SHEAR STRENGTHENING OF REINFORCED CONCRETE DEEP BEAMS USING EMBEDDED THROUGH SECTION (ETS) TECHNIQUE

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Abstract - *Reinforced concrete deep beams have many useful applications in building structures such as transfer girder, wall footing, foundation pile caps, floor diaphragms etc. For reinforced concrete beams with the same shear and flexural reinforcements, shear failure is most likely to occur in deep beams rather than in regular beam. Thus, retrofitting of deep beams with shear deficiencies is of great importance. A new shear strengthening technique, designated as Embedded Through Section (ETS) technique, has been developed to retrofit existing reinforced concrete elements. In this technique the bars of steel or Fibre Reinforced Polymer (FRP) material are introduced into the beam section through the drilled holes and bonded with the adhesive to surrounded concrete. This paper presents the results of an experimental investigation on RC deep beams strengthened in shear using Embedded Through Section (ETS) steel bars. Three point bending tests were conducted to find the effect of ETS bar spacing and ETS bar diameter on the load carrying capacity of RC beams. The experimental results confirmed the effectiveness of ETS method; Increasing the ETS bar diameter and decreasing the ETS bar spacing resulted in a substantial increase in ultimate load.*

***Key Words*: Shear Strengthening, Embedded Through Section (ETS) Technique, ETS steel bar, ETS bar diameter, ETS bar spacing.**

1. INTRODUCTION

A number of studies have been conducted and is still an ongoing venture to improvise the existing shear strengthening methods and also to invent new techniques. External bolting of steel plates (EBR), external prestressing etc. are some of the old shear strengthening methods. The EBR technique later evolved into Near Surface Mounting (NSM) technique. Further researches led to the invention of Embedded Through Section (ETS) technique which practically overcame the shortcomings of the previous methods for shear strengthening. This technique calls for holes to be drilled through the beam section; then bars of steel or FRP materials are introduced into these holes and bonded with adhesives to the surrounding concrete. The ETS method presents many advantages over existing methods, such as externally bonded FRP sheets (EB FRP) and near-surface mounted FRP rods (NSM FRP). Unlike EB and NSM methods where the FRP relies on the concrete cover of RC beams, in the ETS method, the FRP relies on the concrete core of the RC deep beam, which offers a greater confinement and hence improves bonding performance. Additionally, the ETS method requires less concrete preparation compared with EB and NSM methods.

2. EXPERIMENTAL PROGRAMME

2.1 Concrete Mix Proportion

M20 Grade concrete was used for the study. IS 456:2000 was used for the mix design of M20 concrete. 53 grade Ordinary Portland Cement, 20mm size coarse aggregate and M–sand as fine aggregate were used. MASTER GLENIUM SKY 8433 is the admixture used for the concrete mix. The mix proportion used for the experimental study is as shown in Table -1.

Table -1: Mix proportion of M20 grade concrete

Mix proportion	1: 2.020: 3.1690
Water cement ratio	0.45
Percentage of admixture (%)	015
Mass of cement per cubic metre concrete (kg)	372.413
Mass of fine aggregate per cubic metre concrete(kg)	752.325
Mass of coarse aggregate per cubic metre concrete (kg)	1180.1977
Slump (mm)	100

2.2 Test Specimen and Specimen Configuration

The total span of beam is 800mm and the width and depth of the beam are 200mm and 400mm respectively. The design of reinforcement was done according to *IS:456-2000* code. The percentage of tension reinforcement was taken relatively higher value so as to force the occurrence of shear failure in the strengthened beams so that we could study the shear strengthening effectiveness of ETS method. Four numbers of 12 mm diameter bars are used as tension reinforcement and two numbers of 10 mm diameter bars are used as compression reinforcement. And shear reinforcement provided as 8mm diameter bars at 150mm spacing. There are six ETS configurations in this study. The parameters studied are ETS bar diameter and ETS bar spacing, ETS bars used are 8 mm, 10 mm and 12 mm and the spacing of ETS bars studied are 150 mm and 100 mm, i.e., one-fourth and one-sixth of the effective span, L of the beam.Table-2 shows the specifications of deep beam specimens.

