pattern of RC beam strengthened with web bonded steel plates having effective plate thickness by varying plate depth. This paper deals with an experimental program conducted on the flexural capacity of RC beam without strengthening and 5 RC beams strengthened with web- bonded continuous steel plates. The control specimen and the beam with web bonded steel plates of 4 mm thick, 3 mm thick and 1.6 mm thick were tested by using loading frame. The results are compared based on the parameters ultimate load, deflection, and load at first crack and the effective thickness of steel plates is found out and beams strengthened with web bonded steel plates of various widths are studied based on the same parameters. The test results confirmed the effectiveness of web bonded continuous steel plates for strengthening of RC beams. From the comparative study it is obtained that, the beam with web bonded steel plates having 4mm thickness and 80mm width shows higher strength, lower deflection and higher load at first crack as compared to other specimens.

Keywords **— Steel plate, Flexure, Concrete beams, strengthening**

I. INTRODUCTION

Structures may be required to improve the structural behaviour and repair of damaged structures to restore structural performance for economical reasons. Generally, reinforced concrete beams fail in two modes: flexure and shear failure. Shear failure of reinforced concrete beam is sudden and brittle in nature and gives no advance warning prior to failure. Shear failure is more dangerous than flexural failure. Hence, reinforced concrete beam must be designed to develop their full flexure capacity. Many reinforced concrete structures have shear problems for various reasons, like improper detailing of the shear reinforcement, mistakes in design calculations, poor construction practices and reduction of the shear reinforcement steel area due to corrosion in service environment etc. The shear strength of reinforced concrete beam can be affected by concrete properties, beam size, beam shape and reinforcement details. Nowadays, strengthening of reinforced concrete beam by using steel plates, fiber reinforced polymer (FRP), ferrocement is a common task for concrete structures maintenance. Strengthening using materials can be done by two techniques, namely external bonding (EB) and near surface mounting (NSM). The external bonding technique involves adding strengthening material to the external surface of concrete using adhesives whereas NSM technique involves fixing of strengthening material in the pre-cut grooves using adhesives. In both techniques, two component epoxy materials are generally used as adhesives. Near surface mounting technique is proven to have many advantages over the external bonded method such as reduced surface preparation during installation, less chances of debonding and better protection to material due to less exposure to external conditions. External steel plating is a common strengthening and repair technique in RC beams. The ease of application, isotropic property, low prices of the materials used in the process, and limited disruption to the use of the structure are among the factors rendering external plating a relatively convenient method for improving the flexural behaviour and increasing or restoring the load-carrying capacities of RC beams compared with other strengthening or repair methods, including the addition of a new concrete layer and reinforcement to a concrete beam. The ductile stress-strain properties and the high deformation capacity of low-carbon (mild) steel used in external plating contributes to the overall ductility of an externally plated beam, which is one of the superiorities of this method over strengthening or retrofitting a beam with fiber reinforced polymer (FRP) materials, which have brittle stress-strain properties. The low prices and the wide availability of the mild steel can also be counted as advantages of this strengthening technique compared with FRP strengthening methods. Moreover, unlike FRP strengthening techniques, external steel plating does not require skilled labour. External plating aims at both increasing or restoring the load carrying capacity of a beam and decreasing its service-load deflections. Additionally, the externally plated beam is expected to have a ductile flexural behaviour. This paper concentrates on the studies of use of continuous steel plates rather than vertical strips, aligned parallel and symmetrical to beam axis for improving the shear strength and flexural capacity of reinforced concrete beams as it is believed that the advantages of improved anchorage, no bolting requirement and ease of instalment outweigh the disadvantages of weight and material cost and near surface mounting technique is used for the strengthening and therefore less chances of debonding and better protection to material can be enhanced. In this study the effects of steel plate thickness and plate depth on flexural capacity of the specimens are investigated. This study is mainly focused on experimentally investigating the potential of using steel plates as externally bonded strengthening material.

II. OBJECTIVES

The main objectives of this study include

1)To study the effect of web bonded steel plate on the behaviour of reinforced concrete beam

2)To study the flexural capacity and crack pattern of web bonded steel plates by varying the thickness of steel plates

3)To find most efficient thickness of steel plate in case of reinforced concrete beam based on the parameters like flexural capacity and crack pattern

4)To study the flexural capacity and crack pattern of web bonded steel plate by varying the width of plate in the most efficient steel plate

III. MATERIALS

A. Concrete

For concrete the coarse aggregate of size 20mm is used. Msand is used as fine aggregate and cement used is Portland pozzolana cement. Based on the above results the water quantity, cement, fine aggregate and coarse aggregate required for design mix of M20 were calculated based on the procedure given in IS code method in IS 10262:2009. The final mix ratio was 1:1.67:3.67 with water cement ratio of 0.55. Three cube specimens of size 150mm x150mm x 150mm were casted and tested to determine the compressive strength of concrete. The average compressive strength of cube specimen at 7 days and 28 days are obtained as 15.96 MPa and 24.76 MPa respectively.

