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Numerical Study on FRP Retrofitted RC Beam Suffering From IC Debonding

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Abstract - *Fiber reinforced plastic (FRP) also called fiber reinforced polymer. It is a composite material made of polymer matrix reinforced with fibers. The fibers are usually glass, carbon, aramid, and basalt. FRP are commonly used in the aerospace, automotive, marine and construction industries. Fiber Reinforced Polymer (FRP) plates can be bonded to the tension face of a reinforced concrete beam to increase its flexural capacity. Many studies have been done and found that premature failure by debonding of the FRP plate occur before reaching the ultimate flexural capacity of the plated section and the most commonly reported debonding failure mode is commonly referred to as intermediate crack induced due to interfacial debonding or simply intermediate crack (IC) debonding.*

A number of options to suppress this failure mode have been explored, the easiest option is still to install U-Jackets of an appropriate layout outside the FRP plate. The inclined FRP U-Jacketing is among the most attractive one in terms of cost, installation, and durability. FRP composites have excellent corrosion resistance and high strength to weight ratio. FRP U-Jacketing has a significant effect on suppressing IC debonding and improving the load carrying capacity of the beam. Numerical analysis is conducted in ANSYS workbench 16.2 for the Inclined FRP U-jackets for enhancing structural performance of FRP-plated RC beams suffering from IC debonding.

***Key Words*: RC Beam, FRP, Debonding, IC, U-Jacket.**

1. INTRODUCTION

1.1 General Background

One of the challenges in strengthening of concrete structures is selection of a strengthening method that will enhance the strength and serviceability of the structure while addressing limitations such as constructability, building operations, and budget. Structural strengthening may be required due to many different situations. Additional strength may be needed to allow for higher loads to be placed on the structure. Strengthening may be needed to allow the structure to resist loads that were not anticipated in the original design. External bonding of fibre reinforced polymer laminates to the tension face of reinforced concrete beams has been widely used in the flexural strengthening of RC beams. Due to IC debonding failure, the tensile strength of the FRP plate cannot be fully utilized. While a number of options to supress this failure mode have been explored, the easiest option is still to install U-Jackets of an appropriate layout outside the FRP plate. The major debonding failure commonly observed in FRP strengthened RC beam are of two types. In the first case initial debonding of the FRP laminates occur at or near the tip of the main crack (a flexural or a flexural shear crack termed as intermediate crack) or the tributary crack. In the second case debonding failure commonly known as concrete cover separation which starts at the end of the plate and propagate towards the midspan of the beam. FRPs are commonly used in the aerospace, automotive, marine, and construction industries. This paper presents a numerical study on FRP retrofitted RC beam suffering from IC debonding.

2. NUMERICAL INVESTIGATION USING ANSYS WORKBENCH 16.2

2.1 Base Model

Numerical modelling of RC beam model was done using ANSYS 16.2 WORKBENCH, a finite element software for mathematical modelling and analysis. The dimensions of all the specimens are same. width of beam is 200mm, a depth is 450mm and the length is 4000mm.The beam were under-reinforced using three 12mm deformed steel bars as the internal tension reinforcement and two 12mm deformed steel bars as the internal compression reinforcement, and 10mm deformed steel bars with a centre to-centre spacing of 100mm as the stirrups and M35 grade of concrete is used. For concrete, steel and GFRP, Analysis requires input data for material properties are shown in Table 1 and Table 2. Figure 1 showing modelled view of RC beam and Figure 2 showing modelled view of reinforcement.

