Comparative study on CFRP strengthened deep beam by finite element method

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Abstract - *Several reinforced concrete deep beams with different reinforcement technique were analysed in order to investigate the ultimate load, load deflection variation and shear strength. This paper describes analysis of deep beam subjected to two points loading with three different L/D ratios using non-linear finite element method (ANSYS14.5). Three reinforcement technique used were conventional steel reinforcement, CFRP rebars and hollow CFRP rebars. Concrete and reinforcement were modelled using SOLID 65 and BEAM 188 element respectively. The beams were designed by IS 456:2000.*

As the depth of the beam increases the variation in strength and deflection were found to be more and hollow CFRP reinforced deep beams shows better performance compared to other two reinforcement technique.

Key Words: **deep beam, ANSYS, CFRP carbon fiber reinforced polymer, Solid65, Beam188, etc.**

1. INTRODUCTION

Beams with large depths in relation to spans are called deep beams .In IS-456 (2000) Clause 29, a simply supported beam is classified as deep when the ratio of its effective span L to overall depth D is less than 2. Continuous beams are considered as deep when the ratio L/D is less than 2.5.

The deep beams have many useful applications in buildings, bridges, structures such as transfer girders, wall footings, foundation pile caps, floor diaphragms, bunkers, tanks, offshore structures etc. Most of the deep beams are located at places where reinforcement gets corroded easily. And the CFRP materials are non-corrosive and have lots of advantages over conventional steel rebars. Then this thesis attempted to study the effect of CFRP material as reinforcement of deep beams.

2. SPECIMEN DETAILS FOR ANALYSIS

There are three case studies are done on this thesis.

Case 1: Steel rebar reinforced deep beams with 3 L/D ratios.

Case 2: CFRP rebar reinforced deep beams with 3 L/D ratios.

Case 3: Hollow CFRP rebar reinforced deep beams with 3 L/D ratios.

Concrete: 3 simply supported beams are considered, each having overall depth of 350, 375 and 400 mm. The span of the beams is 700mm and the effective span between supports is 600mm. Then the l/D ratios of beams are 1.7, 1.6 and 1.5. Breadth of beam and clear cover are 150mm and 20mm respectively.

Reinforcement:

1) 2 nos. of 10mm dia. bars as tensile reinforcement.

2) 4 nos. of 8mm dia. bars as vertical reinforcement.

3) 2 nos. of 8mm dia. bars on each side as horizontal reinforcement.

For hollow rebar 10mm and 8mm dia. rebars are replaced by 12mm external dis., 6mm internal dia. rebars and 10mm external dia., 6mm internal dia. rebars respectively.

3. NON-LINEAR FINITE ELEMENT ANALYSIS

The finite element analysis calibration study included modeling a concrete beam with the dimensions and properties [1]. To create the finite element model in ANSYS 14.5 there are multiple tasks that have to be completed for the model to run properly. For this model, the graphical user interface was utilized to create the model. This section describes the different tasks and entries to be used to create the finite element calibration model.

3.1 Element Type

The element types are shown in Table 1.

Table -1: Element type

Material	Element type
Concrete	Solid65
Reinforcement	Beam188

3.2 Real Constant

Only real Constant Set 1 is used for the Solid65 element. It requires real constants for rebar assuming a smeared model. A value of zero was entered for all real constants which turned the smeared reinforcement capability of the Solid65 element off.

3.3 Material property

The Solid65 element requires linear isotropic and multi-linear isotropic material properties to correctly model the concrete material. The multi-linear isotropic material uses the failure of the concrete. The Beam188 element was used to model all rebars in the beam .The stress-strain behavior is assumed to be bilinear isotropic for the rebars placed in the beam. The material properties provided are listed in Table 2.

Table -2: Material properties

Sl. no.	Material	Properties	
1	Concrete	**Linear isotropic**	
		E_X	27386
		υ	0.2
		Multilinear isotropic	
		Stress	Strain
		9	0.0003286
		19.22	0.0007942
		25.92	0.0012597
		29.16	0.0017252
		30	0.0021908
		Concrete	
		Shear transfer coefficients for an open crack	0.3
		Shear transfer coefficients for a closed crack	0.9
		Uniaxial tensile cracking stress	3.83
		Uniaxial crushing stress	24
2	Steel	**Linear isotropic**	
		E_X	200000
		υ	0.3
		Bilinear isotropic	
		Yield stress	415
		Tangent modulus	20
3	CFRP rode	**Linear isotropic**	
		E_X	300000
		υ	0.3
		Bilinear isotropic	
		Yield stress	2070
		Tangent modulus	20

3.4 Modeling

Four 3D models, three steel Reinforced Concrete deep beam, three CFRP rebar reinforced deep beams and three Hollow CFRP rebars reinforced deep beams are been modeled. RCC beam has been designed as per IS456-2000.