B. Steel Plates

The ductile stress-strain properties and the high deformation capacity of low-carbon (mild) steel used in external plating contributes to the overall ductility of an externally plated beam, which is one of the superiorities of this method over strengthening or retrofitting a beam with fiber reinforced polymer materials, which have brittle stress-strain properties. The low price, uniform material properties (isotropic), high ductility and high fatigue strength and the wide availability of the mild steel can also be counted as advantages of this strengthening technique compared with FRP strengthening methods.

C. Epoxy Resin

Sikadur 31 epoxy was used as the bonding material between the steel plates and the beams. This epoxy was preferred because of its high strength, abrasion resistance and ease of application owing to its thixotrophic property, meaning that it is fluid when agitated and solid when allowed to stand. It is Suitable for dry and damp concrete surfaces and having high initial and ultimate strengths. The two-part epoxy was mixed in the ratio of 2:1 using a drill with a speed not exceeding 600 rpm until uniform glue line thickness along the plate was achieved.

Table I Technical data of sikadur 31

Property	Description (Value or range)
Property appearance and colour	Resin part A: white, Resin part B: black Part A + B mixed: concrete grey
Service temperature	Temperature between 10^0C and 40^0C
Density	1.85 kg/ltr (Part A+B mixed) (at +27°C)
Tensile strength	60 MPa
Flexural strength	20- 25 MPa (7 days curing time at +30 ^{0}C)
Bond strength	>11 MPa (7 days curing time at +30 ^{0}C)
Compressive strength	300 N/mm^2
Shear strength	15 MPa
E-modulus	4300 MPa
Mixing	Part A : Part B = 2: 1 by weight or volume

Fig. 1 Sikadur 31

IV. EXPERIMENTAL PROGRAMME

External steel plating is a common strengthening and repair technique in RC beams. External plating aims at both increasing or restoring the load carrying capacity of a beam and decreasing its service-load deflections. This study is mainly focused on experimentally investigating the potential of using steel plates as near surface mounted strengthening material.

D. Control Specimen

This paper deals with an experimental program on the flexural capacity of RC beam without strengthening and 5 RC beams strengthened with web-bonded continuous steel plates. The beam has a 150x 230 mm rectangular cross section and a total length of 2m. The beams were reinforced with 2 number of 12mm diameter bars in tension and 2 number of 10mm diameter bars in compression. The beams were provided with 2 legged 8mm diameter bar at 150 mm spacing as stirrups along the beam length. The bottom and side covers are taken as 25mm. Three 150x 150mm concrete cubes were cast to determine compressive strength of concrete. The beams were loaded until failure under two point loading. The reinforcement and casted unstrengthened beam are shown in Fig. 2 and 3 respectively. The cast specimen was removed from moulds after 24 hours and the specimen was kept for water curing.

Fig. 2 Reinforcement of control beam

Fig. 3 Control beam casted

E. RC Beam Strengthened with Web Bonded Steel Plates

This work is to study the flexural capacity of un strengthened RC beam and beam with web bonded steel plates by varying the plate thickness and to find the effective thickness of steel plate based on flexural capacity and crack pattern and to study the flexural capacity and crack pattern of RC beam strengthened with web bonded steel plates having effective plate thickness by varying plate depth.

For the study, two 2000 mm long steel plates having thickness 1.6mm, 3mm and 4 mm having width 50 mm were bonded to the webs of the beams using epoxy adhesive. Two different plate depths, i.e., 40mm and 80 mm were investigated. In this study, the groove cuts are initially prepared before pouring the concrete in to the form work. After 28days of curing, groove surface was cleaned by air brushing to remove fine particles and dust. The grooves are filled half way with 2mm epoxy adhesive before inserting the steel plates. The steel plates were placed immediately inside the grooves and pressed along the entire length of plate on to the adhesive and surface was levelled. After bonding operations is completed, specimens are left for 7 days before testing.

Table II Test variables

Specimen	Thickness of steel plate (mm)	Width of steel plate (mm)
1	1.6	50
2	3	50
3	4	50
4	Effective thickness	40
5	Effective thickness	80

Fig. 4 RC Beam with web bonded steel plates of 1.6mm thick

Fig. 5 RC Beam with web bonded steel plates of 3mm thick

Fig. 6 RC Beam with web bonded steel plates of 4mm thick

Fig.7 RC Beam with web bonded steel plates of 40mm width

Fig. 8 RC Beam with web bonded steel plates of 80mm width

F. Testing of Specimen

The beams were simply supported and they are tested under two point loading. The load was applied by a hydraulic jack and load cell was used to measure the applied load. Mid-span displacement of beams was measured with the help of a linear variable deflection transducer (LVDT). LVDTs are used to measure the displacement of the test specimen and it is placed at mid span of beam. The measured displacement will be displayed in the digital indicator and further it is connected to Data Acquisition system. To measure the strain; strain gauges are attached to mid span of beam. The load is applied at each step and continued until failure. To measure the load applied to the specimen, compression type load cell was used. The load cell is a strain gauge based device which will give proportional output in electrical parameters under the given load. Mid-span deflections, strain values were recorded for every load increment. The specimens were whitened for better observation of the development of cracks. The schematic view of experimental set up and dimensions of beam are shown in fig. 9.

