A Review on Shear Strengthening Of RC Beams Using Embedded Through Section (ETS) Technique

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Abstract – *The Embedded Through-Section (ETS) technique is a recently developed technique for the shear strengthening of reinforced concrete (RC) beams. This technique involves drilling of holes through the beam cross section and bonding steel or fibre reinforced polymer (FRP) bars using epoxy adhesive. Strengthening techniques like external bonding of reinforcement (EBR) and near surface mounting of reinforcement (NSM) are the commonly used shear strengthening methods; however the ETS technique is an even better shear strengthening technique introduced in the recent years. This paper gives a review on the ETS shear strengthening procedure, merits of ETS technique over the conventional techniques like EBR and NSM and also the various parameters influencing the shear strength of RC beams strengthened using ETS technique.*

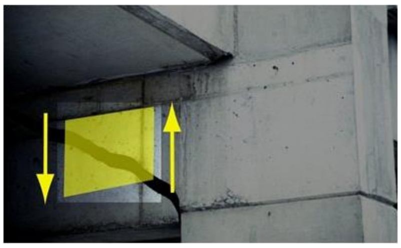
Key Words: Embedded Through Section (ETS), External Bonding of Reinforcement (EBR), Near Surface Mounting (NSM), epoxy adhesive, Carbon Fibre Reinforced Polymer (CFRP). Fibre Reinforced Polymer (FRP)

1. INTRODUCTION

Upgrading of existing infrastructures is a major, challenging concern these days. It becomes necessary due to various reasons such as increased load requirements, inadequate shear provisions in the original design, upgradation of design codes and deterioration of existing structures with time due to environmental effects like corrosion of reinforcement, carbonation, freeze and thaw, etc. Many concrete structures constructed in the past in countries like USA and Japan do not meet the requirements of the current seismic design codes especially concerning shear capacity and ductility. The Hyogoken– Nanbu Earthquake in 1995 caused tremendous damage to concrete structures in Japan. The failure patterns in the structural elements like beams showed insufficient shear capacity and lack of ductility [16]. These structures are thus vulnerable to such big natural disasters. Research works have been progressing in the area of shear strengthening of beams and girders to prevent these catastrophes. Fig -1 shows a diagonal shear crack occurring in a reinforced concrete beam and its shearing action.

(a) A diagonal shear crack occurring in a reinforced concrete beam near its connection to a column

(b) A manipulated version where the portion of the beam below the crack has been moved down to emphasize the mode of failure



(c) Annotated version of above figure highlighting the shearing action and cracking across the long diagonal of the parallelogram

Fig -1: A shear crack and shearing action in an RC beam

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, external bonding of steel plates (EBR), external prestressing etc. are some of the old shear strengthening methods. Steel plates were then slowly replaced by FRP plates and sheets due to their light weight and high yield strength characteristics. The EBR technique later evolved into near surface mounting (NSM) technique [18, 17, 13, 14]. Further researches led to the invention of embedded through section (ETS) technique which practically overcame the shortcomings of the previous methods for shear strengthening. The ETS technique consists of opening holes across the depth of the beam's cross-section where bars are inserted and bonded to the surrounding concrete with suitable adhesive.

2. PROCEDURE FOR ETS SHEAR STRENGTHENING

Breveglieri *et.al* (2014) [9] explained the procedure of shear strengthening using ETS method (For the easiness of drilling holes and inserting the ETS bars, in this paper, the RC beam has been turned upside down as in Fig -2 (b)).There are various steps to be strictly followed for effective shear strengthening. These steps are shown in Fig -2. First of all, holes are drilled in the beam core from bottom to top as shown in Fig -2 (a) and simultaneously dust is removed using a vacuum system as shown in Fig -2 (b). Hole length is defined by preserving 20mm of intact concrete cover at the top side of beam. Rest of the concrete dust is removed by using a helicoidal steel brush as shown in Fig -2 (c). Epoxy resin is poured into the hole and ETS bars are introduced into them, removing the excess resin as shown in Fig. 2 (d). Fig -3 shows the longitudinal section of an ETS shear strengthened beam. The ETS bars are shown as dotted lines in the left shear span.

