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A Finite Element Analysis for Optimization of Flexural Cracked Beam Strengthened using CFRP composites.

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Abstract*- Epoxy-bonding a composite plate to the tension face is an effective technique for repair and retrofit of reinforced concrete beams. Several design methodology, guidelines and researches were established for the feasibility and efficiency of using externally bonded fiber-reinforced polymer composites on retrofit existing reinforced concrete structures. This paper presents a numerical study for optimization of a cracked beam strengthened using externally bonded CFRP plate. The structural components taken into consideration are beams of varying crack-depth subjected to a fixed loading condition. A "Plate Bonding Technique" has applied in integrating CFRP plate of length equal to different percentage of beam length. Entire analyses of undamaged, partially damaged and retrofitted beams were carried out by the general purpose finite element software. It is observed that, "Plate Bonding Technique" reduces the stress at crack tip to a value less than the stress at same position before cracking. Also it is observed that a beam having flexural crack there is an optimum percentage of plate length for which there is a minimum crack tip stress. Finally a general equation has developed by correlating the percentage of crack depth with respect to beam depth and the percentage of optimum plate length with respect to beam span length for the cracked beam subjected to fixed loading condition.*

Keywords: CFRP, Strengthening, Plate Bonding, Flexural Crack, Optimization.

1. INTRODUCTION

Reinforced concrete structures often have to face damage of it ones or more components without total failure of the structure. The main contributing factors for such collapse are change in their use, new design standards, deterioration due to corrosion in the steel caused by exposure to an aggressive environment and accident events such as earthquakes. This damage may cause reduction in occupancy and service ability of the structures and also economical loss of the owner. How this deteriorates structural components can be make strengthened and usable became main headache of the civil engineer now. A lot of research has successfully performed to make the structures strengthened based on FRP composites.

It found that externally bonded CFRP plates increase in maximum load of the retrofitted beam reached values between 7% and 33 % for retrofitting in flexure and increasing the CFRP plate length in flexural retrofitting can make the CFRP more effective for concrete repair and strengthening [1]. But it does not give the information that which length of CFRP plate will give the more reliable result or economic length of CFRP plate.

Again from an experimental study carried on FRP composite as an alternative material to strengthened, upgrade and repair infrastructure [2] found that flexural capacity of retrofitting beam increased by more than 100% of their original strength. In this experiment externally bonded CFRP plate has used on both face of beam to their full length. But it does not provide any effective length of CFRP plate to make the structural components cost effective. Hence more study is required to find out the economical length of CFRP plate for optimization of retrofitting design of structural components. This paper shows an optimized relationship of CFRP plate length dependent with varying flexural crack-depth and beam length.

2. Numerical investigation:

Modeling of Beam: The beam has modeled having all degree of freedom restrained. The beam considered as an element of 15'x15' room of a residential building subjected to distributed load = 1 k/ft^2 and third point loading = 3 kip.

Following materials properties of epoxy adhesive, concrete and CFRP are considered for the present study [3].

Property	Amount/ Condition
Span length	15'
Depth	1'
Width	1'
crack depth	0.15'(15% of depth, initially and then investigate for 5%, 10%, 20%, 25%)
crack opening	0.008'
boundary condition	Restrained all end nodes

Name of the property	Epoxy adhesive	Concrete	CFRP
Density (k/ft^3)	0.08722	0.146	0.48594
Young modulus (k/ft^2)	208800	730800	4280400
Shear modulus (k/ft^2)	85608	302760	1670400
Possions ratio	0.35	0.2	0.3
Tensile strength(k/ft^2)	400	60	8000
Compressive strength (k/ft^2)	1500	1800	8000
Shear strength (k/ft^2)	420	70	8000

3. Finite Element Modeling of Beam:

Reinforced concrete frame is a composite type of structure. Reinforced cement concrete, speaking in very common sense, is a mass of hardened concrete with steel reinforcement embedded within it. In the present practice reinforced cement concrete frames is assumed as a homogeneous and isotropic material. Its assumed that a perfect bond has established between concrete and CFPR elements. For simplicity in analysis plane82 structural solid element of ANSYS has been selected to model the RC beam. The concrete properties are used for plane82 element. Several past studies on RC beam and ACI recommend that if only concrete properties are used for plane82 element, the analysis will give sufficiently accurate result [4]. Plane 82 element is used either as a plane element (plane stress or plane strain) or as an axsymmetric element for 2-D modeling of solid structures. The element is defined by eight nodes having two translational degrees of freedom at each node. The element has plasticity, creep, swelling, stress stiffening, large deflection and large strain capabilities. Special features this elements is it represent plasticity, creep, swelling, stress stiffening, large deflection, large strain, Birth & death, Adaptive [5].