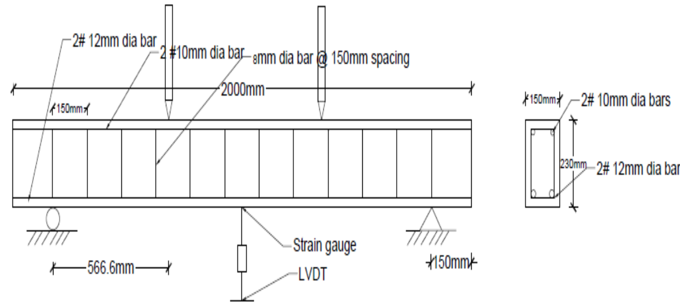

Fig. 9 The schematic view of experimental set up and dimensions of beam

Fig. 10 Test set up for RC Beam with web bonded steel plates

V. RESULTS AND DISCUSSIONS

All specimens were casted. The control specimen and the beam with web bonded steel plates of 4 mm thick, 3 mm thick and 1.6 mm thick, 40mm width and 80mm width were tested by using loading frame. The results of the tests are included here. Maximum load, strain and central deflection are included here

G. Ultimate Load

Beams were tested for ultimate strength. The experimental results for the tested beams having various thicknesses and various widths are given below

1) Ultimate Load for Beams Strengthened with Web Bonded Steel Plates of Various Thicknesses: Table III shows the ultimate load for the beams strengthened with web bonded steel plates having various thicknesses.

Table III Ultimate ultimate load for the beams with plates of various thicknesses

Beam	Ultimate load (kN)
Control beam	60.8
Beam with 1.6mm thick plate	62.2
Beam with 3mm thick plate	63.3
Beam with 4mm thick plate	70

From the results, it is clear that beam with web bonded steel plates have higher strength than the control specimen. As the thickness of steel plates increases, the load at failure also increases. It is found that, the beam with web bonded steel plates of 1.6mm thick, 3 mm thick and 4mm thick have respectively 2.3%, 4.1% and 15.13% higher strength as compared to control specimen.

2) Ultimate Load for Beams Strengthened with Web Bonded Steel Plates of Various Widths: The obtained values of ultimate load for beams strengthened with web bonded steel plates having various widths are given in the table IV.

Table IV Ultimate ultimate load for the beams with plates of various widths

Beam	Ultimate load (kN)
Control beam	60.8
Beam with 40mm width plate	66.7
Beam with 50mm width plate	70
Beam with 80mm width plate	76.3

From the results, it is clear that as the thickness of steel plates increases, the load at failure also increases. It is found that, the beam strengthened with web bonded steel plates of 50mm width and 80 mm have respectively 4.94% and 14.39% higher strength as compared to the beam strengthened with web bonded steel plates of 40mm width. Also it is found that, the beam strengthened with web bonded steel plates of 40 mm width and 80 mm have respectively 9.7% and 25.5% higher strength as compared to the control beam.

H. Load Vs Deflection Behaviour

Load versus deflection behaviour for beams strengthened with web bonded steel plates having various thicknesses and widths are shown below.

3) Load Vs Deflection Behaviour for Beams Strengthened with Web Bonded Steel Plates of Various Thicknesses: When the load attains maximum limit, the specimen got crushed due to the load applied by the load cell. The downward movement of the piston type arrangement of the LVDT gives the central deflection directly to the system provided along with the loading frame. After achieving maximum load, the valve of the loading frame machine is released and as a result, the load value found decreasing. The changes in the load values can be seen in the load versus deflection graph.

Fig. 11shows the load Vs deflection graph for beams strengthened with web bonded steel plates having various thicknesses.