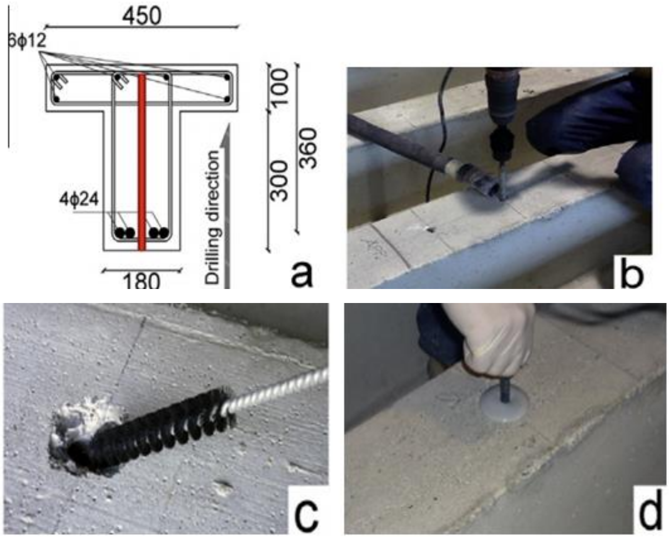


Fig -2: Strengthening procedures for the ETS technique
Source: Breveglieri *et.al* (2014) [9]

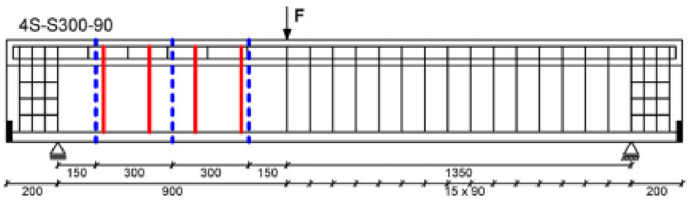
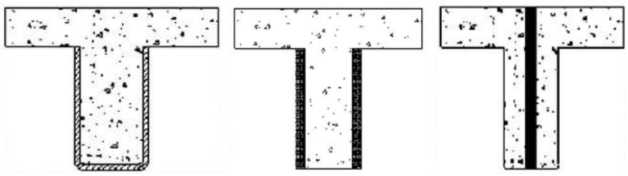


Fig -3: Longitudinal section of RC beam shear strengthened using vertical ETS bars
Source: Breveglieri *et.al* (2010) [8]

3. MERITS OF ETS OVER THE CONVENTIONAL SHEAR STRENGTHENING TECHNIQUES

The aforementioned EBR and NSM techniques are the conventionally used methods for shear strengthening of RC beams. Premature debonding of steel/FRP plate i.e., the debonding of the plate prior to reaching its full tensile strength is the commonly seen failure in EBR shear strengthened beams [18]. The NSM technique- consisting of epoxy bonding of bars or strips into grooves created on the sides of the beam- limits the debonding failure to an extent. They usually fail by separation of the side concrete covers at the internal steel stirrups [13, 14]. This debonding failure usually associated with EBR and NSM is completely absent in ETS technique. It is because the ETS technique relies on concrete core to transfer the stresses between concrete and ETS bar. The concrete core provides better confinement and better bond performance to overcome debonding failure [10]. Thus the ETS technique is the most efficient technique for developing steel and FRP tensile strength potential before the final failure occurs [11]. Chaallal *et.al* (2014) [11] conducted experimental studies to compare the EBR, NSM and ETS techniques using FRP sheets and rods. The effectiveness of these strengthening methods was measured by comparing the gain achieved by each strengthening method for an equivalent amount of FRP to carry shear loads. The shear strengthening configurations of EBR, NSM and ETS techniques used in this study are shown in Fig -4.



(a) EBR (b) NSM (c) ETS

Fig -4: Shear strengthening configurations: (a) EBR; (b) NSM; (c) ETS

Source: Chaallal *et.al* (2014) [11]

The experimental results proved the aforesaid facts about the failure modes of each technique. Chart -1 shows the Load versus deflection curves for Control beam and shear strengthened beams. ETS specimens exhibited a higher deflection at the loading point, and maximum load at failure compared with other specimens. The ETS technique greatly enhanced the overall behavior of the RC beams by increasing the ultimate load carrying capacity and also by increasing the ductility of the beam, which is very important in earthquake prone regions. The maximum deflection of the beam S3-ETS at the ultimate load was 1.30 times that of the S3-NSM beam at the ultimate load (15.2 mm at load 425.5 kN versus 11.7 mm at 380.0 kN) and 1.34 times that of the S3-EB beam at the ultimate load (15.2 mm at load 425.5 kN versus 11.3 mm at 335.2 kN), whereas the control S3-CON beam achieved the smallest deflection at the ultimate load (11.2 mm at 294.0 kN).