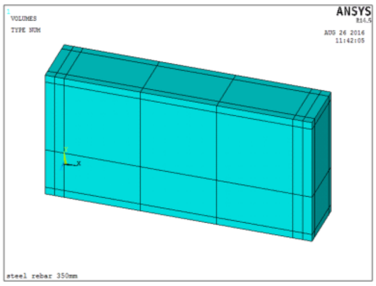

Fig -1: Model of deep beam with 350mm depth

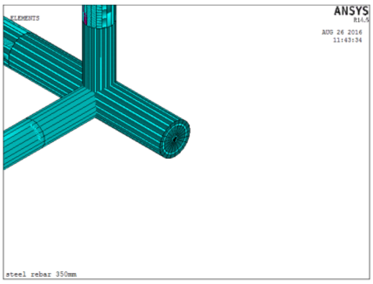

Fig -2: Close view of normal reinforcement bar

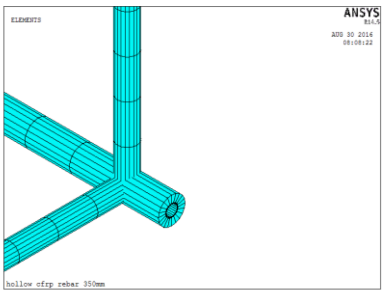

Fig -3: Close view of hollow reinforcement bars

3.5 Meshing

Solid element was meshed by hexagonal volume element. And beam element was meshed by line element

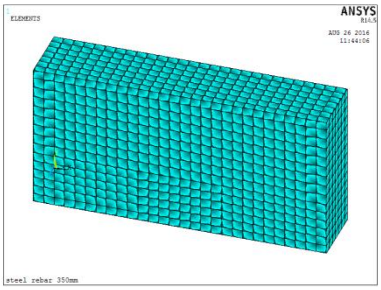

Fig -4: Solid 65 mesh of deep beam with 350mm depth

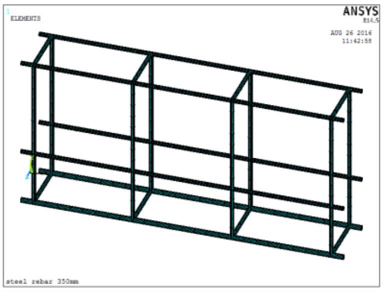

Fig -5: Beam 188 mesh of deep beam with 350mm depth

3.6 Loading and boundary conditions

Two points loading with ultimate load and simply supported boundary conditions were applied.

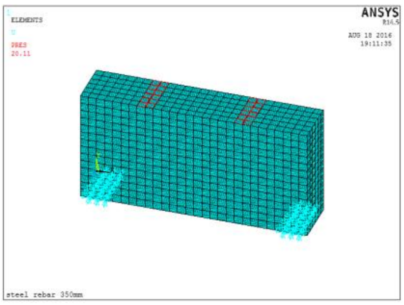

Fig -6: Loading and boundary conditions of deep beam with 350mm depth

3.7 Analysis results

3.7.1 Deformation at 270KN

Deformation diagrams of analysed deep beams at 270KN are shown in below figures.