Table 1. Material Properties of Concrete and steel

Young's modulus of concrete N/mm^2	30000
Poisson's ratio of concrete (ν)	0.18
Density of Concrete	2300 Kg/m^3
Density of steel, (ρ)	7850 Kg/m^3
Modulus of elasticity of Steel, N/mm^2	2×10^5
Poisson's ratio of steel	0.3

Table 2. Material Properties of GFRP

Elastic modulus (E_C) of elasticity in x direction N/mm²	45000
Elastic modulus of elasticity in y direction N/mm²	10000
Elastic modulus of elasticity in z direction kN/m²	10000
Poisson's ratio xy	0.3
Poisson's ratio yz	0.4
Poisson's ratio xz	0.3
Shear modulus (μ) in xy N/mm²	5000
Shear modulus in yz N/mm²	3846.2
Shear modulus in zx N/mm²	5000

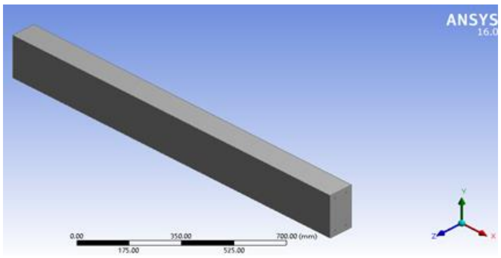

Fig-1: Modelled view of RC beam

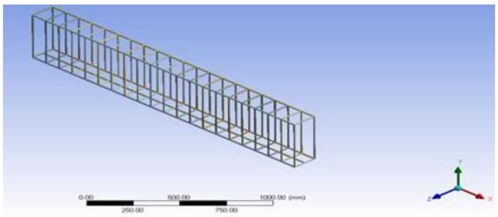

Fig-2: Modelled view of reinforcement

2.2 Cracked RC Beam

Virtual crack closure Technique for Reinforced Concrete Beam Model (VCCT)

To simulate delamination propagation with Finite Element Method (FEM), VCCT and Cohesive Zone Method (CZM) are used. The VCCT is quite appropriate to analyse crack propagations in laminated composite materials with brittle matrix. The procedure selected by the analyst is based on considerations of the strengths and weaknesses of both methods. The VCCT method is a fracture mechanics-based method and therefore requires an initial crack (in the form of a Pre-Meshed Crack) in the geometry. VCCT technique are only supported for lower order crack mesh. Hence, VCCT based fracture parameter computations are only supported for Pre-Meshed Crack object [8].

The VCCT technique is based on two essential assumptions;

•If there is a small amount of crack propagation, the released strain energy is equal to the energy needed to close the fractured surfaces to its original positions [8].

•If the crack propagates a small amount compared to the crack length, there are no noticeable changes at the stresses in the crack tip during crack propagation. [8] Figure 3 shows Symmetric view of cracked beam.

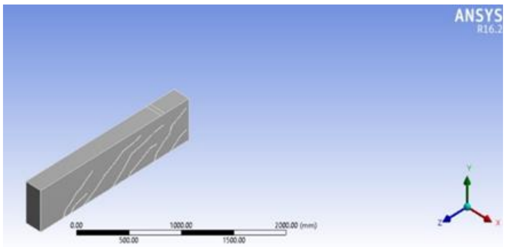

Fig-3: Symmetric view of cracked beam

2.3 FRP PLATED CRACKED RC BEAM

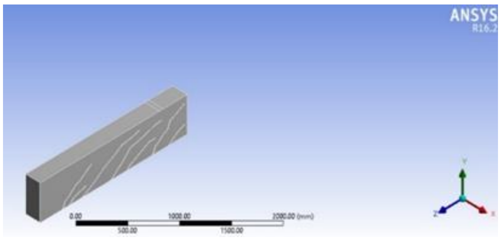

Fig-4: Modelled view of FRP Plated Cracked RC Beam

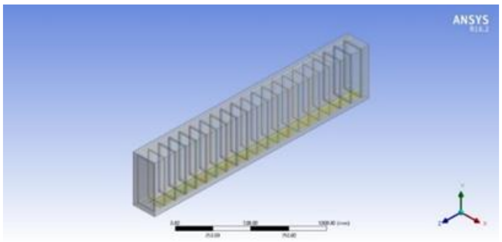

Fig-5: Modelled view of the Reinforcement with GFRP sheet

Intermediate Crack Debonding of FRP Plated Reinforced Concrete Beam

The debonding capability refers specifically to separation of bonded contact. The Contact Debonding object specifies the pre-existing contact region that intend to separate and it also references Material property for the model was selected from engineering data section of the software, where all the available materials are pre-assigned with a default value for various properties are shown in **Table 3.** Select the material properties from the Cohesive Zone category with type Separation-Distance based Debonding or Fracture-Energies based Debonding [17].

