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PREMATURE DEBONDING FAILURES OF PLATE BONDED REINFORCED CONCRETE BEAMS: A LIMIT ANALYSIS APPROACH

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ABSTRACT

Rehabilitation and strengthening of existing reinforced concrete (RC) structures by externally bonded fiber-reinforced polymer (FRP) sheets have become, in recent years, a commonly used technique, allowing simple repair or reinforcement of structural elements, damaged or otherwise structurally inadequate for a variety of reasons.

The efficiency of this technique can be measured if composite action (i.e., the transfer of stresses from concrete to the external sheets) is maintained at all stages of loading, up to failure. In the case of RC beams externally reinforced for flexure, even if the bonding technique is conceptually simple, its reliability depends largely on the integrity of the bonding action to the concrete substrate. The topicality of this subject and lack of specific data have meant that many investigations have been carried out in recent years to evaluate its performance and assess the degree of safety and structural integrity of such reinforcement technique [1].

A critical review of available literature shows that much research on strengthening of RC beams by externally bonded FRP laminates has been devoted to study the various failure modes, and to develop analytical and numerical models for predicting their structural response up to ultimate failure. In particular, special attention has been devoted to the debonding and anchorage failure modes, which occur in the majority of tests of beams strengthened for flexure. These types of failures are dominated by the interfacial bonding conditions along the plate-concrete and concrete-tensile steel interfaces, and take place at load levels significantly lower than the flexural or shear strength of the strengthened member.

Many finite element analyses have been carried out on plated RC beams to predict the structural behaviour, and particularly, the premature plate debonding. However, because the plate debonding phenomenon is very complex, and the factors involved are numerous and interdependent, proper modelling of a composite structure such as a plated RC beam requires significant effort even within the regime of linear elastic analysis. Thus, in practice, the finite element approach is restricted to research and analysis of simple tests.

The limitations and deficiencies inherent in the numerical models have led to the development of simplified global models describing the ultimate behaviour of strengthened RC members. In this context the use of the strut-and-tie model, as already employed for conventional RC structures, has been shown to be particularly effective both for identifying the collapse mechanism governing the problem and for determining the value of the load-carrying capacity at ultimate. However, the behavior of conventional RC members is generally not controlled by bond forces along the internal

reinforcement, while for strengthened RC beams the potential debonding of the plate plays a dominant role on the failure behavior. Thus, current truss models [2], which ignore any load transfer by bond, do not provide a consistent model for the design of repaired beams with respect to shear failure due to plate separation.

The overall aim of this study is to develop a structural model based on truss analogy and the theory of plasticity that will logically reflect the failure processes of plated RC beams, including those influenced by bond slip. From a kinematic point of view, the mechanism associated with this failure mode is characterized by a slipping of the plate located in the shear span zone, together with a diagonal crack along an assumed compression trajectory. It is obvious that the bond failure is a result of various acting components and not simply a localized failure due to slippage. Hence, the bond stress resultant along the bonded plate reaches the ultimate bond strength and the stirrups crossing the assumed compression trajectory reach their yield strength. A key step in the formulation of the model consists on the identification of an adequate value of bond strength, reflecting the average behavior of the concrete/plate/adhesive interface. However, the mechanical interface properties are more difficult to characterize and analyze than the mechanical properties of the constituent materials (steel or FRP, concrete, glue), as they depend on many factors (combination, geometry, characteristics and mechanical properties of materials, surface treatment, etc.). Various authors have analysed the interaction between the concrete surface and the bonded plate in terms of bond-slip relations, or have developed simplified analytical models to predict bond strength. For practical design purposes, the yield condition for the plate/concrete interface has been assumed here as a constant bond strength model and the following relation is proposed for the evaluation of the bond strength, derived on the basis of experimental results [3]:

$$U_y = b[2.77 + 0.06(f_c - 20)] \quad \text{for } f_c > 20 \text{ MPa} \tag{1}$$

where U_y=bond strength; b=effective width of the plate-adhesive interface; f_c=cylinder compressive strength of concrete.

Assuming perfectly plastic behaviour of the materials, the following lower-bound solution is obtained for the plate-debonding failure load:

$$V = p_y d\left[\phi + \alpha - \sqrt{(\phi + \alpha)^2 - 2\phi\beta}\right] \tag{2}$$

where V=shear capacity; α=a/d denotes the ratio of shear span-to-beam depth; $\beta=l_a/d$ the ratio of plate length to beam depth; $\phi=U_y/p_y$ denotes the ratio of bond strength to stirrup tensile strength.

To check the reliability of the model in predicting the ultimate strength of strengthened RC beams, a numerical investigation was carried out by assuming as test beams a series of beam specimens tested by different authors. The prediction of the shear capacity with the proposed model has proven to be sufficiently accurate for the test results considered in the study.

In conclusion, seems that the proposed model provides a simple but efficient design methodology and can be considered as a valid tool in the preliminary design of strengthened reinforced concrete beams, for which a rigorous finite element approach may be too expensive, and, on the contrary, a purely empirical formulation may be too approximate and unreliable.

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