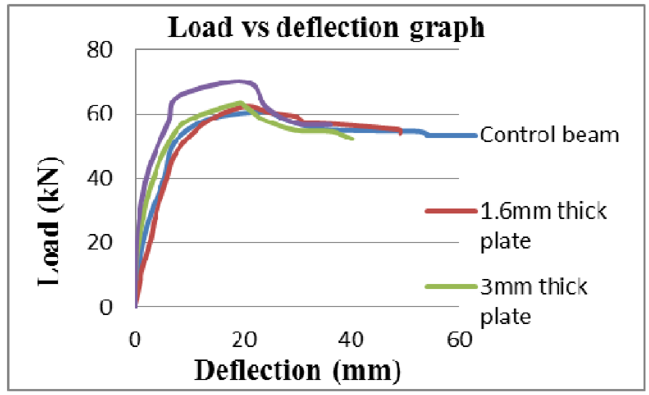

Fig. 11 Load Vs deflection graph for beams strengthened with web bonded steel plates having various thicknesses

From the graph it is clear that for the control beam, the strength is less and the deflection corresponding to maximum load is higher. In the case of beam strengthened with web bonded steel plates, the strength was improved and the deflection at maximum load got reduced. From the results, it is clear that beam with web bonded steel plates have higher strength and lower deflection than the control specimen. As the thickness of steel plates increases, the load at failure increases and deflection decreases. Table V shows the maximum load and deflection details.

Table V Maximum load and deflection details

Beam	Ultimate load (kN)	Deflection (mm)
Control beam	60.8	20.15
Beam with 1.6mm thick plate	62.2	19.56
Beam with 3mm thick plate	63.3	19.29
Beam with 4mm thick plate	70	17.92

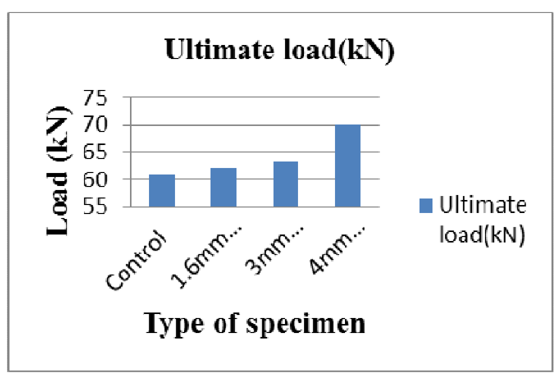

Fig. 12 Ultimate load for beams strengthened with web bonded steel plates having various thicknesses

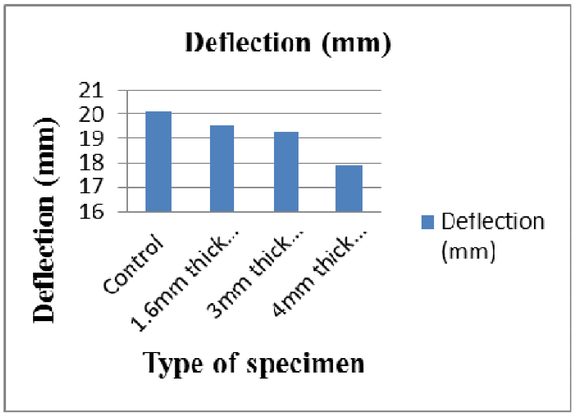

Fig. 13 Deflection for beams strengthened with web bonded steel plates having various thicknesses

It is found that, the beam with web bonded steel plates of 1.6mm thick, 3 mm thick and 4mm thick have respectively 2.3%, 4.1% and 15.13% higher strength as compared to control specimen. Also it is found that, the beam with web bonded steel plates of 1.6mm thick, 3 mm thick and 4mm thick have respectively 15.85 %, 20.12% and 25.79% lower deflection as compared to control specimen. The beam strengthened with web bonded steel plate of 4mm thick is found to be effective as compared to beam strengthened with steel plates of 1.6mm and 3mm thick based on the parameters ultimate load and deflection.

4) Load Vs Deflection Behaviour for Beams Strengthened with Web Bonded Steel Plates of Various Widths: Fig. 14 shows the load Vs deflection graph for beams strengthened with web bonded steel plates having various widths.

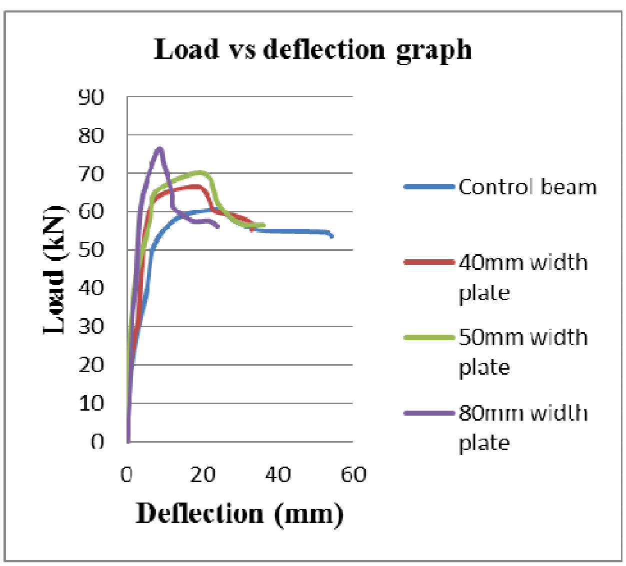

Fig. 14 Load Vs deflection graph for beams strengthened with web bonded steel plates having various widths

From the results, it is clear that beam with web bonded steel plates have higher strength and lower deflection than the control specimen. As the width of steel plates increases, the load at failure increases and deflection decreases. Table VI shows the maximum load and deflection details for beams strengthened with web bonded steel plates having various widths.