Table 3 Debonding properties

Maximum normal contact stress, N/mm²	900000
Contact gap at the completion of debonding, m	0.0001
Maximum equivalent tangential contact stress, N/mm²	0.05
Tangential slip at the completion of debonding, m	0.0001
Artificial damping coefficient, s	0.1

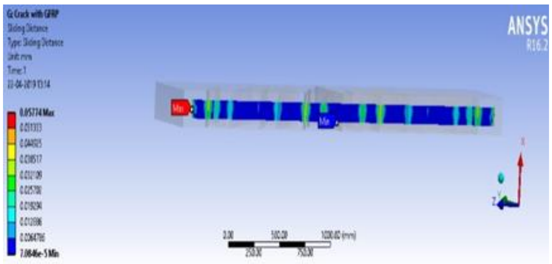

Fig-6: Debonding of FRP plated RC beam

2.3 End Anchorage U-Jacket Used in IC Debonding of FRP Plated RC Beam

RC beam of width is 200mm, a depth is 450mm and the length is 4000mm.The beam were under-reinforced using three 12mm deformed steel bars as the internal tension reinforcement and two 12mm deformed steel bars as the internal compression reinforcement, and 10mm deformed steel bars are used as stirrups with 100mm a centre to-centre spacing. FRP plate was externally attached to the soffit plate of the reinforced concrete beam and it was formed three layers of woven fabric Glass fibre sheets with each layer being 0.333mm thickness, 100mm in width and length is 3800mm and the GFRP sheets were U wrapped in different patterns to optimize the most effective pattern in varying inclination, width and height. The GFRP sheets used for various wraps were 2 layers of 0.333mm thick. Three models V90W100H250, V90W150H250, V90W200H250 were considered. V representing the inclination of the U-jacket to the beam axis, W and H representing the width and height of the U -jacket.

