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MODEL TO SIMULATE THE BEHAVIOR OF CEMENT BASED LAMINAR STRUTURES FAILING IN BENDING AND IN SHEAR

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Smeared Crack Model; Punching; Out-of-plane Shear Softening Diagram; Material Nonlinear Analysis.

ABSTRACT

A multi directional fixed smeared crack model based on the finite element method is described and their capabilities to simulate failure modes in fiber reinforced concrete laminar structures are assessed. Softening stress-strain diagrams are proposed to reproduce, after crack initiation, the evolution of the normal and shear components. To capture the punching failure mode, a softening diagram is proposed to simulate the out-of-plane shear components, after crack initiation. To assess the performance of the model, a punching test of a module of a façade panel fabricated with steel fiber reinforced self-compacting concrete (SFRSCC) was performed and compared with the results of the numerical simulations. The proposed model was implemented by the authors in a finite element computer code.

INTRODUCTION

The Reissner Mindlin theory (Mindlin 1951; Reissner 1945) for shell structures is commonly used for predicting the behavior of laminar concrete structures up to failure (Barros and Figueiras 2001). The thickness of the laminar structure is discretized by layers and these layers are assumed to be in a plane stress state. The use of laws to simulate the nonlinear behavior, after crack initiation, for the in-plane fracture modes is appropriate in most cases and the deformational response of the structure for load configurations inducing flexural failure modes can be predicted with sufficient accuracy. However, the simulation of laminar structures failing in punching is a much more complex task, being the treatment of the out-of-plane shear components of paramount importance. In the present work, in order to explore the use of a simple approach to simulate the material nonlinear behavior of concrete laminar structures failing in punching, a softening law was introduced to model both out-of-plane shear components.

PROPOSED MODEL

The implementation of the crack constitutive model is based on the Reissner-Mindlin theory, adapted to the case of layered shells. The description of the formulation is restricted to the case of cracked concrete, for a selected concrete layer, and at the domain of an integration point of a finite element. According to the adopted constitutive law, stress and strain are related by the following equation

$$\begin{bmatrix} \Delta\underline{\sigma}_{mf} \\ \underline{\sigma}_{s} \end{bmatrix} = \begin{bmatrix} \underline{D}_{mf}^{crco} & \underline{0} \\ \underline{0} & \underline{D}_{s}^{crco} \end{bmatrix} \begin{bmatrix} \Delta\underline{\varepsilon}_{mf} \\ \underline{\varepsilon}_{s} \end{bmatrix} \tag{1}$$

In Eq. (1) the in-plane cracked concrete constitutive matrix, $\underline{D}_{mf}^{crco}$ is obtained with the following equation

$$\underline{D}_{mf}^{crco} = \underline{D}_{mf,e}^{co} - \underline{D}_{mf,e}^{co}\left[\underline{T}^{cr}\right]^{T}\left(\underline{D}^{cr} + \underline{T}^{cr}\,\underline{D}_{mf,e}^{co}\left[\underline{T}^{cr}\right]^{T}\right)^{-1}\underline{T}^{cr}\,\underline{D}_{mf,e}^{co} \tag{2}$$

and the matrix, $\underline{D}_{s}^{crco}$ is defined by

$$\underline{D}_{s}^{crco} = \begin{bmatrix} D_{III,\sec}^{23} & 0 \\ 0 & D_{III,\sec}^{31} \end{bmatrix} \tag{3}$$

The in-plane behavior can be found elsewhere (Sena-Cruz 2004; Ventura-Gouveia et al. 2007)
The out-of-plane shear behavior is assumed to be linear elastic until the tensile strength is reached. After then, the out-of-plane shear stresses are stored and the relation between each out-of-plane shear stress-strain follow an independently softening behavior as shown in Fig. 1. A secant approach is used to obtain each out-of-plane shear moduli.

NUMERICAL SIMULATION

The punching test of a module of the developed SFRSCC lightweight panel is used to assess the performance of the proposed model. More details about the corresponding experimental program can be found elsewhere (Barros et al. 2007).
The results of the numerical simulations are compared with the experimental data obtained in the punching test of the panel module.
The influence of mesh refinement and some model parameters in the results of the numerical simulations were carried out. One of these simulations is here presented.
The finite element idealization, load and support conditions used in the numerical simulations of the punching test are shown in Fig. 2.

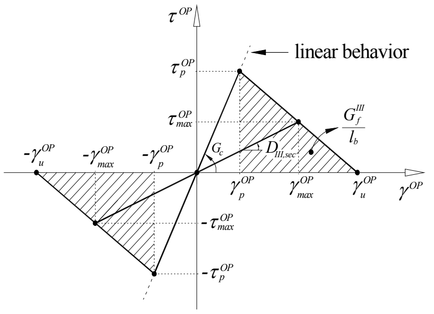

Fig. 1 - Generic out-of-plane (OP) shear stress-strain diagram.

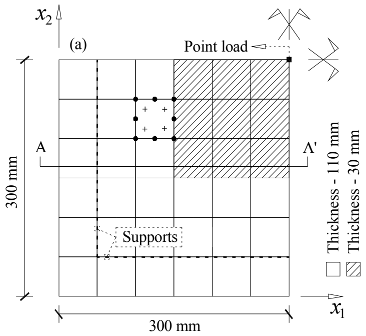

Fig. 2 - Geometry, mesh, load and support conditions used in numerical simulation of the punching test - coarse mesh.

In Fig. 3 the responses obtained with the numerical model are compared with the experimental results. Up to a 10 kN load all the curves depicted in Fig. 3 are practically coincident. Afterwards, the straight line that represents the response assuming a linear elastic behavior no longer follows the curves that correspond to the experimental test. The other numerical analysis takes into account the material nonlinear behaviour of SFRSCC. A good agreement can be observed up to a deflection of 2.5 mm. For larger deflections, an over estimation of the load carrying capacity of the prototype panel occurs when a linear elastic behavior is assumed for the out-of-plane shear components. At a deflection of about 3 mm the experimental curve suddenly falls, indicating the failure of the panel by punching, as visually confirmed in the experimental testing. This load decay that is not simulated when assuming a linear elastic behavior for the out-of-plane shear components is, however, well captured when the bilinear function represented in Fig. 1 is used.

CONCLUSIONS

In this paper, a model to simulate the behavior of cement based laminar structures failing in bending and in shear is presented. A softening diagram was proposed to model, after crack initiation, both out-of-plane shear strain constitutive laws. It was verified that the model is capable of simulating the behavior of cement based laminar structures failing in bending and in shear.

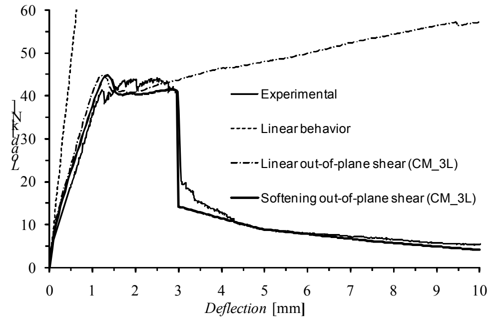

Fig. 3 - Relationship between load and deflection at the center of the test panel.

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