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Reliability of CFRP on Shear Strengthening of Beams

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***Abstract* - Strengthening of beams is most popular technique over decade in order to compensate the deficiency of reinforcement, misplacing, or due to unusual practices etc either in tension or in shear point of view. This study mainly focuses on effect of Carbon fiber reinforced laminate stirrups on strengthening of beam in shear criteria. The objective of this study is to find out the increase in load carrying capacity and deflection profiles of shear deficient beams which are strengthen by CFRP laminates in 900 strip orientation and 450 strip orientations for different span to depth ratios 3 and 4. Over all six beams were modeled and analyzed numerically through Abaqus 6.1 version. All six beams categorized into span to depth ratio 3 and 4. Each group having a control beam, and remaining beams strengthened with 90degrees and 45degrees orientation of CFRP stirrups.**

***Index Terms* - CFRP, shear strengthening, span to depth ratio, ductility.**

I.INTRODUCTION

Over a decade strengthening techniques are widely used to construction faults, change of use of buildings, old construction practices etc people are likely to go for retrofitting and rehabilitation methods. Structural parts are retrofitted/rehabilitated with steel jacketing, RC jacketing and FRP jacketing etc. Overall, the other methods, FRP jacketing become popular because of its high stiffness-to-weight ratio, light weight, high durability, high strength-to-weight ratios, high tensile strength, and easy to installation when compared to conventional construction materials. Carbon has better fatigue properties when compared to glass, so CFRP become popular and more economic for strengthening applications of flexure and shear.

The strengthening of shear for RC beams can be done in many patterns. The increase in CFRP does not give proportional increase in shear capacity and 90deg orientation to the longitudinal axis of beam has more strengthening in shear whereas compared to 00 ply test specimen which has no contribution [1]. Strain measurements shows that the thinner fabric has better utilization of fabric and the best choice for placing of CFRP is perpendicular to shear crack [2].The width of strip limit to 0.8d, beyond the maximum strip width unnecessary constraint occurs[3].

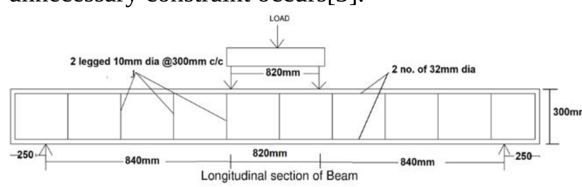

Fig-1: Reinforcement Details in RC Beam having a/d=3

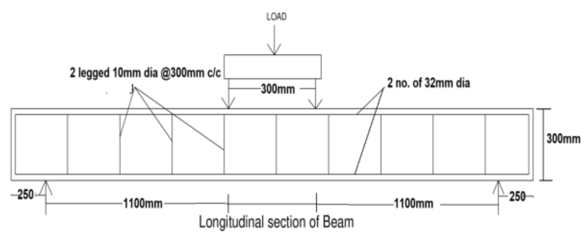

Fig-2: Reinforcement Details in RC Beam having a/d=4

The shear strength is independent of a/d ratio, but most of beams failed by beam action rather than arch action when the shear span to effective depth ratio greater than 2.5[4]. Coming to strip width, broad CFRP strips shows greater shear capacity compared to narrow strips. The efficiency ratio of CFRP is higher for beams strengthen with strips than beams strengthen with continuous sheets [5]. For smaller beams, the contribution of CFRP for shear strength enhancing is more when compared to large depth beams, because the vertical strain of CFRP stirrups in large beams is reduced [6]. Externally bonded CFRP sheets can be applied to the regions where the positive and negative moment develop in order to increase the shear capacity [7]. Increase in strip width increases the load carrying capacity and stiffness improved beyond yield by lower values of strip spacing and the ductility also increases

[8]. Beams having stirrups shows inclination of shear cracks less than 450 and FRP contribution is lower than expected due to several diagonal cracks on bond of sheets to concrete [9].

II. RESEARCH SIGNIFICANCE

RC beams which are deficient in shear strengthened by CFRP laminate under various methods depends on different parameters which affects the behaviour of strengthening and mode of failure. In this study the behaviour and failure of different strengthening methods with CFRP studied. The main objective is to find out the increase in capacity of load and deflection of various strengthening methods. Amount and orientation of fibres, span of shear to effective depth ratio(a/d) are the main parameters in this study.