Table -2: Specifications of deep beam Specimens

Name of Specimen	ETS Bar Diameter	ETS Steel Bar Spacing	ETS shear strengthening ratio
CB	-	-	-
EB6-8-3	8mm	L/4	0.16
EB7-8-5	8mm	L/6	0.25
EB3-10-3	10mm	L/4	0.26
EB4-10-5	10mm	L/6	0.39
EB1-12-3	12mm	L/4	0.38
EB2-12-5	12mm	L/6	0.57

Fig -1 shows the schematic diagram consisting of cross section and longitudinal section of the control specimen showing their geometry and reinforcement detail.

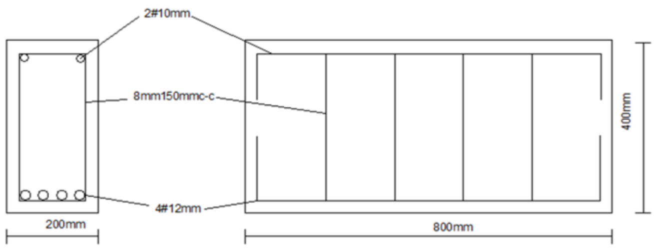

Fig -1: Cross-section and Longitudinal section of Control beam

The different ETS strengthened deep beam configurations as mentioned in Table-2 are diagrammatically represented in Fig-2 and Fig-3. The other strengthened deep beam specimens which used 10mm and 12mm diameter ETS steel bars followed a similar pattern to that of the specimens EB7-8-5 and EB6-8-3.

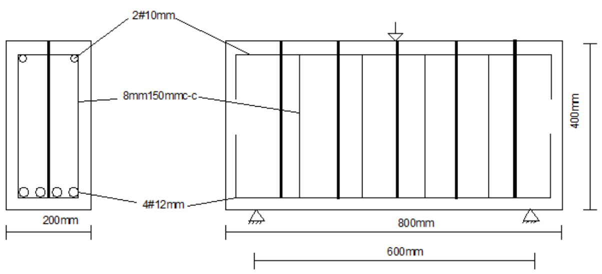

Fig -2: Schematic diagram :Cross-section and Longitudinal section of beams EB7-8-5

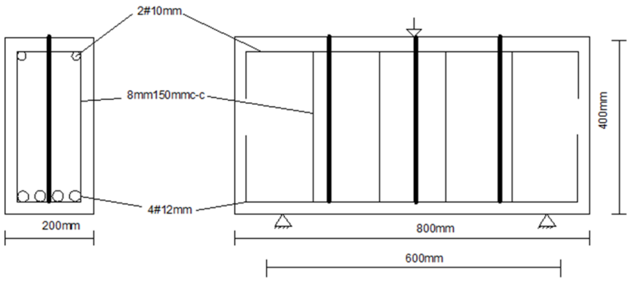

Fig -3: Schematic diagram :Cross-section and Longitudinal section of beams EB6-8-3

2.3 Strengthening Technique

Seven deep beam specimens were cast in moulds of dimension 800 mm x 200mm x 400mm. During the casting process ,for the purpose of introducing ETS steel bars in the deep beams for strengthening, holes with depth upto cover i.e., 380 mm are made in them. The diameter of holes is more than the diameter of ETS steel bar to be inserted . For making holes, round and smooth steel rods with handles are placed in the beam mould before the casting process. After 5 to 6 hours of casting the beam, the steel rods are removed by slowly rotating and pulling them out slowly. One such deep beam after 24 hours of casting is shown in Fig-4.

Fig -4: Deep beam casted with hole

After 28 days of membrane curing, the deep beams were taken out to dry for a day, the holes are cleaned, then the ETS bars are inserted into the holes and bonded with the surrounding concrete using the adhesive Lokfix-S.A strengthened beam is shown in Fig-5.

Fig-5: A strengthened deep beam

2.4 Test Setup

The deep beams cast using the above procedure is tested in UTM, the Universal Testing Machine with load range chosen as 0-1000 kN. The load is applied at midpoint of the beam specimen, increasing the load at a uniform rate till failure. The specimens are arranged with simply supported conditions with an effective span of 600 mm. Deflection of the beam was measured using a dial gauge of least count 0.01 mm at centre of the specimen. The three point loading test setup for the beams is shown in the Fig-6.

Fig-6: Three point loading arragement in UTM

3. RESULTS AND DISCUSSION

The control deep beam and strengthened deep beams were tested under three point bending and the results are obtained in terms of the ultimate load and deflection at ultimate load. The failure modes were noted .The control beam CB and the strengthened deep beam specimens all failed in shear as designed. The beam test results are tabulated in Table 3. A significant increase in ultimate load is found in each of the strengthened deep beams. Atleast 23.84% increase in ultimate load is obtained for the strengthened deep beams. This shows that, ETS method for shear strengthening is a very effective method. Also, by varying the various parameters, i.e., by decreasing the spacing of ETS bars and increasing the diameter of ETS bars, a maximum of 67.69% increase in ultimate load is obtained.