Table VI Maximum load and deflection details

Beam	Ultimate load (kN)	Deflection (mm)
Control beam	60.8	20.15
Beam with 40mm width plate	66.7	18.25
Beam with 50mm width plate	70	17.92
Beam with 80mm width plate	76.3	8.39

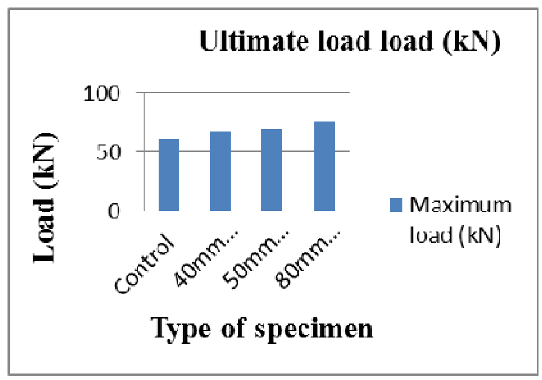

Fig. 15 Ultimate load for beams strengthened with web bonded steel plates having various widths

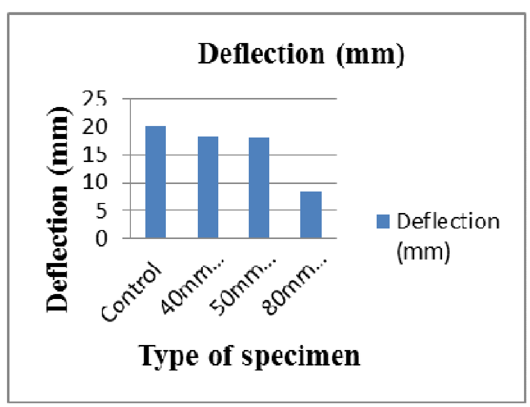

Fig. 16 Deflection for beams strengthened with web bonded steel plates having various widths

It is found that, the beam with web bonded steel plates of 40mm width, 50mm width and 80mm width have respectively 9.7%, 15.13% and 25.5% higher strength as compared to control specimen. Also it is found that, the beam with web bonded steel plates of 40mm width, 50mm width and 80mm width have respectively 24.43 %, 25.79% and 65.25% lower deflection as compared to control specimen.

I. Crack Patterns

Crack patterns for control beam and the beams strengthened with web bonded steel plates having various thicknesses and widths are shown below.

5) Crack Patterns for Beams Strengthened with Web Bonded Steel Plates of Various Thicknesses: Cracks developed on the control specimen, beam strengthened with web bonded steel plates of 1.6mm, 3mm and 4mm thick are shown in fig. 17, fig. 18, fig. 19 and fig. 20 respectively. The debonding of steel plates occurs after attaining particular load. Debonding of steel plates after yielding of the longitudinal reinforcement was observed. The load at debonding for the beam strengthened with steel plates of 1.6 mm, 3 mm and 4 mm are 32 kN, 35 kN and 40 kN respectively. It is observed that there is increment in the load at debonding with increase in thickness of plate.

Fig. 17 Crack pattern of control beam

Fig. 18 Crack pattern of beam with web bonded steel plates of 1.6mm thick

Fig. 19 Crack pattern of beam with web bonded steel plates of 3mm thick

Fig. 20 Crack pattern of beam with web bonded steel plates of 4mm thick

From the figures it is observed that cracks formed on beams strengthened with web bonded steel plates is less as compared to control specimen. The cracks are occurred at the flexural region only. Mainly flexural cracks are formed at a position in between the loading points. Table VII gives the crack details of tested beams.

Table VII Crack details of beams with plates of various thicknesses

Beam	Load at first crack (kN)	Load at de-bonding (kN)
Control beam	19	-
Beam with 1.6 mm thick steel plate	24	32
Beam with 3 mm thick steel plate	28	35
Beam with 4 mm thick steel plate	34	40

From the table it is clear that the load at first crack of beams strengthened with web bonded steel plates are higher as compared to load at first crack of control beam. Fig. 21 shows the variation of load at first crack and fig. 22 shows the variation of load at debonding.

