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Strengthening and Evaluation of Reinforced Concrete Beams for Flexure by Using External Steel Reinforcements

[1]Akhtar Gul, [2]Bashir Alam, [3]Fayaz A Khan, [4]Yasir Irfan Badrashi, [5]Khan Shahzada
[1,3,4]Depaertemnt of Civil Engineering, University of Engineering & Technology Peshawar Campus-III Bannu Pakistan,
[2,5]Depaertemnt of Civil Engineering, University of Engineering & Technology Peshawar Pakistan,
[1]akhtarwazir@uetpeshawar.edu.pk,[2]bashir@gwmail.gwu.edu , [3]fayazuet@yahoo.com,
[4] yasir_badrashi@ uetpeshawar.edu.pk, [5]shah_civil2003@yahoo.com

Abstract:The most implementable and favorable technique, used for the flexural strengthening of reinforced concrete (RC) beams is the attachment of external steel members. Attachment of external steel sections or fiber reinforced polymers is considered as a common technique used for the enhancement of flexural capacity of the existing structural elements. To investigate and evaluate the flexural capacity of reinforced concrete beams, strengthened with external steel bars, a research study was carried out and is presented in this paper. Three reinforced concrete beams reinforced with minimum reinforcement ratio were constructed and tested. Two beams were strengthened by attaching external steel bars with bottom layer of shear reinforcement and one specimen without external steel bars was tested as control sample. The area of reinforcement to be provided as external steel bars was calculated on the basis of maximum steel ratio as per the ACI-(318-08) 10.3.5. Welding was used for the attachment of the external steel bars to the existing shear reinforcement. All the three beams were tested in positive bending under third point loading as per the ASTM C78/C78M-10. Test result shows that great enhancement in strength capacity and better distribution of cracks may be achieved by using this technique of flexural strengthening of beam.

Keywords :Strengthening and Evaluation, Beams, Steel Bars, Cracks, Flexural Capacity

1. Introduction

In the past various techniques were developed for flexure strengthening of RC members to restore or enhance their load carrying capacity. The strengthening techniques for RC structural members are commonly needed due to increasing loading demands, improper maintenance, and change in function or in code of practice and due to the exposure of structure to earthquake and blasts. All these strengthening techniques are favorable and best suited for a given condition and situation and has some advantages and disadvantages. Most of the existing structures in Pakistan are in good condition but are under more loading demands which require strengthening of the structural elements. And also Pakistan was stuck by disastrous earthquake, flood and is facing the tragic situation of the terrorism due to which most of the RC structures are damaged which need repair/strengthening. This research work was aimed at strengthening technique for the existing RC beams, to enhance their flexural resistance. In this research work the local available materials/steel bars were used, with the hope to be easy in use and can be applied effectively while the structure is in use. By using this strengthening technique the size of the beam will not grow significantly and thus no head room problems will occur.

The use of external steel members as strengthening material was started in the 1960s and significant experimental data has been reported on their strength enhancement when used for strengthening of RC beams. But, very little work has been done on the performance of the steel bars when used as external strengthening material for flexure. It was reported that high flexural strength and good ductility will result by using steel plates as an external reinforcement, provided with sound structural detailing and design, good quality of materials and workmanship [1, 2]. Bilal Ahmad used steel angles as partial confinement of RC beams and reported that the overall response of the strengthened beam was greatly enhanced [3]. Christopher M. Foley and Even R. Buckhouse in 1998 used steel channels as an external steel for flexural strengthening and reported that overall, the design methodology used for the strengthening of existing beams for flexure is suitable and adequate [4]. S.U Khan, S.F.A Rafeeqi and T. Ayub used ferrocement as external strengthening material for flexure and concluded that the flexural strength was greatly enhanced [5].