Table -3: Beam Test Results

Specimen	ETS Shear Strengthening Ratio	Ultimate Load (kN)	Increase In Ultimate Load (%)	Deflection At Yield Load (mm)	Deflection At Ultimate Load (mm)
CB	-	260	-	3.32	5.5
EB6-8-3	0.16	322	23.84	3.49	8
EB7-8-5	0.25	402	54.61	5.06	9
EB3-10-3	0.26	362	39.23	4.46	7
EB4-10-5	0.39	418	60.76	5.02	9
EB1-12-3	0.38	368	41.53	4.24	7
EB2-12-5	0.57	436	67.69	3.86	7

3.1 Influence of ETS Bar Spacing

The influence of ETS bar spacing in the load carrying capacity of the strengthened deep beams is one of the major parameters considered in this study. Two different spacing is chosen for the study are L/4 and L/6 where L is the effective span of the beam. All the specimens tested in this study follow a similar pattern for its load- deflection curve till its yield point and then there is an abrupt increase in the deflection followed by a sudden shear failure with minimal warnings. The specimen EB7-8-5 has an increase in ultimate load of 54.61% compared to the 23.84 % increase for the specimen EB6-8-3. It is clear from Chart-1 which shows the load Vs deflection curves for the strengthened specimens with ETS bar diameter of 8mm for the two ETS bar spacing. From it, we can see that, the ultimate load is greater for the strengthened beam with ETS bar spacing of L/6.

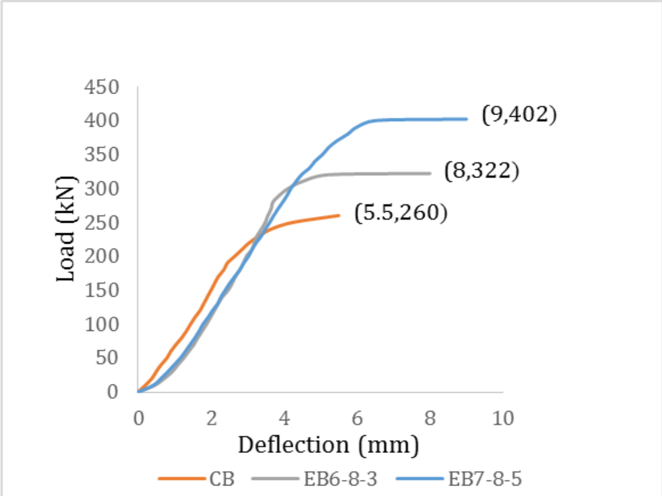

Chart -1: Load Vs deflection curves for ETS bar diameter of 8mm for the two ETS bar spacing

A very similar result is obtained for the next set of strengthened beams ie.,from Chart-2, EB3-10-3 and EB4-10-5. The specimen EB4-10-5 has an increase in ultimate load of 60.76 % compared to the 39.23% increase for the specimen EB3-10-3 as shown in Chart-2 which shows the load Vs deflection curves for the strengthened specimens with ETS bar diameter of 10 mm for the two ETS bar spacing. Thus, the ultimate load is greater for the strengthened beam with ETS bar spacing of L/6 when the ETS bar diameter is 10 mm

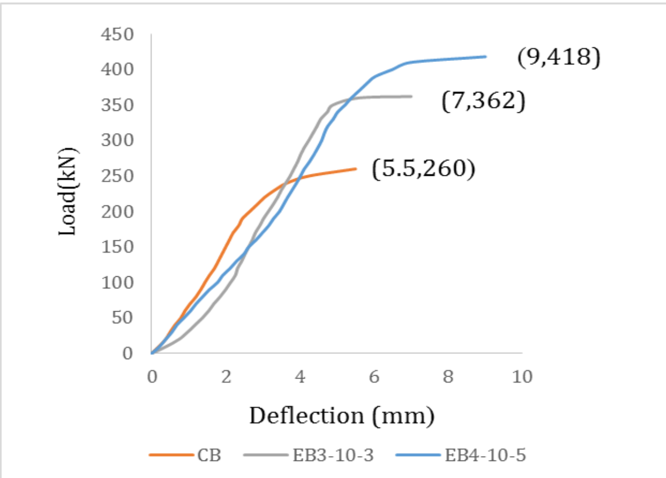

Chart -2: Load Vs deflection curves for ETS bar diameter of 10mm for the two ETS bar spacing

