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Shear retrofitting of RC Beams

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Abstract: *Studies on rehabilitation and retrofitting are gaining importance due to the need for restoration of partially damaged structures due to wind load and earthquake. This project presents an experimental investigation on retrofitting the capacity of damaged RC beams. In this work retrofitting of shear deficient RCC beam using diagonal stitching method will be studies. Nine beams of size 120mm x 210mm x 1500mm were cast. Out of this one control beam was used and remaining 8 beams are categorized in to two sets of beams with each set containing 4 beams as shear deficient beams. Out of these 8 beams, two beams were tested without retrofitting and remaining six beams were shear deficient used for retrofitting. Control Beam designed for ultimate shear & flexure was loaded up to ultimate load in the Loading frame (of capacity 1000 kN) using a Hydraulic jack of 500 kN capacity. Shear deficient beams were retrofitted using diagonal stitching and cover concrete was bonded Nitto bond. Load deflection behaviour of beams, retrofitted with different layers of stitched mat was compared. All the beams were casted using M25 grade concrete and Fe500 steel. After the 28 days of curing they were tested and kept safe for retrofitting. It was observed that stitching method is effective in restoring the capacity of damaged beams. Among all the shear retrofitting techniques, diagonal stitching is effective and easy to implement.*

Introduction

The development of civil infrastructure is one of the main factors that uses the national wealth in the form of money as well as resources. For sustainable development of the nation the structures being constructed are required to be long lasting. Unless the resources are properly used to design and develop infrastructural systems, it will create negative impact on the economy. In present days new techniques and methods are experimented in the civil engineering field to have better infrastructure. Strengthening or Retrofitting means enhancing the structural performance of an existing structure. By strengthening some selected elements, the life of the whole structure may be extended. Strengthening of a structural element can be done by adding some technology, accessory, component or feature to it. This process is termed as retrofitting. Retrofitting is required when there is excess loads due to new combination of loads. Life extension of structures is an unavoidable need of a sustainable world. It could be made possible through structural retrofitting. A lot of materials are experimented in the wide field of retrofitting. Reinforced concrete beams were mostly retrofitted for flexure and shear.

Literature Review: Many researchers have worked on shear rehabilitation and retrofitting of beams. Many methods have been developed in the recent past. However, the need for skilled personnel to implement them is a challenge to structural engineers. A representative sample of innumerous works done on rehabilitation is presented here.

Matteo Breveglieri et al., (2014) designated a new shear strengthening technique that has been developed to retrofit existing reinforced concrete (RC) elements. The technique is developed by drilling the holes in to the beams. Then bars or FRP materials are introduced in to these holes and these bars are bonded with adhesives. An increase of shear capacity up to 109% and 136% in the beams with and without internal stirrups respectively was obtained.

Hemaanitha and Kothandaraman (2014) critically reviewed the strengthening techniques developed so far with reference to the effect of each technique and their salient features in enhancing the strength of RC beam elements. However, it is hoped that the review on the use of different techniques for retrofitting of RC beams presented is widen the horizon to retrofitting technology as a cost effective and easy to execute method.

Antony Jeyasehar and Balamuralikrishnan (2012) conducted experimental, analytical and numerical studies on beams retrofitted using HPFRCCs. Two-point loading was used. Results obtained from the three studies were similar.

Antony Jeyasehar and Balamuralikrishnan (2009) used SIFCON and SIMCON for retrofitting**.** Retrofitting using both SIFCON and SIMCON are found to be effective, of which SIMCON was better in practical applications.

Adhikary and Mutsuyoshi (2006) conducted an experimental investigation on enhancing the shear capacity of RC beams by using various techniques. Initially these beams are designed in such a way that they fail in shear mode. These beams are strengthened with steel brackets, steel plates, vertical stirrups and externally anchored stirrups. He observed that the all techniques were found effective. In these techniques external anchored stirrups are most effective. Strengthening by this technique resulted in a failure load of almost 117% higher than that of control beam.

Objective and Scope

Objective: The objective of this study is to experimentally compare the performance of shear retrofitted Reinforced Concrete beams using diagonal stitching method, to study the relation between load, deflection and failure modes for shear deficient beams which are retrofitted.

Scope: The studies performed on the shear retrofitted RC beams using traditional method like Diagonal stitching are limited. Therefore it is required to study the shear carrying capacity of shear deficient beams by retrofitting with diagonal stitching.

Nine beams of size 120 mm × 210 mm × 1500 mm were cast. All the beams were caste using M25 grade concrete and Fe 500 steel and effective span of 1440 mm and a clear cover of 20 mm was adopted.