2. Experimental setup

Three RC beams were constructed having rectangular x-section. One beam was used as a control specimen and other two were used for strengthening with external steel bars. The length of beams was 11 feet and the web and depth dimensions are 12 inches and 9 inches respectively. As per the ACI code 3000 psi compressive strength of concrete was used in the design of specimen. The summary of design of the three beams is described in table 1.

2.1 Design of Control Specimen

By using the basic concepts for the rectangular RC beams as given in the ACI-318-08, the flexural capacity of the control beam Mc may be calculated as shown in Figure 01. All the three beams were designed with minimum steel ratio i.e.

$$\rho_{min} = 3\frac{\sqrt{f_c'}}{f_y} \geq \frac{200}{f_y} \quad \text{(a}$$

Using grade 60 steel, each beam was provided with two #4 (13 mm) for flexure which is based on ρmin . Two #3 (10 mm) bars were placed at the top of the beam web for stirrups holding.

Maximum shear reinforcement was provided as per ACI code, to prevent shear failure. The maximum shear demand was calculated from bending moment diagram.

$$P = \frac{3M_c}{L} \quad \text{(b}$$

$$M_c = A_{smax}\, f_y (d_{ave} - a/2) \quad \text{(c}$$

$$A_{smax} = 0.015\ b\ d_{ave} \quad \text{(d}$$

Where:

Asmax = Maximum steel area required for maximum flexural strength

P = Maximum shear force

Mc = Moment capacity of control specimen

On the basis of above shear demand; the beam was designed using #3 (10 mm) 40 grade steel bars as shown in Figure: 1

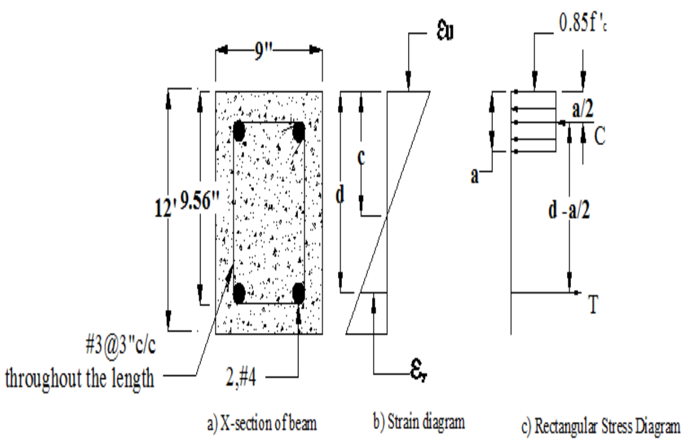

Figure. 1 (a) X-section of Beam (b) Strain Diagram c) Rectangular Stress Diagram

2.1 Design of Strengthened beams

For the design of strengthening of RC beams for flexure, the simple procedure for rectangular beam given by ACI code may be used [4]. For calculating the steel are of external steel section, the Whitney equivalent rectangular stress distribution diagram was used. Regular reinforced concrete design formulas were used for calculating the external steel area. Area of the external steel was considered as an additional steel as shown in Figure 2.

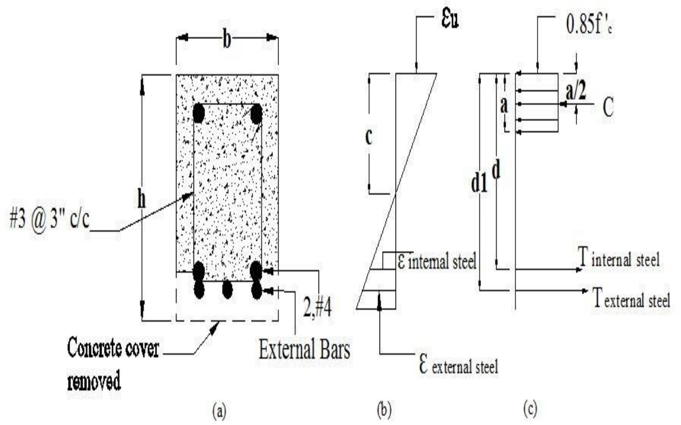

Figure 2 a) X-Section of Beam b) Strain Diagram c) Rectangular Stress Diagram

The external steel was provided on the basis of maximum reinforcement area "Asmax" as given under ACI-code section 10.2. Asmax, thus calculated was divided into (As)c and (As)ext as given in equation (e).