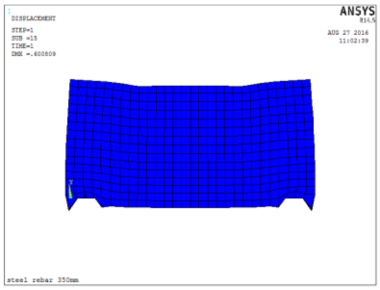

Fig -7: Deformaton diagram of steel reinforced deep beam with 350mm depth

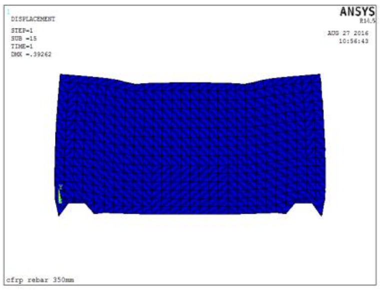

Fig -8: Deformaton diagram of CFRP reinforced deep beam with 350mm depth

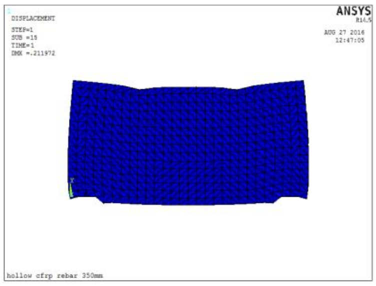

Fig -9: Deformaton diagram of Hollow CFRP reinforced deep beam with 350mm depth

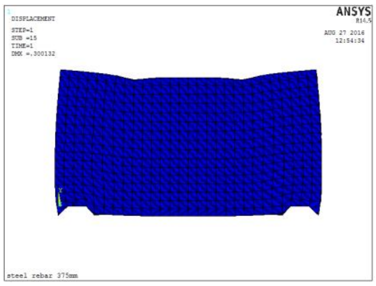

Fig -10: Deformaton diagram of steel reinforced deep beam with 375mm depth

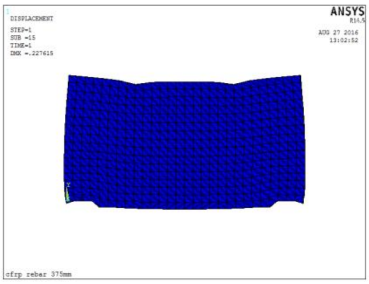

Fig -11: Deformaton diagram of CFRP reinforced deep beam with 375mm depth

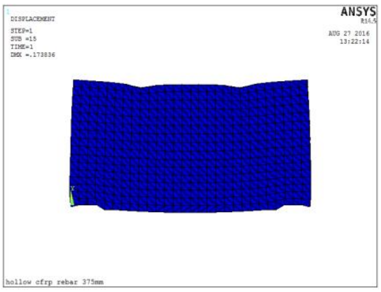

Fig -12: Deformaton diagram of Hollow CFRP reinforced deep beam with 375mm depth

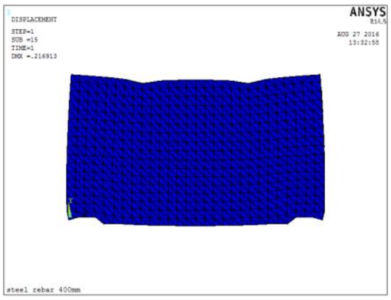

Fig -13: Deformaton diagram of steel reinforced deep beam with 400mm depth

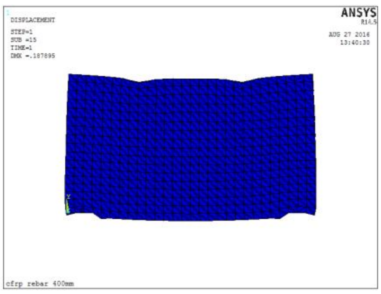

Fig -14: Deformaton diagram of CFRP reinforced deep beam with 400mm depth

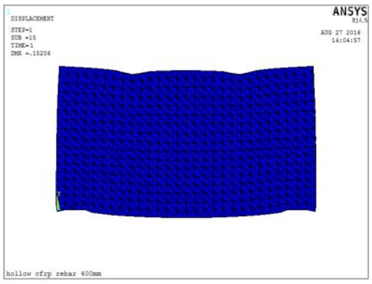

Fig -15: Deformaton diagram of Hollow CFRP reinforced deep beam with 400mm depth

3.7.2 Crack pattern at 270KN

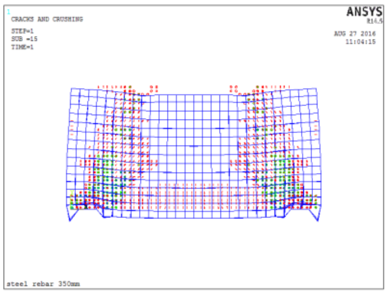

Fig -16: Crack pattern of steel reinforced deep beam with 350mm depth

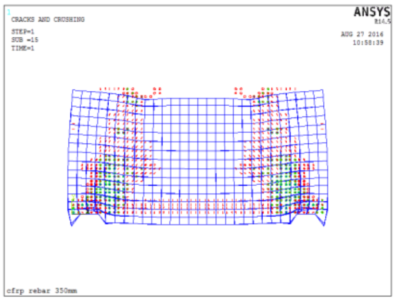

Fig -17: Crack pattern of CFRP reinforced deep beam with 350mm dept

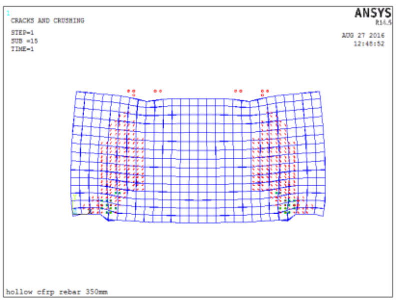

