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ANALYSIS OF BEAMS STRENGTHENED WITH FRP MATERIAL

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ABSTRACT

There are a many situations where it becomes necessary to increase the load carrying capacity of a structure. In the past, the increase in strength has been provided by casting additional reinforced concrete or dowelling in additional reinforcement. Actually there is a growing use of externally bonded fibre composites (FRPs) to strengthen a wide range of structural elements.

Many experimental work show that FRP composites, used in the beams as external tensile reinforcement, increase the strength and the stiffness of the structure.

This paper presents the flexural strength enhancement provided by FRP laminate. The analysis is performed using finite element method. Two dimensional plane stress element with layered cross section are used for the discretisation of concrete. The modifications of neutral axis position and the materials properties during the loading process are taken into account. The predicted results show an increase of the carying capacity of the streingthened beams. They are in good correlation with those of literature review.

KEYWORDS: strengthened beam, FRP laminate, numerical analysis, flexural capacity.

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INTRODUCTION

There are a number of situations where it may become necessary to increase the load carrying capacity of a structural elements. In the past, the increase in strength has been provided by casting additional reinforced concrete or dowelling in additional reinforcement. Actually, Fiber-reinforced polymer (FRP) has become attractive material to do it. This material, originally developed for use in the automotive and aerospace sectors, have been considered for use as external reinforcement for concrete structures since the last twenty years. It has many advantages over steel plates in this applications.

The method used to strengthen reinforced concrete beams is to attach FRP material to the bottom surface of these beams.

A number of authors have recommended the use of a bonded strip to prevent a catastrophic brittle failure of a beam [1, 2, 3].

NUMERICAL MODELING

A multi-layered approach is used for determining the deflecions of strengthened reinforced concrete beams. A cross section is subdivided into a different geometrical and mechanical properties of layers in direction perpendicular to the axis of symmetry. The geometry of each layer is defined by its length, width and the distance between its mid-height and the neutral axis figure 1. In each cross section the stiffness matrix is obtained by summation of concrete, steel and FRP layer matrices, taking into account the models of different materials. It is assumed that the layer becomes plastic when the stress in the middle of the layer reaches the yield value [4].

The following additional assumptions are required:

1. FRP is assumed as perfectly linear-elastic material. It acts as a tensile component and does not bend.The failure of the beam section can be due to FRP rupture or to concrete crushing
2. Plane sections remain plane during bending.
3. Perfect bond exists between concrete and steel reinforcement and between FRP reinforcement and concrete;
4. Concrete compressive stress-strain curve is described in EC2 [5]. The concrete in tension behaves linearly up until rupture, and then carries no load so the cracking concrete layer is eleminated as soon as the calculated stress reaches its tensil strength.
5. Steel is treated as elastic-perfectly plastic, with strain hardening neglected,

SOLUTION PROCEDURE

During the loading rc beam changes from symmetric to asymmetric structure. The position of neutral axis is changed and redistribution of stresses along the beam height occurs. The neutral axis is determined by

$$Y = \frac{\sum b_i E_i y_i}{\sum b_i h_i E_i} \tag{1}$$

with

y_i : ordinate of ith layer , b_i : width of the of ith layer
E_i : elastic modulus of ith layer , hi : thickness of ith layer

The Bernoulli- Navier's hypothesis that a plane cross section remain plan and orthogonal gives the linearity of the strain distribution so,

$$\varepsilon_i = \varepsilon_1 - \phi y_i \tag{2}$$

where
ε_i: strain at ith layer, ε_1: maximum compression strain of concrete
ϕ: curvature , y_i : coordinate of ith of layer

the strains in the FRP layer and tensil steel are given respectively as:

$$\varepsilon_{frp} = \varepsilon_{cu} \frac{h-Y}{Y} \tag{3}$$

and

$$\varepsilon_s = \varepsilon_{cu} \frac{h-Y}{Y} \tag{4}$$

If the calculated strain in the FRP layer reaches its maximum value ε_{frpu} then it will be assumed that $\varepsilon_{frp} = \varepsilon_{frpu}$. Hence, the Young' s modulus are updated using material models and the neutral axis is determined according to relation (1), so the strain at the extrem compression fibre is checked to verify if it is less than the maximum value [6]

$$\varepsilon_c = \varepsilon_{frpu} \frac{Y}{h-Y} < \varepsilon_{cu} \tag{5}$$

By using the material models, the internal bending moment is then calculated as

$$M = \sum_{i=1}^{nc} A_{ci} \sigma_{ci} + \sum_{j=1}^{ns} A_{sj} \sigma_{sj} + A_{frp} \sigma_{frp} \tag{6}$$

where
nc : number of concrete layers , ns : number of steel layer
A_i : area i th layer

And the load is incremented when the internal bending moment is equal to to the external bending moment within a certain tolerance. This processus is repeated until the failure maximum iteration number is exceeded.