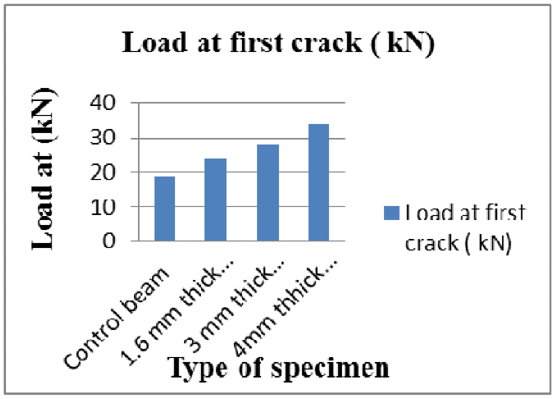

Fig. 21 Load at first crack for beams strengthened with web bonded steel plates of various thicknesses

It is found that, the beam strengthened with web bonded steel plates of 1.6mm thick, 3 mm thick and 4mm thick have respectively 26.3%, 47.3% and 78.9% higher load at first crack as compared to control specimen.

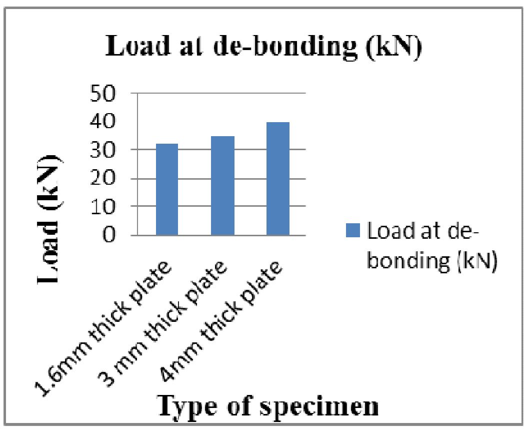

Fig. 22 Load at de-bonding for beams strengthened with web bonded steel plates of various thicknesses

Debonding of steel plates after yielding of the longitudinal reinforcement was observed. It is found that, the beam strengthened with web bonded steel plates of 3 mm thick and 4mm thick have respectively 9.3% and 15.6% higher load at de-bonding as compared to beam strengthened with web bonded steel plates of 1.6 mm thick.

6) Crack Patterns for Beams Strengthened with Web Bonded Steel Plates of Various Widths: Cracks developed on the control specimen, beam strengthened with web bonded steel plates of 40mm and 80mm widths are shown in fig. 23 and fig. 24 respectively. The debonding of steel plates occurs after attaining particular load. Debonding of steel plates after yielding of the longitudinal reinforcement was observed. The load at debonding for the beam strengthened with steel plates of 40 mm and 80 mm widths are 37 kN and 45 kN respectively.

Fig. 23 Crack pattern of beam with web bonded steel plates of 40mm width

Fig. 24 Crack pattern of beam with web bonded steel plates of 80mm width

From the figures it is observed that cracks formed on beams strengthened with web bonded steel plates is less as compared to control specimen. The cracks are occurred at the flexural region only. Mainly flexural cracks are formed at a position in between the loading points. It was observed that the flexural cracks for all beams initially occurred in the mid span zone. Load producing the first flexural crack of beam with web bonded steel plates are higher than control specimen. Then as the load increased, the flexural cracks appeared in the shear span zone. In case of control beam, the numbers of flexural cracks were found more than in beam with web bonded steel plates. In case of beam with web bonded steel plates, fewer cracks developed in shear span zone than in control beam. Tests were terminated when the concrete in the compression zone was crushed. **Rendy Thamrin** ***et al*** reported almost same crack patterns as a result of their experimental study on RC beam strengthened with web bonded steel plates. Table VIII gives the crack details of tested beams. Fig. 25 shows the variation of load at first crack and fig. 26 shows the variation of load at debonding.

Table VIII Crack details of beams with pates of various widths

From the table it is clear that the load at first crack of beams strengthened with web bonded steel plates are higher as compared to load at first crack of control beam.

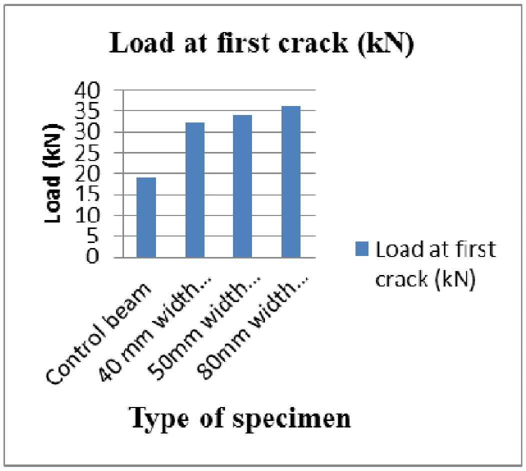

Fig. 25 Load at first crack for beams strengthened with web bonded steel plates having various widths

It is found that, the beam strengthened with web bonded steel plates of 40mm width, 50 mm width and 80mm width have respectively 68.42%, 78.94% and 89.47% higher load at first crack as compared to control specimen.