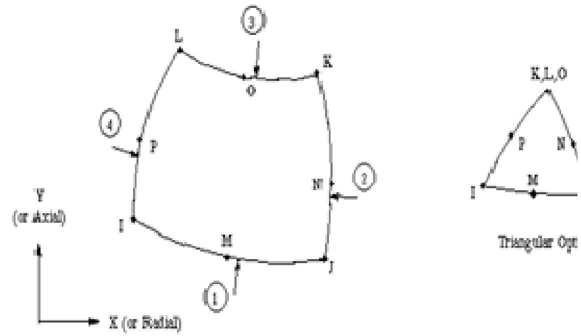

Figure 3a: PLANE 82, 2-D Structural Solid.

The element solution output associated with the element is in two forms: 1) nodal solution, 2) some additional element output. Several items are illustrated in the following figure:

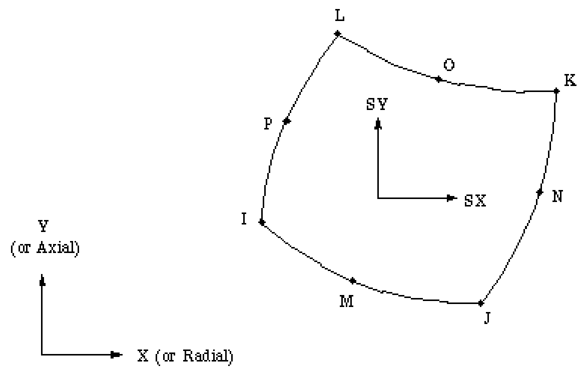

Figure 3b: PLANE 82 Stress output.

The element stress directions are parallel to the element coordinate system. Surface stresses are available on any face. Surface stresses on face IJ, for example, are defined parallel and perpendicular to the IJ line and along the Z axis for a plane analysis or the hoop direction for an axisymmetric analysis.

The area of the element must be non-zero. The element must lie in a global X-Y plane as shown in the figure above and the Y-axis of symmetry for axisymmetric analysis. An axisymmetric should be modeled in the +X quadrants. A triangular may be formed by defining duplicate K and L node numbers. The extra shapes are automatically deleted for triangular elements so that a constant strain element results.

4. Finite Element Analysis of Uncracked & Cracked Beam:

The modeled beam was discretized by 8-nodded plane-82 rectangular element & the surrounding of crack has discretized by 6-nodded triangular plane stress elements. Non uniform meshing was provided by introducing fine mesh at the stress concentration zone and coarse meshing at less stress concentration region. Finite element meshing of uncracked and cracked beam is shown in figure: 4.1a and 4.1b. The crack has modeled having opening 0.008' and depth 0.15' (15% of the depth of the beam) at the mid span of the tension zone of the beam. The beam is initially retrofitted using 2cm CFRP plate. An epoxy glue of 2mm thick has used to ensure proper bonding between CFRP plate and concrete [6].

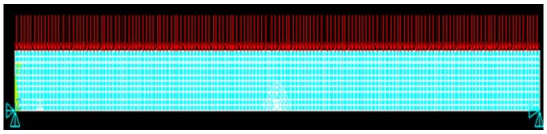

Figure 4.1a: Uncracked beam model

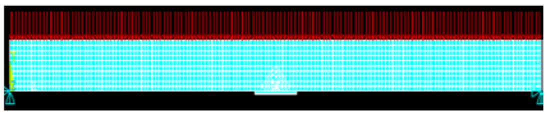

Fig 4.1b: Cracked beam model with CFRP Plate

From analysis it's found that before crack formation stress is 53.145 k/ft. After crack formation the stress at crack tip (same point of uncracked beam) became 291.833 k/ft^2 which is approximately 6 times greater than the uncracked beam stress as shown in figure:4.1c & 4.1d. After retrofitting the crack tip stress is 56.322 k/ft^2 which is same as that of original unracked beam.