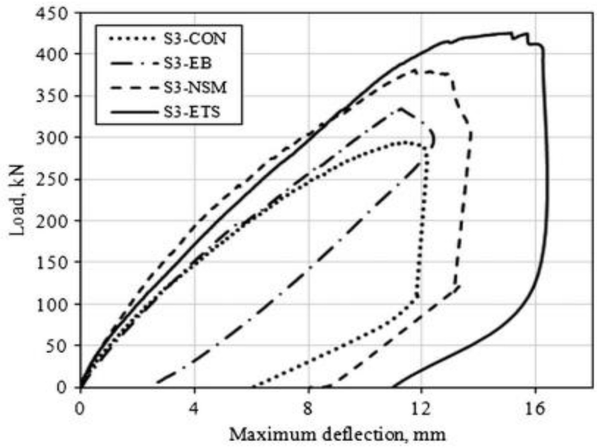


Chart -1: Load versus deflection curves for Control beam and shear strengthened beams
Source: Chaallal *et.al* (2014) [11]

Apart from increasing the load carrying capacity and ductility of the RC beams, the ETS technique has other advantages such as greater protection against corrosion, fire and vandalism. It is because, the ETS bars are completely confined by the concrete beam unlike the EBR and NSM plates and bars which are exposed to the atmosphere [5]. Also, time consuming surface preparation is not required. Less epoxy consumption compared to EBR and NSM techniques is another advantage of ETS. This method can also be used in case of bridge beams made contiguous with a deck so that only the top and bottom faces of the concrete member are accessible [12]. The ETS technique is thus a cost competitive and feasible solution when EBR and NSM techniques cannot be applied [7].

4. FACTORS AFFECTING THE EFFICIENCY OF ETS METHOD

4.1 FRP Reinforcement

Mofidi *et.al* [2] conducted experimental tests on RC beams strengthened in shear using the embedded through section CFRP method. The types of CFRP ETS bars used were sand coated and plain surface CFRP bars. It was found that the ETS CFRP strengthening method is very effective in increasing shear strength of beams. An average increase in shear carrying capacity of 35% was found for the ETS CFRP retrofitted specimens. CFRP rods with a plain surface were 7.83% more effective than sand coated CFRP rods. It is due to better shear transfer existing between plain finished CFRP rods and epoxy compared to that between sand coated CFRP and epoxy.

Breveglieri *et.al* [6] conducted a comparative study using steel and CFRP ETS bars in RC beams. Chart -2 shows the Load Vs Deflection curve for RC beams strengthened with ETS steel bars and ETS CFRP bars. The specimens 4S-C180-90 and 4S-C180-45 represent the beams shear strengthened with ETS CFRP bars while, the specimens 4S-S180-90 and 4S-S180-45 represent the beams shear strengthened with ETS steel bars. 4S-C180-90 has a higher load carrying capacity than 4S-S180-90 and 4S-C180-45 has a higher load carrying capacity than 4S-S180-45. This proves that ETS CFRP bars are more effective than ETS steel bars.

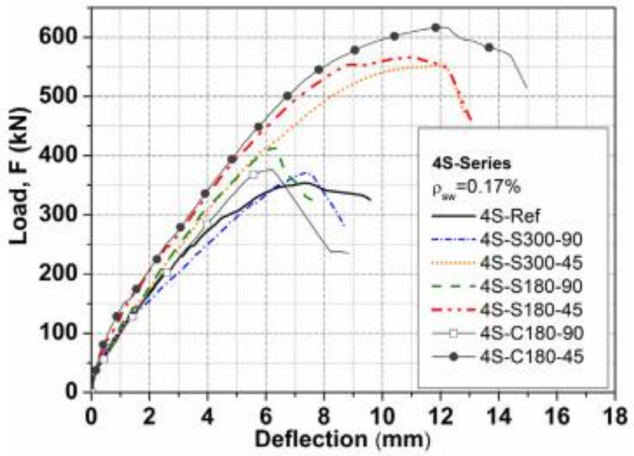


Chart -2: Load Versus Deflection curve for RC beams strengthened with ETS steel bars and ETS CFRP bars
Source: Breveglieri *et.al* (2015) [6]

4.2 Inclination Of ETS Bars

The inclination of cracks is close to 45 degrees in the RC beams that fail in shear. The efficiency of the ETS shear strengthening technique can be increased by placing the ETS bars in the direction perpendicular to that of the direction in which the shear cracks occur, thus slowing down the propagation of the shear cracks. This increase in efficiency can also be attributed to the large available resisting bond length. Fig -5 shows the longitudinal section of RC beam shear strengthened using inclined ETS bars, the dotted lines being the ETS bars.