DISCUSSION OF RESULTS

A four-point loaded beam tested by Felikss et al. [2] is examined in the present model. Concrete compressive strength was *33 MPa*, and its modulus of elasticity is 25 GPa. The material properties of FRP are, tensile Strength of *3000 MPa*, modulus of elasticity of *400 GPa*. The yielding stress of steel is 340 MPa and its modulus of elasticity is 2.10^5 MPa. Three thickness values (t_i) of the FRP material are tested. They are equal respectively to 0 mm, 0.17 mm and 0.34 mm.

Figures 2 and 3 illustrate the obtained results. As shown in Figure 2, the predicted results of moment deflection response are in a good agreement with those predicted by Felikss et al.[2] however certain discrepancies are observed. Figure 3 confirms the contribution of the FRP thickness (volume) on the enhancement of flexural capacity of beams. The load carrying capacity increases with the volume ratio of FRP material.

CONCLUSION

A model of strengthened beam with FRP material is proposed. Modelisation is based on the layer model. Materials proporties are updated at each iteration. The primary results have shown an acceptable agreement with those of litterature review. They confirmed the contribution of FRP material in the improvement of load carrying capacity. However this model should be refined to take into account more parameters.

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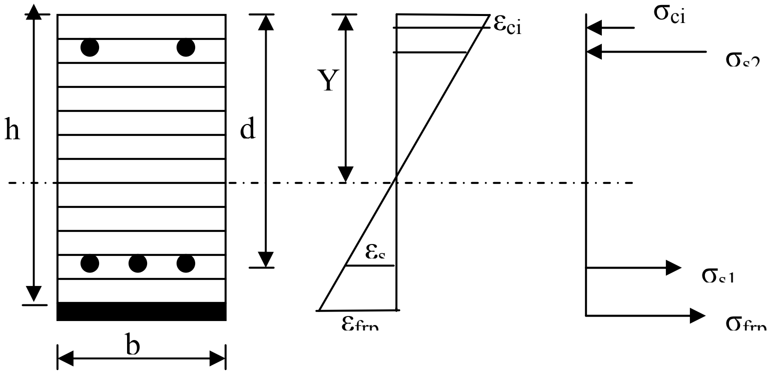

Fig. 1. assumed layered model linear strain and stress distribution

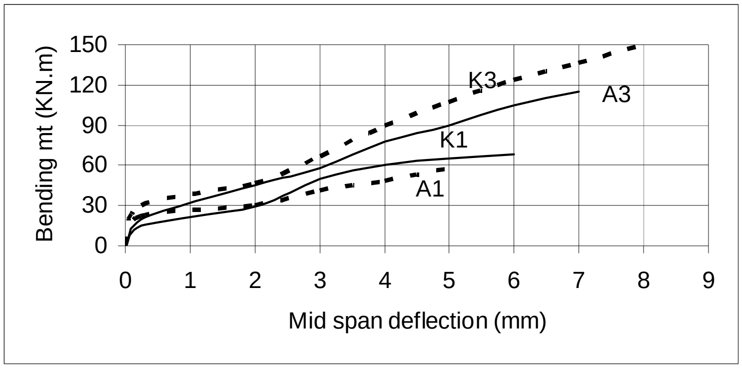

Figure 2. Bending moment vs mid-span deflections
Comparison of present model with Felikss et al. model
K i : Felikss et al. model , A i : Present model
Indice i corresponds to FRP thickness t_i

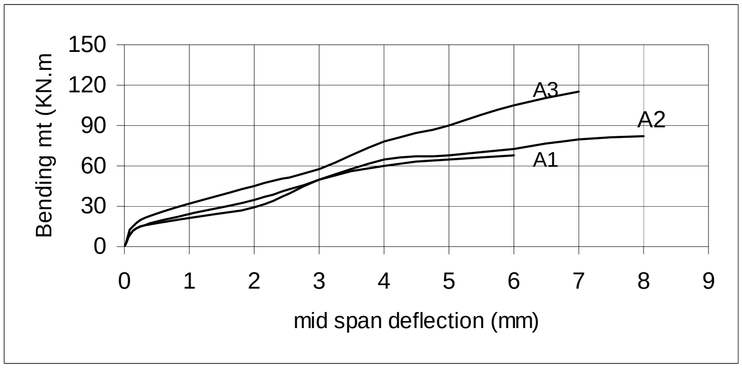

Figure 3. Effect of the FRP volume on the moment – deflection response
Ai corresponds to FRP thikness t_i