To describe the specimens conducted in this study, the following notations are adopted.

C - Control beam (both flexure & shear)

S1 - Shear Deficit Control Beam

S2,S3&S4 - Shear Retrofitted Beams

S5 - Shear Deficit Control Beam

S6,S7&S8- Shear Retrofitted Beams

For conducting this study a typical RC beam with the following specifications was considered.

Cross section = 120 x 210 mm^2

Effective span = 1440 mm

Overall span of beam = 1500 mm

Retrofitting is done by providing links across the possible shear crack position. Three specimens are retrofitted in each series by varying the depth up to which the links are grouted. Links are spaced equally across the possible diagonal crack line. The enhanced shear strength in retrofitted beams vs. un-retrofitted (with respect to shear deficient control beams) beams for different link depths is determined experimentally to assess the shear enhancing capacity of this method.

Materials and Methodology

The materials used for the present investigation is described as below.

Cement : Ordinary Portland cement (53 Grade) conforming to IS: 12269 available in the local market of standard brand was used in the investigation.

Fine Aggregate: The locally available river sand is used as fine aggregate in the present investigation and it is found that the fine aggregate conforms to IS: 2386 and IS: 383 .

Coarse Aggregate: Machine crushed angular granite metal of 20mm nominal size from the local source is used as coarse aggregate and all coarse aggregate material properties were found to be satisfactory as per IS: 2386 and IS: 383.

Water: The locally available potable water used for mixing , curing and in the experimental investigation and ensured that the pH value should not be less than 6.

Grouting material & Bonding Agent: CEBEX 100 (Fosroc product) is used as grouting material and Nitto bond is used as bonding agent in order to get proper bonding of retrofitted concrete face surface with covering concrete.

Reinforcement : The Reinforcement steel of Fe500 grade was used and all beams were designed having 2-Y12, 2-Y10 & 1-Y8 mm diameter bars in tension zone and 2 – Y12 mm diameter bars in compression zone , for control beam (both shear & flexure) 8mm dia stirrups with spacing of 144 mm c/c and for shear deficient control beams 8mm dia stirrups with spacing of 360 mm c/c as Beam series 'A', 8mm dia stirrups with c/c spacing of 205mm were used for Beam Series' B' .

Concrete Mix: Concrete strength is an important parameter in the testing of reinforced concrete beams and can significantly affect the test results, especially when estimating the shear strength. Therefore, in the present experimental program, all nine beams were prepared so that the concrete strength was nearly the same (compressive strength of concrete cubes used to make the beams, after 28_days, was in and around 30 MPa.) . The specimens were cured under the same conditions to reduce the variation in concrete strength.

Mix Proportions for M25 Grade concrete: Mix design of M25 grade concrete was carried out in accordance with IS 10262: 2009 and following mix proportions for **1 m³ concrete** were obtained .

Cement 385 kg.

Water 197 litres.

Coarse aggregate 1166 kg.

Fine aggregate 714 kg.

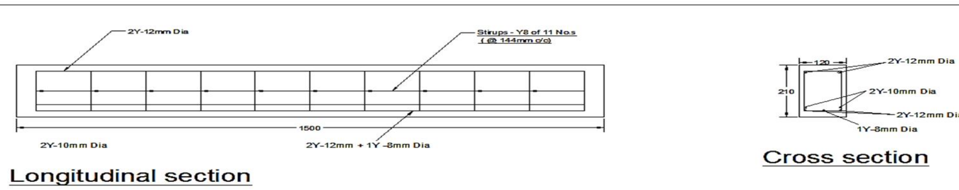
Preparation of Testing Specimens: Mixing of ingredients is done in pan mixer of capacity 40 liters. The cementitious materials are thoroughly blended and then the aggregate is added and mixed followed by gradual addition of water and mixing. Before casting the specimens, workability of the mixes was found by Slump cone test. The specimens are left in the moulds undisturbed at room temperature for about 24 hours after casting. The specimens are then removed from the moulds and immediately transferred to the curing pond containing clean and fresh water and cured for required period as per IS 516-1969.

Shear Retrofitting Methodology

Shear-deficient RC beams are retrofitted by using Diagonal Stitching (DS). Retrofitting is done by providing links across the possible shear crack position. Six specimens are retrofitted in two series A & B (by providing links spaced equally across the possible diagonal crack line). The increased shear strength in retrofitted beams vs. un retrofitted (respective shear deficient control beams) beams shear strength and original control beam (both flexure & shear) is determined experimentally to assess the shear increasing capacity of a beam by a given percentage.