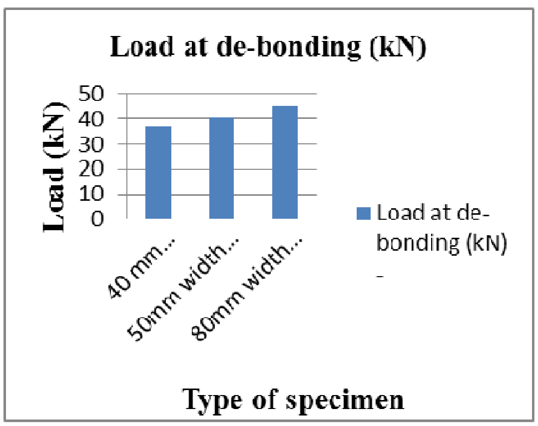

Fig. 26 Load at de-bonding for beams strengthened with web bonded steel plates having various widths

Debonding of steel plates after yielding of the longitudinal reinforcement was observed. It is found that, the beam strengthened with web bonded steel plates of 50mm width and 80mm width have respectively 8.1% and 21.6% higher load at de-bonding as compared to beam strengthened with web bonded steel plates of 40mm width.

J. Discussions

Beam	Load at first crack (kN)	Load at de-bonding (kN)
Control beam	19	-
Beam with 40 mm width steel plate	32	37
Beam with 50 mm width steel plate	34	40
Beam with 80 mm width steel plate	36	45

Experimental investigations were carried out on the control beam and beam strengthened with web bonded steel plates. Load carrying capacity, maximum deflection and failure patterns were analyzed for control beam and strengthened beams.

- The flexural capacity of the reinforced concrete beams was substantially increased by the strengthening of beams using web bonded steel plates.
- As the thickness of steel plates increases, the load at failure increases and deflection decreases.
- The beam with web bonded steel plates of 1.6mm thick, 3 mm thick and 4mm thick have respectively 2.3%, 4.1% and 15.13% higher strength as compared to control specimen.
- The beam strengthened with web bonded steel plates of 1.6mm thick, 3 mm thick and 4mm thick have respectively 26.3%, 47.3% and 78.9% higher load at first crack as compared to control specimen.
- The beam with web bonded steel plates of 1.6mm thick, 3 mm thick and 4mm thick have respectively 15.85 %, 20.12% and 25.79% lower deflection as compared to control specimen.
- Beam strengthened with web bonded steel plates of 4mm thick have 15.13% higher strength and 78.9% higher load at first crack as compared to control specimen and 25.79% lower deflection as compared to control specimen
- The beam strengthened with web bonded steel plate of 4mm thick is found to be effective as compared to beam strengthened with steel plates of 1.6mm and 3mm thick based on the parameters ultimate load, deflection, and load at first crack.
- The beam strengthened with web bonded steel plates of 40 mm width and 80 mm have respectively 9.7% and 25.5% higher strength as compared to the control beam.
- The beam strengthened with web bonded steel plates of 40mm width, 50 mm width and 80mm width have

respectively 68.42%, 78.94% and 89.47% higher load at first crack as compared to control specimen.

- The beam with web bonded steel plates of 40mm width, 50mm width and 80mm width have respectively 24.43 %, 25.79% and 65.25% lower deflection as compared to control specimen.
- The beam with web bonded steel plates having 4mm thickness and 80mm width shows higher strength, lower deflection and higher load at first crack as compared to other specimens.
- The beam strengthened with web bonded steel plates of 3 mm thick and 4mm thick have respectively 9.3% and 15.6% higher load at de-bonding as compared to beam strengthened with web bonded steel plates of 1.6 mm thick. Debonding of steel plates after yielding of the longitudinal reinforcement was observed.
- The beam strengthened with web bonded steel plates of 50mm width and 80mm width have respectively 8.1% and 21.6% higher load at de-bonding as compared to beam strengthened with web bonded steel plates of 40mm width.

VI. CONCLUSIONS

The control specimen and the beam with web bonded steel plates of 4 mm thick, 3 mm thick and 1.6 mm thick were tested by using loading frame. The results are compared based on the parameters ultimate load, deflection, and load at first crack and the effective thickness of steel plates were found out and beams strengthened with web bonded steel plates of various widths are studied based on the same parameters. Few prominent conclusions are as follows:

