Flexural reinforcement of concrete beams using FRP plates

Flexural Reinforcement of Concrete Beams using FRP Plates

Antonio LA TEGOLA
Full Professor
Faculty of Engineering
Lecce, Italy

Orazio MANNI
Ph.D. Student
Faculty of Engineering
Lecce, Italy

Giovanni NOVIELLO
Ph.D. Student
Faculty of Engineering
Lecce, Italy

Summary

With reference to the restore and strengthening of reinforced concrete structures, the *Wrapping* technique using FRP materials, appears rather effective, for results which can be obtained and the easiness of applications in situ.
Experimental tests carried out on beams reinforced with FRP plates, have shown particular failure mechanisms which are different from usual ones characterising reinforced concrete structures. For this reason, the dimensioning and disposition of FRP plates need of a particular attention.
The purpose of this paper is to define a theoretical model for the prediction of the real flexural behaviour up to failure of concrete beams reinforced using FRP plates.

Keywords: Reinforcement, Concrete, Flexural Behaviour, FRP Plates.

1. Analysis of a reinforced concrete beam strengthened with resin-bonded FRP plate

Since 1960, the strengthening of reinforced concrete beams using steel plates and epoxy resin has represented an efficient methodology for structural reinforcement. In fact, this procedure presents many advantages, i.e. low cost, easy installation and very small variation of the element dimensions.
On the other hand, the production of composite plates (Fibre Reinforced Polymer) having very high tensile strength, high fatigue and corrosion resistance, small weight has encouraged the substitution of steel plates with the FRP ones.
The strengthening of reinforced concrete beams with FRP plates have been described by many researchers that have initially tried to quantify the increasing of the capacity and stiffness obtained with external bonded FRP sheet, putting in evidence the dependence of this system from FRP strength and elastic modulus and resin properties.
Moreover, a large number of experimental tests have shown that the failure of beams strengthened by epoxy bonded FRP plates is strongly related to the properties of concrete-resin-plate interface; in fact, besides the failure for crushing of concrete or tensile rupture of plate, the tested beams collapsed because of debonding of plate at the interface (peeling) and failure of concrete layer between the plate and longitudinal steel rebars (concrete cover). By the light of these experimental results, an interesting problem of research with reference to the concrete beams externally reinforced with FRP plates, has been and is still the theoretical prediction of the flexural behaviour and modes of failures of the strengthened element, in order to correctly define its capacity and stiffness.
In this paper, with reference to a beam element having infinitesimal length, a function which correlates the interface shear stress to the stress characteristics (shear and bending moment)acting in a cross-section is obtained.
This function is also used in order to determine the moment-curvature diagram, taking into account the slip at the concrete-glue-plate interface.
The proposed model is developed adopting the following assumptions:

- concrete constitutive law is defined by C.E.B. parabola-rectangle;
- the steel constituve law is defined by a bilinear curve taking into account the effect of strain-hardening;
- the plate constituve law is linearly elastic up to failure;
- the interface glue has an elastic-perfectly plastic constitutive law;
- the concrete cross-section remains plane after deformation.

2. A numerical application of the model

Considering a simple supported plated beam subjected to two concentrated loads, symmetrical about mid span, the proposed model allows to obtain the moment-curvature diagram of the cross-section (fig. 2.a) and the diagram of the interface shear stress versus the shear force (fig. 2.b).

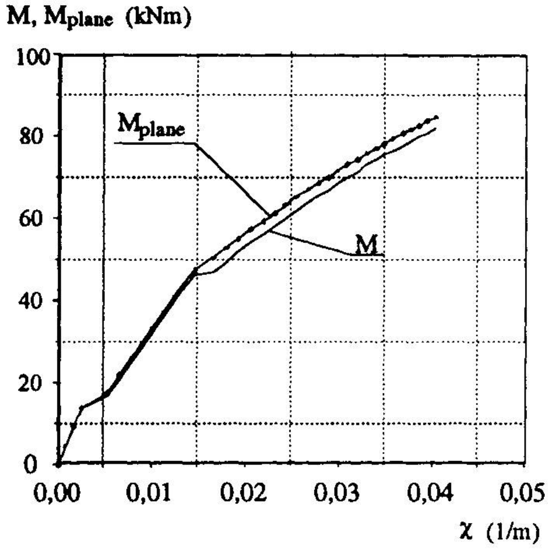

Fig. 2.a: $M-\chi$ Diagram

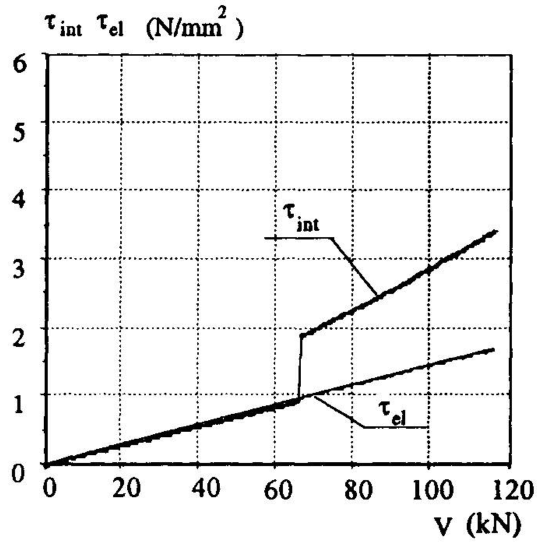

Fig. 2.b: $\tau - V$ Diagram

It can be observed that the assumption of plane behaviour for the strained cross-section does not allow important differences with reference to the prediction of the ultimate bending moment ($M^u_{plane} = 1.034M^u$); the same consideration is not valid for the evaluation of the interface shear stress, necessary in order to predict failures for peeling or debonding of concrete layer between the plate and longitudinal rebars.
In fig 2.3.1.b the diagram of the interface shear stress calculated by using equation (2.2.5) and the diagram of the one calculated considering a linearly elastic behaviour of the materials are indicated. As it can be noted, the two diagrams are almost coincident up to the shear force reaches the value correspondent to the yield of steel rebars. At this value, the shear stress τ_{int} non linearly calculated has a discontinuity and becomes much higher than the one calculated in elastic hypothesis.
In the case of beams strengthened with steel plates (the steel used for the plates is generally the same one used for the longitudinal rebars), the reinforcing plate, normally, reaches the yield before the steel rebars, being its strain greater, and the interface shear stress correspondent to the ultimate shear force of the beam can be calculated in elastic hypothesis with a good approximation.
This is not valid for the FRP plated beams (in fact the FRP plates have a linearly elastic behaviour up to failure). In this case the yield of the steel rebars occurs, in many cases, before the collapse of the beam; for this reason, the interface shear stress has a significant discontinuity which cannot considered adopting an elastic formulation.
The possibility to evaluate the interface shear stress varying the applied load, allows a numerical comparison with the admissible value of the interface shear stress τ_{adm} correspondent to the failure for end peeling or longitudinal debonding of cover concrete.
Actually, some empirical and/or theoretical formulations which permit to calibrate the value of the admissible shear stress τ_{adm} are proposed.
On the other hand, the different numerical values proposed (the admissible shear stress depends strongly from a large number of geometrical and mechanical parameters) and the significant shear stress concentration at the end of the beam make necessary a research on these problems, in order to adequately predict the numerical value of the ultimate load when the collapse of the FRP plated beam appears in the above-mentioned premature modes.