Table 1: Details of No. of beams used with & with out retrofitting

Sl. No.	Designation of Beams	No. of Vertical stirrups /Shear reinforcement spacing	Without Retrofitting	With Retrofitting
1	C (Control)	11/144	1	---
2	A series	5/360	1	3
3	B series	8/205	1	3



Longitudinal and cross Section of RC beam - CONTROL BEAM (C)

Fig.1 Longitudinal and cross section details of Control beam with reinforcement

Diagonal Stitching (DS) Method

In this method, the beams are retrofitted with the help of additional reinforcement to the shear deficient beams. In order to resist shear along the crack, it is necessary to use diagonal stitching and concrete is stitched by 6mm dia steel rods diagonally along the possible crack path with stitches of different lengths (60,100,160mm) of u-shaped bends are used for retrofitting in shear that are embedded into up to specified depth . Holes are drilled on the shear deficient beams and reinforcement links are provided perpendicular to the possible shear crack up to a depth of 50 mm in to the beam and an extra cover concrete is provided on two sides of reinforcement.

Shear reinforcement links of 6mm diameter are provided in holes of 8 mm diameter and 50 mm deep. These are provided at all possible shear crack path lines on either side of beam faces as shown in the figure. Beams are chipped and the dust is removed completely and cleaned. The holes shall be cleaned with compressed air and water jet to remove all the dust etc. and then the shear links are fixed in the holes using CEBEX 100 anchor grout material. The links are made in ‘U’ shaped so that the horizontal portion is perpendicular to the crack and placed across the possible shear crack. NITTO - bond (a chemical agent which is used for the bonding between old and new concrete) applied on the surface. Over the diagonal shear links concrete cover is maintained throughout the beam.

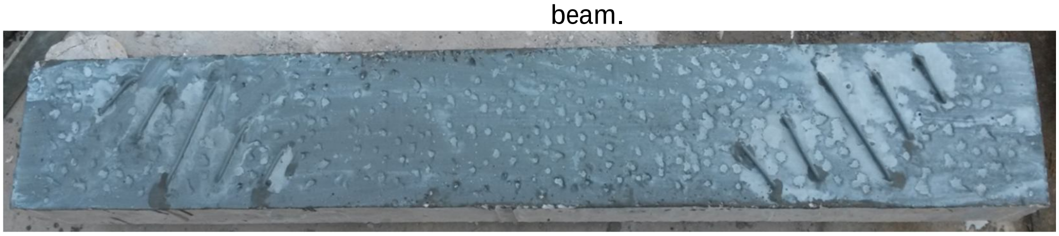


Fig.2 Application of Nitto bond prior to providing cover concrete

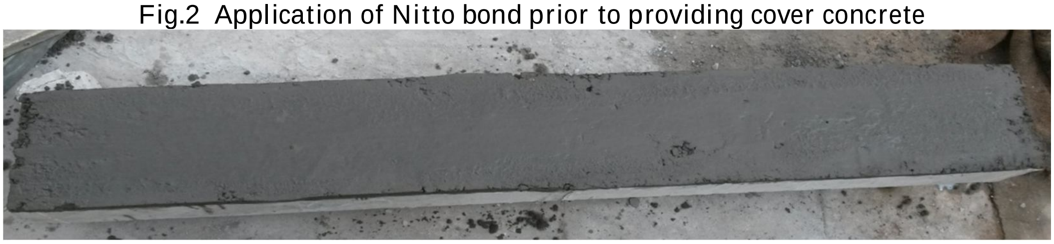


Fig.3 Cover concreting is applied to either side of beam faces

Fig.4 Control beam (C) before Testing (testing set up)

Fig.5 Control beam (C) after Testing

Results & Discussions

Table 2 : Comparison of Shear strength of beams (Original & After Retrofitting):

Beam Designation		Shear Strength (N/mm^2)		
		Theoretical	After Retrofitting	% Increase
Series-A	S1	1.83	---	---
	S2	1.60	2.13	34
	S3	1.59	2.43	53
	S4	1.63	2.51	54
Series-B	S5	2.59	---	---
	S6	2.16	2.30	6
	S7	2.15	2.43	13
	S8	2.25	3.05	35

Table 3: Comparison of Deflection of beams (Original & After Retrofitting):

Beam Designation		Deflection (mm)		
		Theoretical	After Retrofitting	% Increase
Series-A	S1	5.33	---	---
	S2	5.33	6.80	28
	S3	5.24	7.72	47
	S4	5.45	9.14	68
Series-B	S5	5.36	---	---
	S6	5.36	8.95	67
	S7	5.16	8.78	70
	S8	5.47	10.55	93