(As)ext = As max – (As)c (e)

Where:

(As) c = steel area provided to control specimen

(As) ext = external steel area provided for strengthening purpose

The design summary of the strengthened beam is shown in Figure 3.

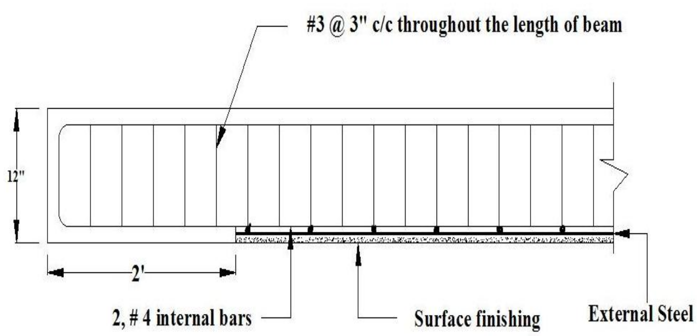

Figure 3 Half Section of Strengthened Beam

With the help of welding three steel bars as external reinforcement were attached with the stirrups of the beam. Two # 6 bars have been attached to the corner of the stirrups and one # 4 bar at the center of beam web (Figure 02, b). Cut off point of the longitudinal external bars form the end was calculated from the bending moment diagram, drawn after the addition of the external steel bars. The external steel bars were cut 2 feet from the end based on 71 % cutting of steel for simply supported beam, as shown in Figure 03:

Name of Beam	Size of Beam bw x h (inches)	Details of External Steel Bars Bar No. (ø inches)
BS1	9 x 12	------
BS2	9 x 12	2, # 4 + 1, # 6
BS3	9 x 12	2, # 4 + 1, # 6

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3. Test Results

The beams were so placed on testing frame to act as a simply supported and the loads were placed at an equal spacing of 3.33 feet (1015 mm), using third point loading criteria.

3.1 Control RC specimen (TS1)

At a load of 4.5 kips the control beam BS1 was in elastic range. The corresponding deflection at the elastic load was .04 inches. It has been shown in figure 04 that stiffness degrades beyond the elastic load and becomes linear. The maximum load carried by the control beam was 14.5 kips and the corresponding maximum deflection was 0.5 inches. Figure 04 shows the load-deformation relationship of the control beam BSI.

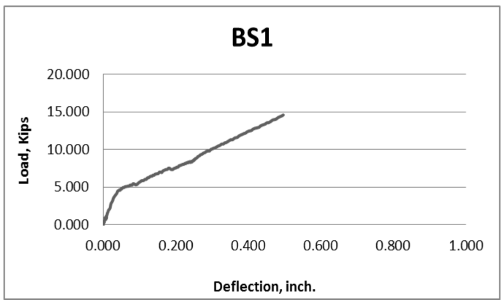


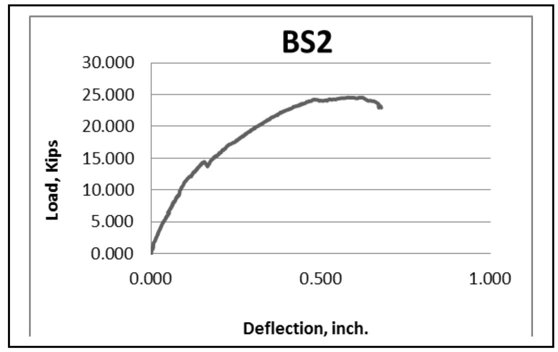
Fig: 4 Force deformation relationship of control beam BS1