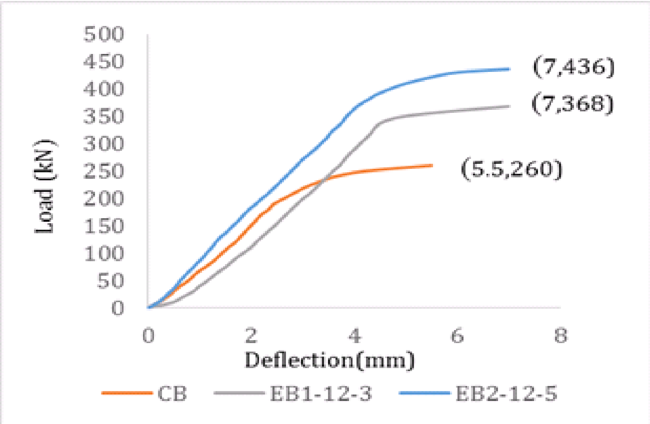

Chart -3: Load Vs deflection curves for ETS bar diameter of 12mm for the two ETS bar spacing

Also, in the next set of strengthened beams: EB1-12-3 and EB2-12-5, the latter has an increase in ultimate load of 67.69% compared to the 41.53% increase for the former. as shown in Chart -3 which shows the load Vs deflection curves for the strengthened specimens with ETS bar diameter of 12 mm for the two ETS bar spacing. The ultimate load is clearly greater for the strengthened beam with ETS bar spacing of

L/6 when the ETS bar diameter is 12 mm.

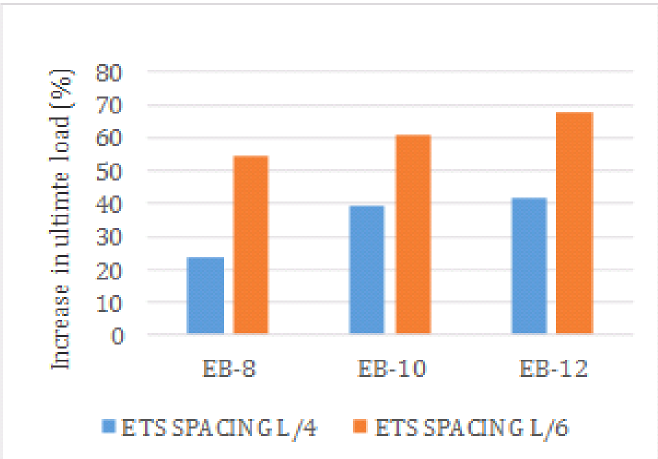

Chart -4: Bar chart showing the effect of ETS bar spacing on the percentage increase in ultimate load

Chart-4 depicts a bar chart showing the effect of ETS bar spacing on the percentage increase in ultimate load of deep beam. The three sets of results indicate the fact that the ultimate load carrying capacity is positively affected by the decreased spacing of the ETS bars.

3.2 Influence of ETS Bar Diameter

The influence of ETS bar diameter on shear strength is another main parameter considered in this study. The two spacing chosen for the study are L/4 and L/6 where L is the effective span of the deep beam . Also the different ETS bar diameters taken are 8mm, 10mm and 12mm respectively. The effect of these ETS bar diameters on the shear strength is explained here.

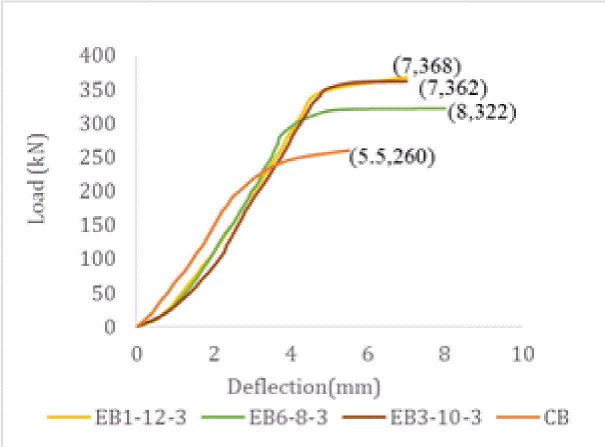

Chart -5: Load Vs deflection curves for ETS bar spacing L/4 for various ETS bar diameters