Fig.6 Load vs. deflection for Comparison of Control Beam with Beam Series-A:

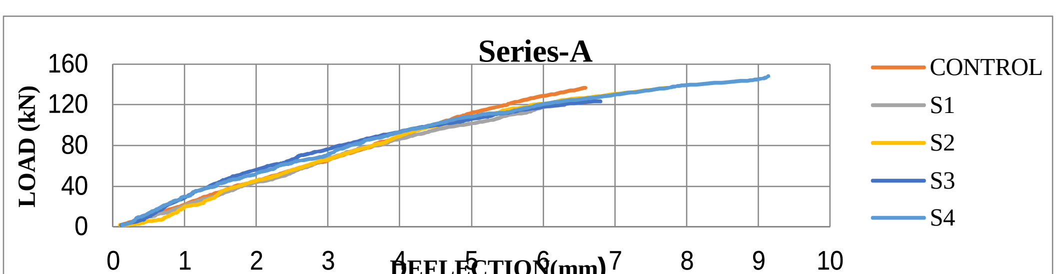
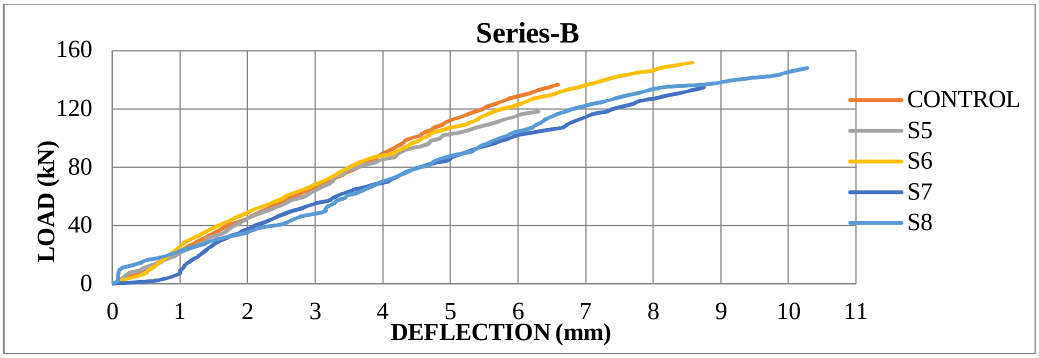


Fig.7 Load vs. deflection for Comparison of Control Beam with Beam Series-B:



The improvement in Shear strength of retrofitted shear deficient beams using shear links diagonal stitching method was up to 34% for shear link depth of 35 mm, 53% for depth of 50 mm & 54% for depth of 60 mm shear links in case of Beam Series ‘A. For Beam Series ‘B’ the improvement in Shear strength of retrofitted shear deficient beams using diagonal stitching method was up to 6% for shear links depth of 35 mm, 13% for depth of 50 mm & 35% for 60 mm depth of shear links.

The improvement in Deflection of retrofitted shear deficient beams using shear links diagonal stitching method was up to 28% for shear link depth of 35 mm, 47% for depth of 50 mm & 68% for depth of 60 mm shear links in case of Beam Series ‘A. For Beam Series ‘B’ the improvement in Deflection of retrofitted shear deficient beams using diagonal stitching method was up to 67% for shear links depth of 35 mm, 70% for depth of 50 mm & 93% for 60 mm depth of shear links.

Conclusion: The following conclusions can be made based on the analysis of the results as presented in this thesis.

1. The strengthening method which is used in this thesis has proven to be an effective way to increase the shear capacity of simply supported RC beams even in the presence of a limited amount of internal transverse steel reinforcement.

2. The results shows that shear capacity of retrofitted specimens using diagonal stitching method increased, as the depth of shear links into existing concrete increases. Beams strengthened in shear using the diagonal stitching method with a greater embedded depth of shear links achieved greater values of shear contribution than beams retrofitted with a smaller embedded depth of shear links. It can be said that there is relation in between the shear contribution of embedded depth of diagonal links to the spacing of vertical stirrups used as transverse steel in un-retrofitted RC beams.

3. The crack pattern changes widely spaced to narrow closely spaced in shear zone both ends.

4. For both beams series of “A” and “B” retrofitted shear deficient beams have performed well.

5. From this study, it is concluded that shear retrofitting of RC beams using traditional method like Diagonal stitching is more effective and easy to implement.

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