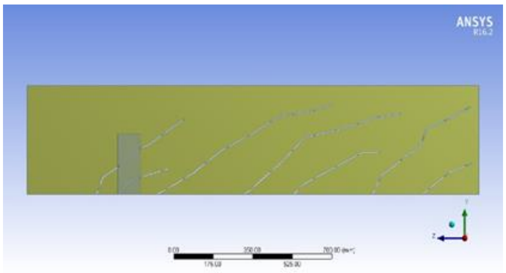

Fig-7: Modelled view of V90W100H250

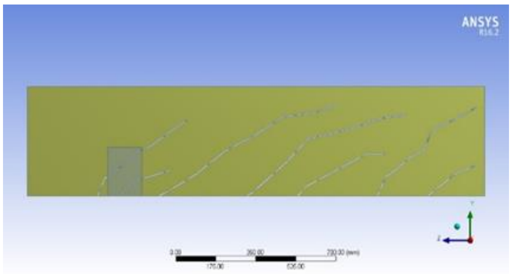

Fig-8: Modelled view of V90W150H250

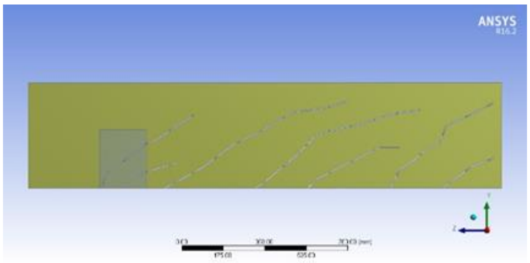

Fig-9: Modelled view of V90W150H250

3. RESULTS

3.1 Load Deflection Analysis

Influence of U-Wrap on Beam

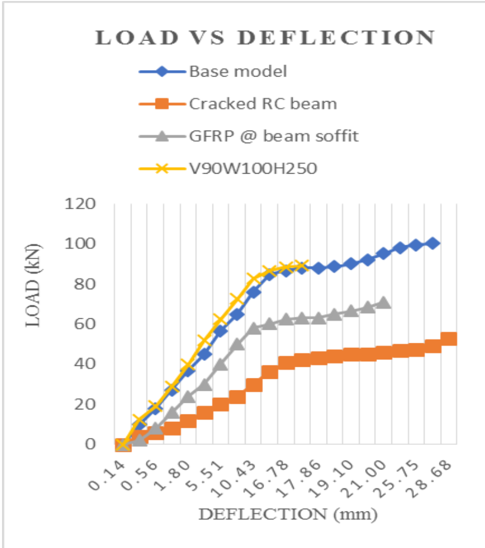

Fig -10: Load vs. Deflection for base model, Cracked RC beam, GFRP @ beam soffit and V90W100H250

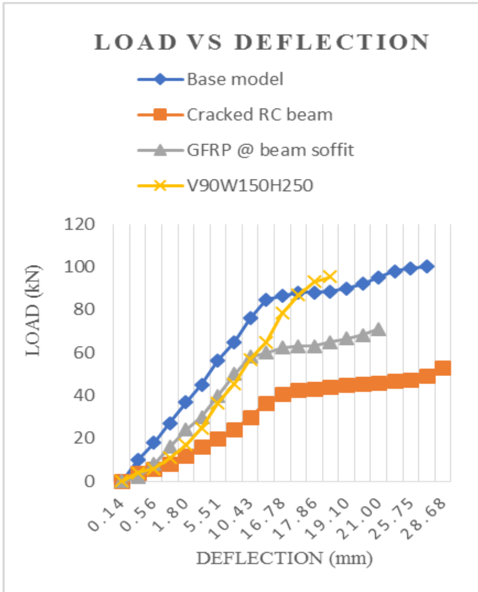

Fig-11: Load vs. Deflection for base model, Cracked RC beam, GFRP @ beam soffit and V90W150H250

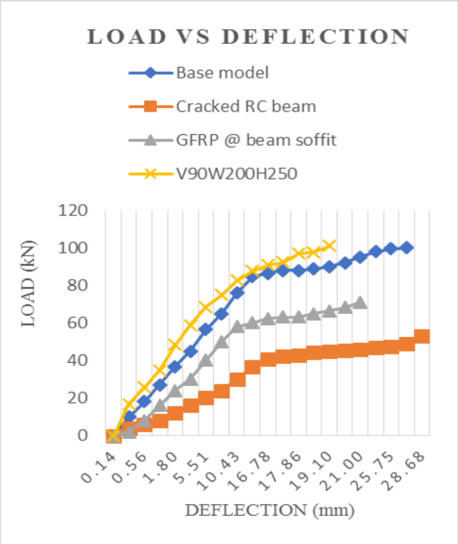

Fig-12: Load vs. Deflection for base model, Cracked RC beam, GFRP @ beam soffit and V90W200H250

The ultimate deflection of beams (Cracked Beam with GRPF @beam soffit and V90W100H250, V90W150H250, V90W200H250) were reduced compared to the RC beam. The percentage reduction in the deformation for the externally bonded GFRP sheet in tension phase of the beam and u-wrap at the end anchorage of the beams corresponding to the ultimate deflection of RC beam was shown in Table 4

Table 4. Percentage reduction in deflection for beams retrofitted with GFRP Sheet

Model	Deflection corresponding to the RC beam (mm)	Percentage reduction in deformation w.r.t RC beam (%)
BASE MODEL (RC Beam)	26.14	-
Cracked Beam	28.68	9.71
Cracked RC Beam with GRPF @ beam soffit	21	19.66
V90W100H250	17	34.96
V90W150H250	18.47	29.34
V90W200H250	19.1	26.93

3.2 Static Analysis

The first crack in the beam were generated by virtual crack closure technique. The first crack was seen near the support were there was no GFRP sheet. Then cracked beam retrofitted with GFRP sheet using in the beam soffit, it is failed due to debonding of the GFRP sheet followed by IC debonding. The same beam was again retrofitted with End anchorage U wrap in 90-degree inclination by varying width and constant height. The test results are tabulated in the Table 5.