III. METHODOLOGY AND ABAQUS MODELLING

Overall, six beams of size 150×300×3000mm were modelled in Finite Element Analysis software Abaqus 6.1 version. And these are categorized into 2 groups based on span of shear to effective depth ratio(a/d) as 3 & 4. Each group having one control beam and remaining beams strengthened with 90degrees and 45degrees orientation of CFRP stirrups. All beams are subjected to four point bending system and analysed. Meshing can be done through C3D8R elements, at each node three degrees of freedom. Non-linear Analysis is used, and Newton-Raphson iterations can be used to get equilibrium conditions. Force convergence tolerance kept at 0.1.

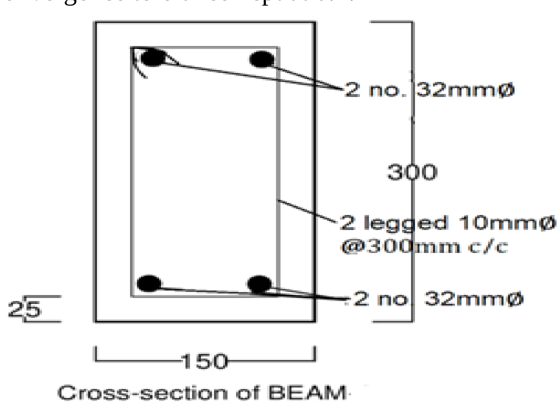

Fig: -3 Cross-section of beam for both a/d=3 &4

IV. MATERAIAL SPECIFICATIONS

All the beams have same flexural reinforcement and having 2 no. of 32mm diameter bars as top and bottom reinforcement. 2 legged 10mm diameter stirrups at 300mm c/c spacing. M30 grade concrete was used for design and modelling and Fe415 steel for reinforcement properties are given in Table-1. CFRP laminates are used as strips to strengthen the beams in shear criteria in two different methods. Table-2 describes properties CFRP properties.

Table-1: Concrete properties used in Abaqus modelling.

Compressive strength of Concrete	30MPa
Elastic modulus of Concrete	27386N/mm^2
Density	25 KN/m^3
Poisson's ratio	0.18
Yield Strength of Steel	415 N/mm^2
Density of Steel	78.5 KN/mm^2
Young's modulus of steel	2e5 N/mm^2

Table-2: Properties of CFRP

Fibre orientation	Unidirectional fibre
Weight of fibre	200 g/m^2
Density of fibre	1.8 g/cc
Fibre thickness	0.3mm
Ultimate Elongation (%)	1.5
Tensile strength	3500 mm^2
Tensile Modulus	285e3 N/mm^2

CFRP strips placed at side faces in the 900 and 450 orientation to the beam longitudinal axis. Fig-4&5 shows the strengthening of beam with stirrups. Table-3 represents the effective length and other factors of strengthening scheme. The width of CFRP strips are 100mm and the c/c spacing of CFRP stirrups is 220mm shown in Fig-4&5.

Table-3 Strengthening with CFRP data

Specification of method	Effective length Le (mm)	K1	K2	Kv
Side strips 90^0	32.122	1.072	0.770	0.156
Side strips 45^0	32.122	1.072	0.770	0.156

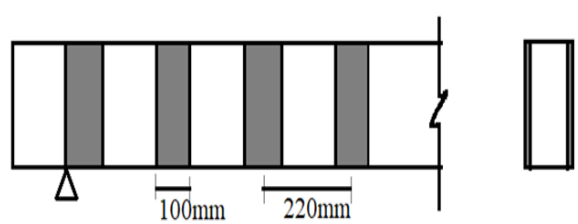

Fig-4: CFRP Strengthening of beam with 900 oriented side stirrups

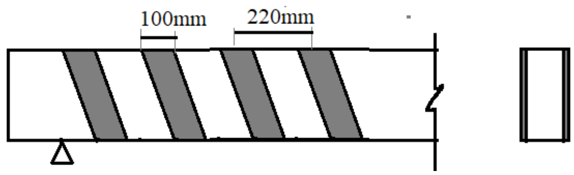

Fig-5: CFRP Strengthening of beam with 450 oriented side stirrups

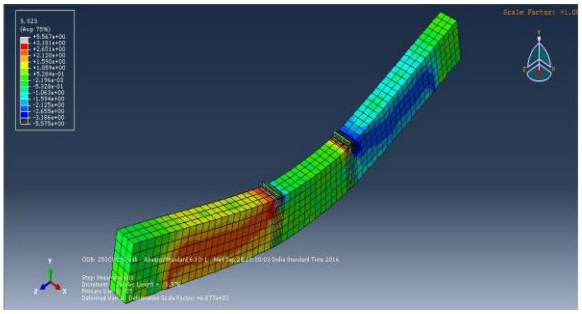
Fig-6: Control beam a/d= 3-stress contour