Fig -18: Crack pattern of Hollow CFRP reinforced deep beam with 350mm depth

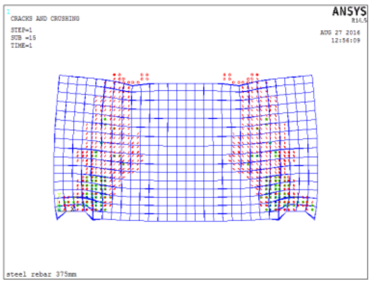

Fig -19: Crack pattern of steel reinforced deep beam with 375mm depth

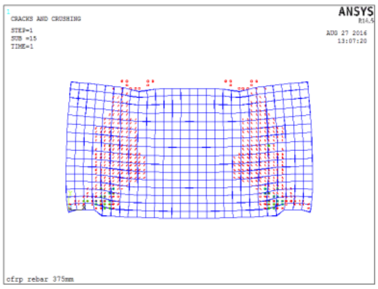

Fig -20: Crack pattern of CFRP reinforced deep beam with 375mm depth

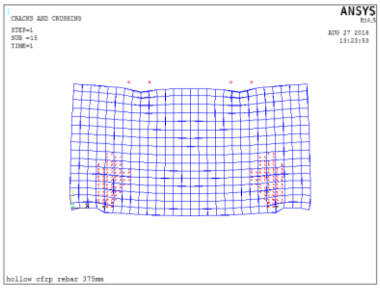

Fig -21: Crack pattern of Hollow CFRP reinforced deep beam with 375mm depth

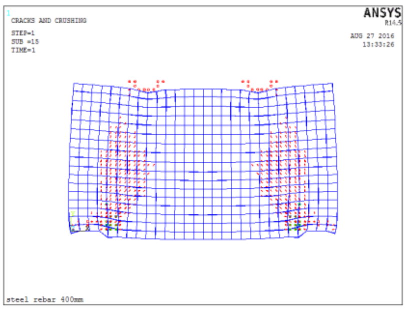

Fig -22: Crack pattern of steel reinforced deep beam with 400mm depth

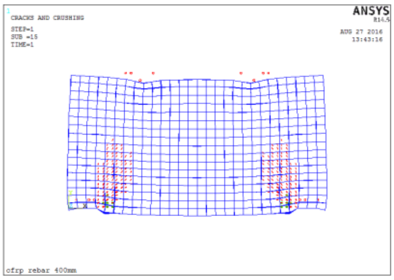

Fig -23: Crack pattern of CFRP reinforced deep beam with 400mm depth

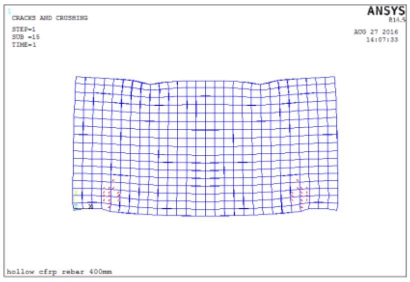

Fig -24: Crack pattern of Hollow CFRP reinforced deep beam with 400mm depth

3.8 Results and discussions

3.8.1 Ultimate load and load deflection vatiations

The failure loads and its mid span deflections at failure are listed in Table 3. And the load deflection coparison of three reinforcement techniques are plotted in Chart 1, Chart 2 and Chart 3 for 1.7,1.6 and 1.5 L/D ratios respectively. From these results it is clear that the increase in load carrying capacity of deep beam and decrease in mid span deflection are with respect to decrease in L/D ratios in all three reinforcement techniques. CFRP rebar shows better load carrying capacity compared to steel rebar and from CFRP rebars hollow CFRP rebars shows highest load carrying capacity.