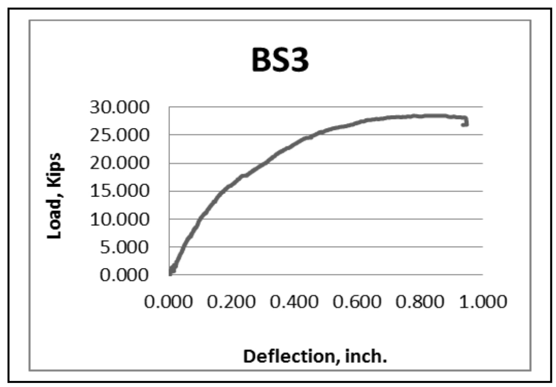
The failure of the control specimen BSI is shown in figure 05 and is clear that the cracks are flexural. First flexure crack was initiated at the bottom of the beam surface at a load of 7.7 kips (3.5 tones) and propagated quickly towards the upper face of the beam. The deflection at first crack was recorded as 0.19 inches. This crack was in the region of the maximum bending moment. The yield load and corresponding deflection were analytically calculated and is 4.9 kips and 0.08 inches respectively. The flexural yield strength, ultimate strength and shear capacity of the section required for the application of load were calculated and are 3 kip, 9.7 kips and 31.3 kip respectively. The measured flexure strength of the specimen is more than the calculated value and this is because of the high strength of steel used for flexure.

Figure: 5 Failure of Control Specimen BS1

3.2 Beams strengthened with external steel bars

The elastic behaviour of the specimen strengthened with external steel bars BS2 and BS3 were almost identical. The yielding load ranged between 22.4 kip and 24.23 kip and the corresponding deflections are 0.43 inches and 0.47 inches. The elastic stiffness of the two specimens BS2 and BS3 is almost equal to that of the control specimen BS1. The maximum measured loads and corresponding maximum deflections in the inelastic phase were 22.83 kip and 0.57 inches for specimen BS3 and 24.50 kip and 0.62 inches for BS2. The load-deformation curve shows that the strengthened specimen behaved in stiffen manner





Charts of Samples

Figure: 7 Failure of Beams Strengthened with External Steel Bars

Table: 02 Comparison between theoretical and experimental loads

Series	Specimen ID	Computed yield Loads (kips)	Experimental yield Loads (kips)
Control	TS1	6.20	5
Steel Bars	TS2	18.5	14
	TS3	18.5	13

Table: 03 Percentage of strength enhanced

Series	Specimen ID	% increase
Control	TS1	------
Steel Bars	TS2	76
	TS3	70

4. Interpretation of test results

The test results of the two strengthened beams specimens showed a dramatic enhancement in the flexural capacity of the control beam specimen due to the attachment of external bars. The pattern of cracks of the tested beam specimens shown in Figure 07 indicates that the failure mode of the strengthened is a flexural. Flexural cracks were started at the mid span and gradually propagated towards the supports.

In the elastic range, the contribution of external steel in overall stiffness of strengthened beams was minimal. Thus, the elastic stiffness of control as well as strengthened beams was almost equal. The yield load of the strengthened beams was greater than the control specimen. A logical expression for this result is that the bending curvature of the strengthened beam forced the external steel to bend and enhance the strength of the strengthened beam. A significant observation is that the quantity and spacing of weld played a major role in enhancing the strength and ductility of the beams.

5. Conclusions

The following conclusions were made from this research work.

1. The flexural response of RC beams strengthened with external steel members was greatly enhanced. Flexural strengthening of beams showed uniform distribution of flexure cracks.
2. The failure of strengthened beam resulted in a very favorable mode as compare to the control RC beam specimen.
3. The beams strengthened with steel bars showed better ductility.
4. The finishing cover was strong enough and made good bond with the existing concrete.
5. Welding was provided as per the design code of LRFD but the delaminating of steel bars requires more attention.
6. The strengthening technique can now be implemented practically for strengthening beams both in building and bridges.

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