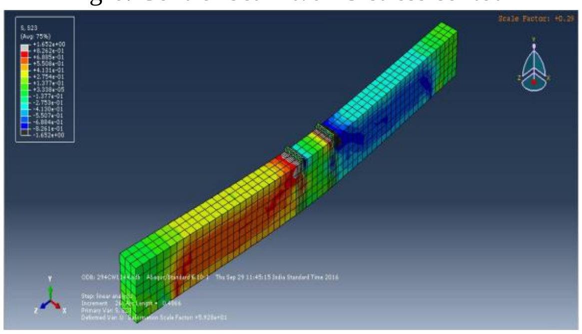
Fig-7: Control beam a/d= 4-stress contour

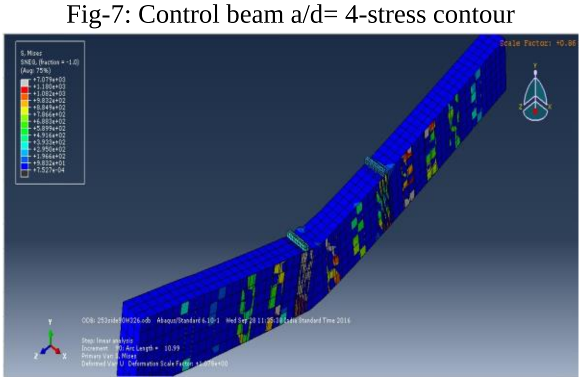
Fig-8: Beam with a/d=3- stress contour in 90deg stirrups

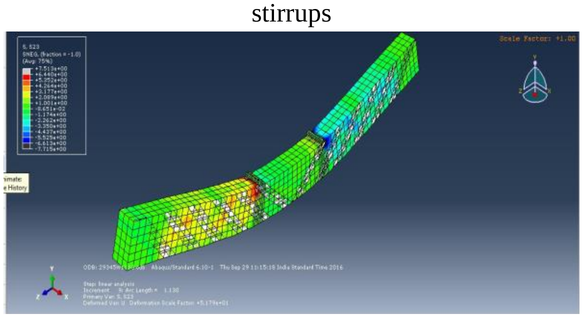
Fig-9: Beam with a/d=3- stress contour in 45deg stirrups

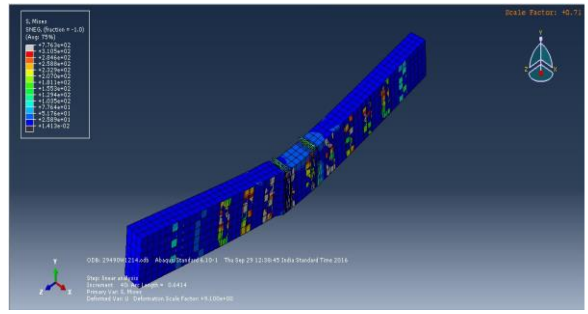
Fig-10: Beam with a/d=4- stress contour in 90deg stirrups

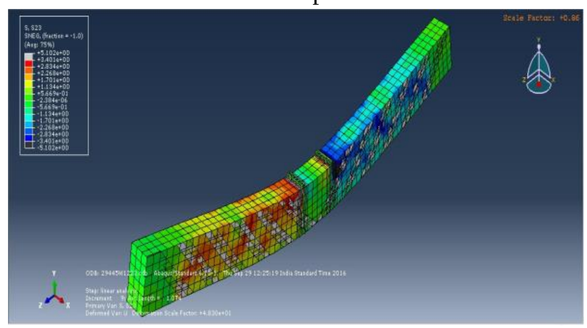
Fig-11: Beam with a/d=4- stress contour in 45deg stirrups