Table -3: Failure loads and deflections at failure

Deep beam	Failure load (KN)	Mid span Deflection at failure(mm)
Steel reinforced deep beam		
350mm	301.65	1.469
375mm	308.10	1.565
400mm	320.25	1.601
CFRP rebar reinforced deep beam		
350mm	302.25	0.848
375mm	314.60	0.965
400mm	338.02	1.201
Hollow CFRP rebar reinforced deep beam		
350mm	318.76	0.690
375mm	330.82	0.790
400mm	389.66	0.954

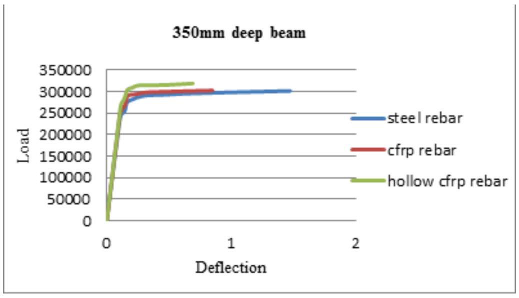

Chart -1: Load deflection variations of 1.7 L/D deep beams

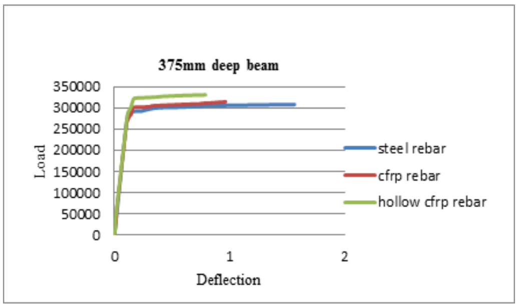

Chart -2: Load deflection variations of 1.6 L/D deep beams

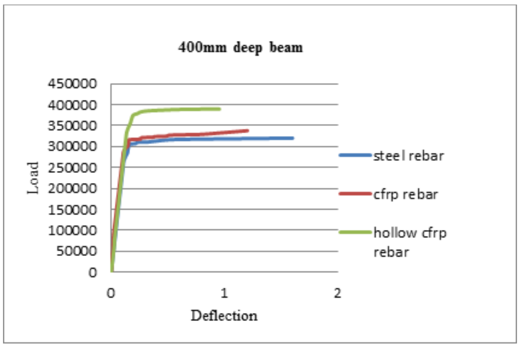

Chart -3: Load deflection variations of 1.5 L/D deep beams

3.8.2 Shear strength

As the boundary conditions are simply supported the shear at supports are half of applied load then the shear strength is the half of ultimate load. This study found that shear strength increases with decrease in L/D ratio. It is also identified that shear strength has an increament from steel rebar reinforced deep beam to CFRP rebar reinfored deep beam and hollow CFRP rebar reinforced deep beam. The comparison of shear strength of nine deep beams analysed are charted in chart.4

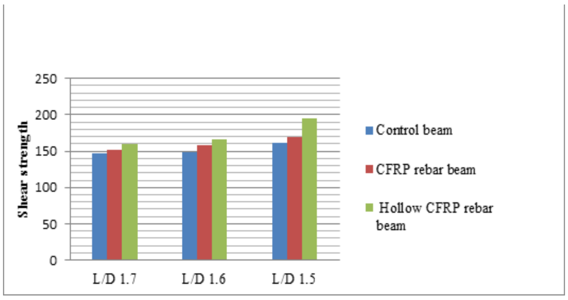

Chart -4: Shear strength variation

4 CONCLUSION

Carry out analytical study using ANSYS 14.5 for the prediction of mid-span deflection and shear strength of nine deep beams. In all cases deep beam fail due to diagonal cracking. And shear strength increased with decrease in L/D ratio.

Hollow CFRP rebar reinforced deep beams have more strength than CFRP rebar reinforced and steel reinforced deep beams. Then the Hollow CFRP rebar deep beam have deflection less than control beam and CFRP reinforced beam. CFRP reinforced beam have shear strength greater than steel reinforced deep beams. For the L/D ratio 1.5, Hollow CFRP rebar has shear strength 21.38% greater than steel reinforced beam. Then it is concluded that CFRP rebar can be use better than steel rebars for getting increased load carrying capacity of deep beams and in the places of steel rebar get corroded easily. In CFRP rebars Hollow CFRP rebars provide much more improved load carrying capacity and shear strength.

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