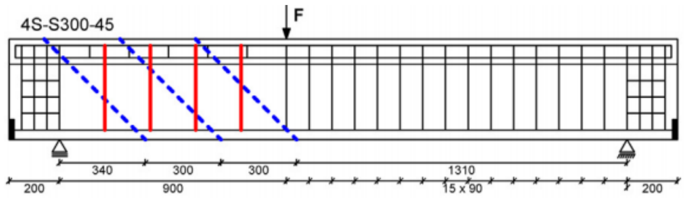


Fig -5: Longitudinal section of RC beam shear strengthened using inclined ETS bars bars
Source: M. Breveglieri et al (2014) [9]

Breveglieri *et.al* [9] conducted experiments to study the influence of inclination of ETS bars, spacing of ETS bars and percentage of existing stirrups on the ETS shear strengthening efficiency. The Chart -3 shows a bar chart representing the results of four sets of ETS shear strengthened beams. The vertical axis represents the percentage increase in shear strength. The first bar of each set represents the RC beams shear strengthened with vertical ETS bars and the others represent RC beams shear strengthened with 45 degrees inclined ETS bars. Vertical ETS bars provided an increase of load carrying capacity in the interval of 5-68% while the inclined ETS bars assured a higher strengthening effectiveness with an increase in load carrying capacity from 53% to 136%. Hence, providing 45 degrees inclination in ETS bars increases the efficiency of shear strengthening.

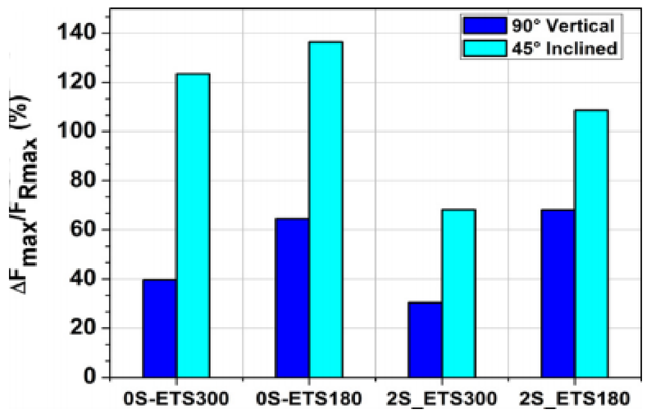


Chart -3: Bar chart showing influence of the inclination of ETS bars, spacing of ETS bars and presence of existing stirrups on the ETS shear strengthening effectiveness Source: M. Breveglieri et al (2014) [9]

4.3 Spacing of ETS bars

As the spacing of the ETS bars decreases, the shear strengthening ratio increases. This causes the increase in the shear strengthening efficiency. This is true in the case of both steel and FRP ETS bars. In Chart -3, the specimens 0S-ETS300 and 2S-ETS300 have ETS bar spacing of 300mm; the specimens 0S-ETS180 and 2S-ETS180 have ETS bar spacing of 180mm. Also, 0S and 2S are two different series of specimens. We can see that, the specimens with ETS bar spacing of 180 mm have higher load carrying capacity than those with spacing of 300mm when considered within the same series. Thus, it is clear that, decreasing the ETS bar spacing increases the shear strengthening effectiveness [9].

4.4 Percentage of Existing Stirrups

In Chart -3, the 0S series represent the beams with nominal stirrups i.e., one stirrup each at the two supports and one at the point of loading; the 2S series represents the specimens with stirrups placed at 300 mm spacing. From this chart, we can see that, the load carrying capacity of the specimens in the 2S series is less than that of their corresponding 0S series specimens. Thus, it is clear that as the percentage of already existing shear stirrups increases, the ETS shear strengthening efficiency decreases [9].

5. CONCLUSIONS

- The ETS shear strengthening technique can significantly enhance the shear capacity of RC beams. The ETS shear strengthened beams had an increase in load carrying capacity upto 136 % [9].
- The ETS shear strengthening technique is a superior technique compared to the conventional EBR and NSM techniques [11].
- There is a significant increase in ductility when the beams are shear strengthened with ETS bars. Thus it can be applied to buildings and bridges in regions of high seismic activity.
- Inclined ETS bars provide more shear strengthening effectiveness than vertical ETS bars. This is due to the large available resisting bond length and their better orientation which is perpendicular to the inclination of shear cracks [5, 6, 7, 8, 9].
- As the spacing of ETS bars increases, the shear strengthening efficiency decreases. It is due to the decrease in the ratio of the ETS shear strengthening bars [2, 3, 5, 6, 7, 8, 9].
- As the percentage of shear stirrups already present in the RC beam increases, the contribution of ETS bars to the shear capacity of beam decreases [9, 10].
- Further studies should be done to optimise the above mentioned parameters such as spacing, inclination etc. of ETS bars for a better understanding and implementation of this technique in the real life structures.

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