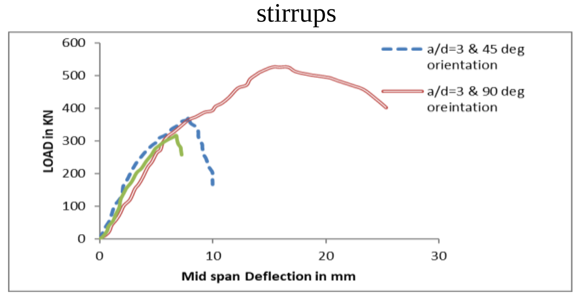

Fig-12: Beam with a/d=3 Load vs deflection graph

V. RESULTS AND DISCUSSIONS

Beams with a/d ratio=3

A diagonal shear crack pattern was observed in control beam, and which was started under loading point and it was extended to the nearest support on the both sides. Control beam load carrying capacity was 302KN, beams with 90deg orientation stirrups carries 520KN and with 45deg stirrups the load carrying capacity was 380KN. Beams with 90deg stirrups, having high stress concentration at load and support. Beams having 45deg stirrups, having high concentration at centre of load and support.

Beams with a/d ratio=4

Contour pattern of stress was similar to beams with a/d=3 for control beam. The load carrying capacity was 210KN which was less than the beams with a/d=3 due its high shear span to effective depth ratio. Beams with 90deg stirrups carrying 380KN, and 45deg stirrups 330KN. The load carrying capacity was less when compared to a/d=3, but the utilization of CFRP on strengthening was fully utilized, which was concluded from strain produced in CFRP strips.

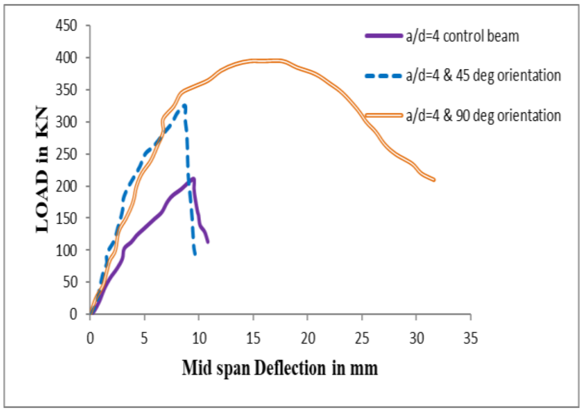

Fig-13: Beam with a/d=4 Load vs deflection graph

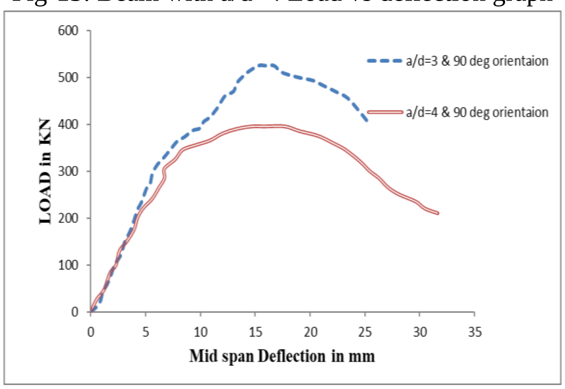

Fig-14: Comparison of a/d = 3 & 4 -90deg stirrups orientation

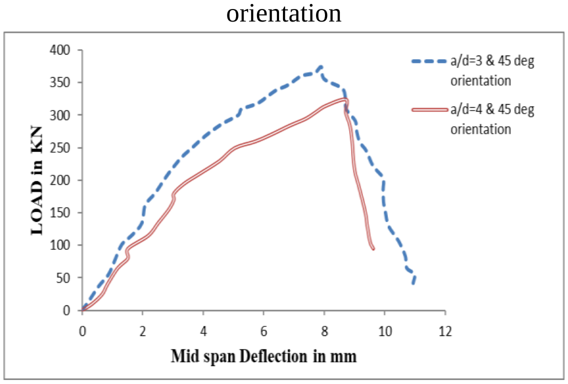

Fig-15: Comparison of a/d = 3 & 4 -45deg stirrups orientation

Deflection criteria

The deflection was more in 90deg stirrups, and at the same deflection when compared to 45deg stirrups, 90deg stirrups took more load. As expected, under the same load, a/d=3 carries more load, but the strain produced in a/d=4 was greater which concludes the effective utilization CFRP was achieved.

VI.CONCLUSION

The shear load capacity increases by 72% for a/d =3 90deg stirrups and 25.8% for 45deg stirrups when compared to control beam. For beams a/d=4, it was increase by 81% for 90deg and 57% for 45deg stirrups. In fiber orientation view, strengthening with 90deg stirrups carries more load. In ductility aspect, 90deg stirrups owing more ductile.

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