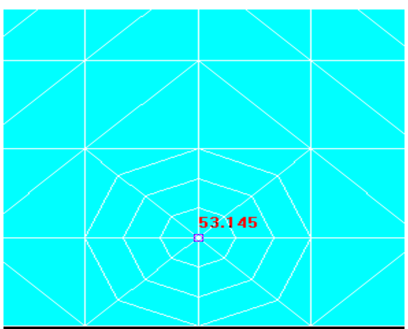

Figure 4.1c: Uncracked stress of the beam

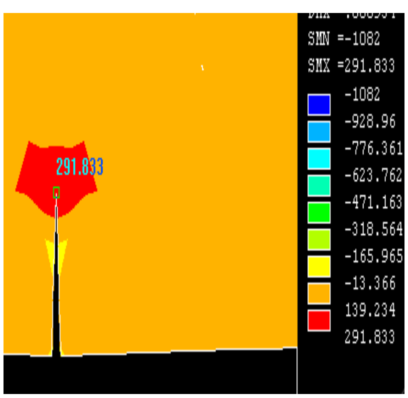

Figure 4.1d: Cracked tip stress

4.2 Determination of Optimum Plate Length:

To establish the relation of CFRP plate length with depth of crack and length of beam, several studies of varying crack-depth and CFRP plate length has carried out. In all cases the thickness of CFRP plate and glue layer remains constant.