- The test results confirmed the effectiveness of web bonded continuous steel plates for strengthening of RC beams.
- Beam strengthened with web bonded steel plates of 4mm thick have 15.13% higher strength and 78.9% higher load at first crack as compared to control specimen and 25.79% lower deflection as compared to control specimen
- The beam strengthened with web bonded steel plate of 4mm thick is found to be effective as compared to beam strengthened with steel plates of 1.6mm and 3mm thick based on the parameters ultimate load, deflection, and load at first crack.
- The beam strengthened with web bonded steel plates of 80mm width have 25.5% higher strength and 89.47% higher load at first crack as compared to control specimen and 65.25% lower deflection as compared to control specimen
- The beam strengthened with web bonded steel plate of 80mm width is found to be effective as compared to beam strengthened with steel plates of 40mm and 50mm width based on the parameters ultimate load, deflection, and load at first crack.
- The beam strengthened with web bonded steel plates of 3 mm thick and 4mm thick have respectively 9.3% and 15.6% higher load at de-bonding as compared to beam strengthened with web bonded steel plates of 1.6 mm thick.
- The beam strengthened with web bonded steel plates of 50mm width and 80mm width have respectively 8.1% and 21.6% higher load at de-bonding as compared to beam strengthened with web bonded steel plates of 40mm width.
- It is obtained that, the beam with web bonded steel plates having 4mm thickness and 80mm width shows higher strength, lower deflection and higher load at first crack as compared to other specimens.
- The use of near surface mounted strengthening delayed the appearance of the first crack. Bonded steel plates caused a significant increase in the experimental first crack loads, serviceability and maximum capacity of strengthened beams, compared to the control beam. Beams strengthened with larger steel plates achieved larger loads.
- The external bonded steel plate increased the overall stiffness of the strengthened sections, resulting in high cracking load and maximum capacity, and high reductions in mid-span deflections
- Further experimental studies will be required to confirm the effectiveness of using near surface mounted steel plates in strengthening and also to investigate the effect of different thicknesses, width and orientations of near surface mounted steel plates in strengthening of RC beams.

REFERENCES

[1] Ahmed Khalifa, Gustavo Tumialan, Antonio Nanni, and Abdeldjelil Belarbi ,"Shear strengthening of continuous rc beams using externally bonded CFRP sheets", *International Symposium on FRP for Reinforcement of Concrete Structures*, 995-1008,1999

[2] Bimal Babu Adhikary and Hiroshi Mutsuyoshi, "Shear strengthening of RC beams with web-bonded continuous steel plates", *Construction and Building Materials*, Vol. 20, 296–307,2006

[3] By Alex Li, Jules Assih, and Yves Delmas, "shear strengthening of rc beams with externally bonded CFRP sheets", *Journal of structural engineering,* Vol. 127, 374-380,2001

[4] H. M. Al-Hassani, S. A. Al-Taa, A. A. Mohammed, "Behavior of Damaged Reinforced Concrete Beams Strengthened with Externally Bonded Steel Plate", *Tikrit Journal of Engineering Sciences*, Vol. 20, 48-59, 2013

[5] J.G. Dai, T. Ueda, Y. Sato and T. Ito,"Flexural strengthening of rc beams using externally bonded FRP sheets through flexible adhesive bonding", *Proceedings of the International Symposium on Bond Behaviour of FRP in Structures,*205-213,2005

[6] Liang Huang, Bin Yan, Libo Yan, Qi Xu, Haozhi Tan, Bohumil Kasal , "Reinforced concrete beams strengthened with externally bonded natural flax FRP plates", *Composites Part B*, Vol. 91, 569- 578, 2016

[7] Ms. Seema A. Bhagat, Mrs. Jyoti P Bhusari, "Improving shear capacity of rc beams using epoxy bonded continous steel plates", *International Journal of Advanced Technology in Civil Engineering*, Vol. 2, 2231 – 572, 2013

[8] M. Z. Jumaat and M. A. Alam, "Plate bonded strengthened RC beams with end and intermediate anchors", *International Journal of Engineering and Technology,* Vol. 4, 185-193, 2007

[9] Rendy Thamrin, Ricka Puspita Sari, "Flexural capacity of strengthened reinforced concrete beams with web bonded steel plates", *Procedia Engineering*, Vol. 171, 1129 – 1136, 2017
[10] Sabahattin Aykac, Ilker Kalkan, S.E., Aff.M.ASCE, Bengi Aykac, Servet Karahan, and Sinan Kayar, "Strengthening and Repair of Reinforced Concrete Beams Using External Steel Plates", *Journal of structural engineering,* Vol. 139, 929-939, 2013
[11] Soo-Yeon Seo, Luciano Feo, David Hui, "Bond strength of near surface-mounted FRP plate for retrofit of concrete structures", *Composite Structures*, Vol. 95, 719–727, 2013
[12] IS 10262: 2000 Indian Standard Concrete Mix proportioning-guidelines
[13] IS 456: 2000 Indian Standard Plain and reinforced concrete – code of practice
[14] IS 383: 1970 Indian Standard Specification for coarse and fine aggregates from natural sources for concrete
[15] IS 2386 (Part1): 1963 Indian standard Methods of test for aggregates for concrete Part I particle size and shape
[16] IS 2386(Part3): 1963 Indian standard Methods of test for aggregates for concrete
[17] P.C Varghese, Limit state design of reinforced concrete, Prentice- Hall
[18] M.S Shetty, Concrete Technology, Chand and Co.