The load Vs deflection curves for the strengthened specimens with ETS bar spacing of L/4 for the three ETS bar spacing with respect to control deep beam specimen are shown in Chart -5, i.e., for the specimens EB1-12-3, EB3-10-3 and EB6-8-3. From Chart -5 it is clear that, the ultimate load is greater for the strengthened deep beam with ETS bar diameter of 12mm ie., EB1-12-3 with an increase in ultimate load of 41.53% compared to the 23.84% and 39.23% increase for specimens EB6-8-3 and EB3-10-3 respectively. Also, as the diameter of ETS bars increases, its contribution towards the load carrying capacity of the RC deep beam also increases.

Now, decreasing the spacing of ETS bars from L/4 to L/6.the graphs of which are given Chart -6 in similar results as mentioned above is obtained, which is of course an increase in the ultimate load of RC deep beams as a result of increasing the diameter of ETS bars i.e., 67.69% increase in ultimate loads for the specimens EB2-12-5, 60.76% and 54.61% for EB4-10-5 and EB7-8-5 respectively.

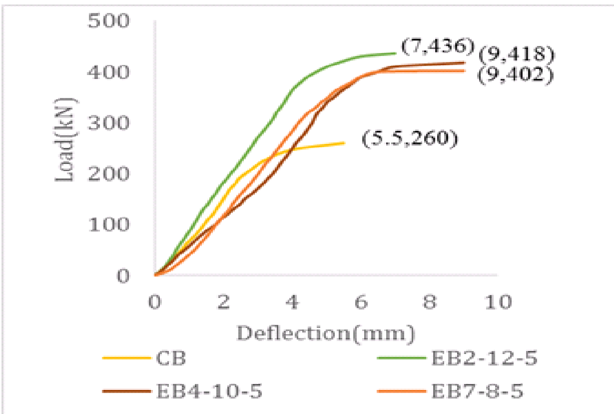

Chart -6: Load Vs deflection curves for ETS bar spacing L/6 for various ETS bar diameters

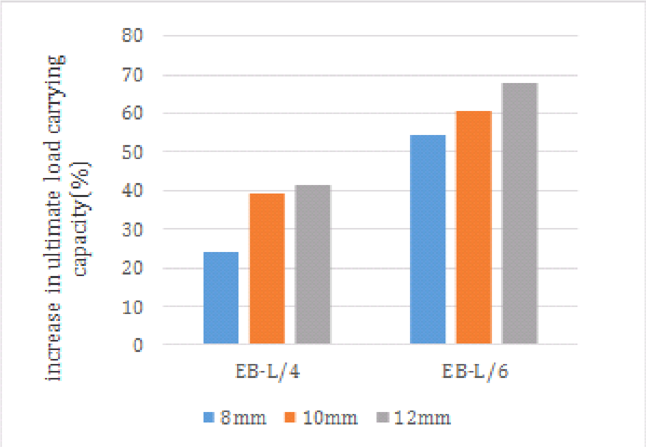

Chart -7: Bar chart showing the effect of ETS bar diameter on the percentage increase in ultimate load

Chart -7 shows the bar chart showing the effect of ETS bar diameter on the percentage increase in ultimate load in deep beams. The two sets of results in it indicates that the ultimate load carrying capacity increases as the spacing of the ETS bars decreases.

4. CONCLUSIONS

An experimental program on reinforced concrete deep beams shear strengthened with a recent technique denominated Embedded Through Section (ETS) was described and relevant results are presented and discussed. The influence of spacing of ETS bars and diameter of ETS bars was investigated.

From the results it can be concluded that :

- The ETS shear strengthened deep beams have 23.84% to 67.69% increase in load carrying capacity when strengthened with 8mm,10mm and 12mm ETS bars with L/4 and L/6 spacing, compared to the un strengthened deep beam.
- The load carrying capacity of ETS strengthened deep beams increases as the diameter of the ETS bars increases. Upto 17.69% increase in ultimate load is found when the diameter of ETS bars increased from 8mm to 12mm.
- The load carrying capacity of ETS strengthened deep beams increases as the spacing of the ETS bars decreases. 30.77% of increase in ultimate load is obtained when the spacing of ETS bars decreased from L/4 to L/6.

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