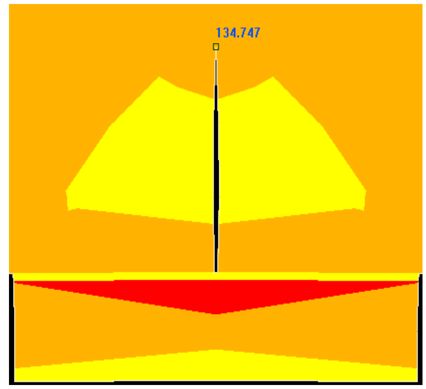

Figure 4.2a: 2 % plate length

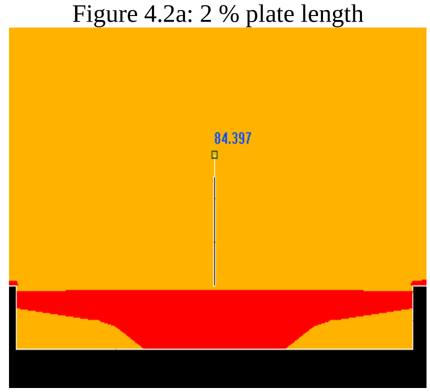

Figure 4.2b: 4 % plate length

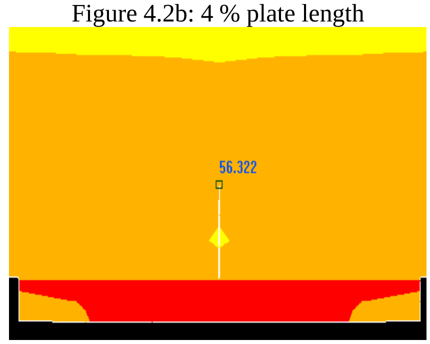

Figure 4.2c: 6 % plate length

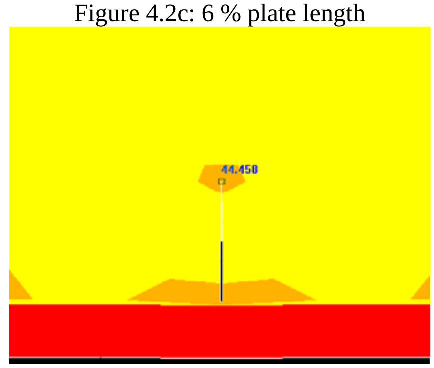

Figure 4.2d: 8 % plate length

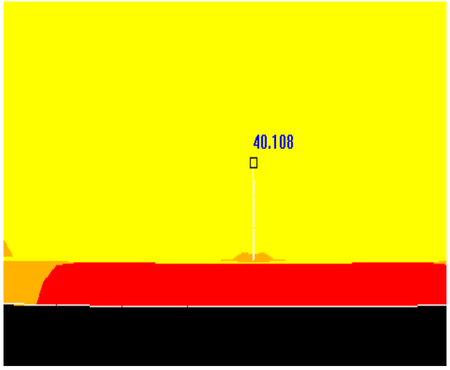

Figure 4.2e: 10 % plate length

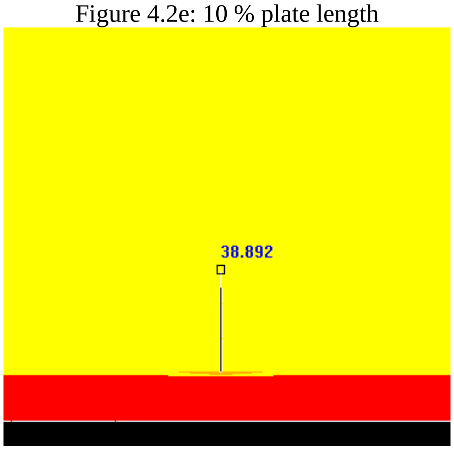

Figure 4.2f: 12 % plate length

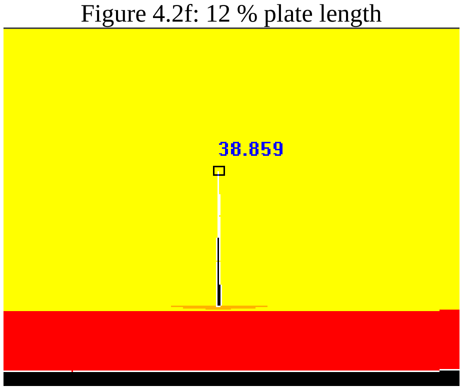

Figure 4.2g: 14 % plate length (lowest)

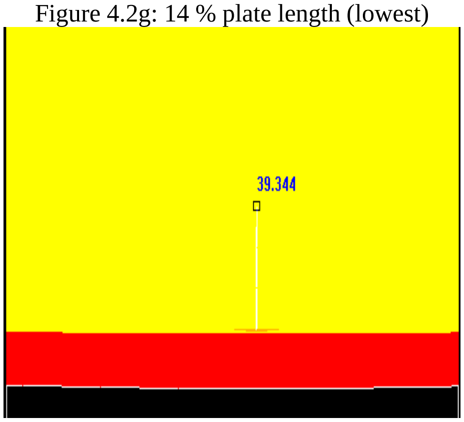

Figure 4.2h: 16 % plate length (increasing)

Now it is necessary to find out the optimum length for a fixed crack depth, for which there will be a minimum crack tip stress. For this several length plate were glued with the beam bottom surface for a fix crack depth of 15% of the overall beam depth. At each case flexural stress at the crack tip was determined. Longitudinal stress contour plot for different length of the CFRP plate are given in figure: 4.2a to 4.2h.

In tabular form the length of CFRP plate for different depth of crack are as follows:

For 5 % crack depth

Plate length (ft)	% of plate len. W.r.t. span len	Crack tip stress (k/ft^2)
0	9	344.762
0.1	0.67	211.301
0.2	1.33	162.631
0.3	2	133.018
0.4	2.67	109.54
0.5	3.33	92.053
0.6	4	80.47
0.7	4.67	74.43
1	6.67	68.58
1.2	8	63.157
1.4	9.33	62.18 (Lowest)
1.5	10	62.39 (Increasing)

For 10 % crack depth

Plate length (ft)	% of plate len. W.r.t. span len	Crack tip stress (k/ft^2)
0	0	309.325
0.2	1.33	165.536
0.4	2.67	117.748
0.6	4	84.966
0.8	5.33	66.722
1	6.67	58.037
1.2	8	54.539
1.4	9.33	53.366
1.6	10.67	53.19
1.8	12	52.11 (Lowest)
2	13.33	52.87 (Increasing)

For 15 % crack depth

Plate length (ft)	% of plate length w.r.t. span length.	Crack tip stress (k/ft^2)
0	0	291.833
0.3	2	134.747
0.6	4	84.4
0.9	6	56.32
1.2	8	44.458
1.5	10	40.108
1.8	12	38.892
2.1	14	38.859 (lowest)
2.4	16	39.34 (increasing)
3	20	40.99 (increasing)