Table 5 Test Results

Model	Ultimate Load at Failure in (kN)
BASE MODEL (RC beam)	100
Cracked RC Beam	53
GFRP@ beam soffit	71
V90W100H250	89
V90W150H250	95.46
V90W200H250	101

3.3 Ultimate Load Carrying Capacity

The load carrying capacity of the RC beam, cracked beam, cracked beam with externally bonded GFRP sheet @ beam soffit. Externally bonded End anchorage (V90W200H250) are plotted below.

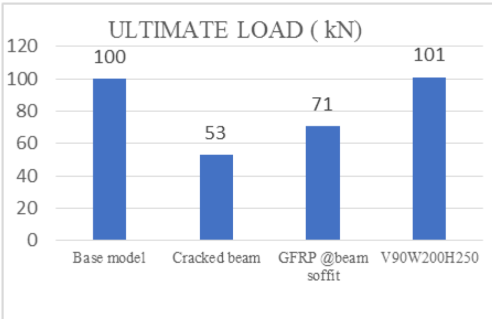

Fig -13: Ultimate load carrying capacity

3.4 Effect of Width

The effect of varying width was investigated. The ultimate load obtained by varying width with 2 layers of GFRP sheet oriented at 90 degree is shown in the figure 13.

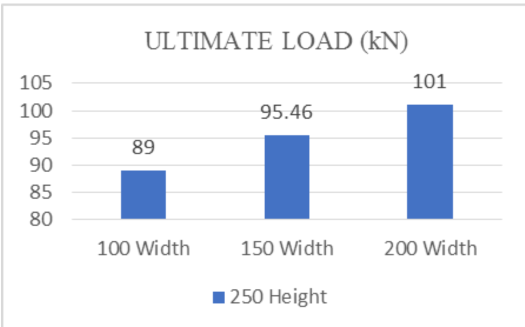

Fig -13: Ultimate load by varying width at 90 degree

4. CONCLUSIONS

The following observations and test results are obtained from the numerical investigations of Base Model, Cracked RC beam, Externally bonded GFRP sheet at beam soffit and U - Wrap at 90 degree by varying width and constant height.

- Woven fabric GFRP sheet is properly bonded to the tension face of the RC beams can enhance the load carrying capacity 33.9% than cracked RC beam. U - wrap specimen exhibit an increase in load carrying capacity 42.25% than GFRP sheet is externally bonded to the beam soffit and 1% than the RC beam (base model).

- The cracked beam has high deflection than the RC beam. The behavior of the cracked beam when bonded GFRP sheet in tension phase of the beam are better than the RC beam. And U-Wrap using in the beam are better than RC beam and GFRP sheet used in the beam soffit.

- The use of a 3 layers GFRP sheet externally bonded to the beam soffit for retrofitting reinforced concrete beams is very efficient. A strength capacity increases of 33.9% is obtained for the retrofitted beam specimen in comparison with the cracked RC beam.

- The u-anchorage retrofitting configuration is an effective method to increase its ultimate load carrying capacity. However , the deformation of the beams is significantly reduced.

- Load carrying capacity is also effected by width of End anchorage (GFRP sheet). the width of GFRP sheet were varied as 100mm,150mm,200mm. it was observed that increase in width increases the load carrying capacity of u-wrap using in FRP Plated RC beam. U-Wrap width is 200 gives the better result than other two.

- Vertical U-Jacket has a significant effect on the performance of FRP Plated RC beams, and the specimen with a 90 degree inclination with 200 mm width and constant height 250mm is best scheme used to retrofitting RC beams suffering from IC debonding.

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BIOGRAPHIES

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