For 20 % crack depth

Plate length (ft)	% of plate length w.r.t. span length.	Crack tip stress (k/ft^2)
0	0	296
0.4	2.67	111.988
0.8	5.33	58.867
1.2	8	34.672
1.6	10.67	26.435
2	13.33	24.27
2.2	14.67	24.18 (lowest)
2.4	16	24.34 (increasing)
0	0	296
0.4	2.67	111.988

For 25 % crack depth

Plate length (ft)	% of plate length w.r.t. span length.	Crack tip stress (k/ft^2)
0	0	255.879
0.5	3.33	74.859
1	6.67	29.4
1.5	10	11.957
2	13.33	7.125
2.5	16.67	6.847 (lowest)
3	20	7.98 (increasing)

For 30 % crack depth

Plate length (ft)	% of plate length w.r.t. span length.	Crack tip stress (k/ft^2)
0	0	244.067
0.6	4	48.893
1.2	8	7.477
1.8	12	-5.96
2.172	14.84	-8.016
2.544	17.6	-8.35 (lowest)
2.916	19.99	-7.82 (increasing)

It obvious that the flexural stress obtained at the crack tip for different lengths of the plate bonding are not constant. This stress gradually reduces with the increasing of plate length. From table it's seen that when plate length increased beyond optimum sizes then the stress start to increase because of change of stress distribution. When the plate is bonded with the beam the stress is transferred from its end & the stress at the crack tip is reduced. But as the plate length is increasing gradually & going beyond the optimum limit then the stress is transferring from its end which is far from crack, giving release at the centre. So the stress at the crack tip is increasing again [7].

The tabular value of percentage of plate length and percentage of crack-depth are represented by following figure which gives relation between this two variable.

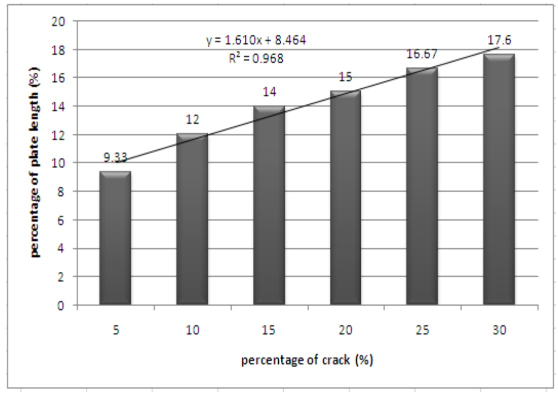

Figure 4.2i: Correlation between crack depth and CFRP plate length

The correlation equation obtain here is y = 1.610x + 8.464 where x represent % of crack depth w.r.to beam depth and y represent % of bonded plate length w.r.to beam length.

Conclusion:

Retrofitting of damaged building beam is introduced in the present study. After considering several cases, it is concluded:

1) Plate bonding technique can be effectively used for flexural crack as it reduces the stress at the crack tip to a value less than the stress at that position before cracking.
2) Retrofitting work increase the stress at the location other than the crack location as the stress transferred from bonding to the concrete. However this stress doesn't exceed the design stress of the concrete.
3) There is a specific (optimum) percentage of plate length (w.r.t span length) for specific percentage of crack depth (w.r.t beam depth) for which there is minimum crack teeth stress.
4) A correlation equation between the percentage of optimum plate length & the percentage of crack depth was developed for obtaining approximated plate length for the certain percentage of crack. As the value of R^2 (R^2 is a measure of accuracy of graph) of the graph is 0.968 so the developed equation can be used for the determination of optimum plate length.

Recommendations for future investigations:

The study presented in this investigation has carried out only for beams components that can be carried out for other parts of the structural components like column, beam-column joint. Also the beam is subjected to different failures but here only considered the flexural crack. So the torsional failure, shear failure may also be studied.

Following is a list of recommendations that may be carried out for further advancement of research.

1) For flexural crack the plate has bonded only at the bottom of the beam that can be also bonded at the side of the beam.
2) Here the plate is bonded with the concrete a new analysis can be made by bolting the plate with the concrete.
3) The general equation that has developed for the flexural crack that can be developed for the shear crack also.

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