11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

HOMOGENIZED GLOBAL NONLINEAR CONSTITUTIVE MODEL FOR RC PANELS UNDER CYCLIC LOADINGS

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Key Words: *Nonlinear analysis, Seismic design, Cracking, Global model, RC panels*

Industrial buildings, in particular Nuclear Power Plants (NPP), are subjected to severe seismic requirements. These facilities, generally built in Reinforced Concrete (RC), have large dimensions and therefore computational time costly dynamic analyses are necessary. The use of global modeling approaches (relative big size finite elements) however can assure rational computational costs, numerical efficiency and robustness. This type of modeling strategy is often used in civil engineering design offices adopting linear elastic constitutive laws. Recent requirements for NPP introduced however the use of more realistic RC non-linear models.

In this sense, two global nonlinear constitutive models (linking RC stress resultant $\boldsymbol{\sigma}^o$ with the generalized strains $\boldsymbol{\varepsilon}^o$) for RC shells have been recently introduced in the finite element software *Code_Aster*, commonly used for the static and dynamic (including seismic) analysis of industrial buildings in France and, specially, for NPP. Initially, an approach based on a global damage variable describing the mechanical non-linearities was developed (GLRC_DM model [1]). Nevertheless, it was soon observed that this approach underestimates energy dissipation. The performance was significantly improved taking into account the debonding between steel and concrete, through a homogenization procedure (DHRC model [2]).

The previous global modeling approaches, however, do not take explicitly into account phenomena of great importance for industrial facilities (especially for durability and confinement issues in NPP) such as crack apparition and evolution. The crack parameters (orientation, spacing and width) are thus often computed adopting suitable post-processing procedures. The limitations of these procedures have been highlighted in [3].

In this work, a novel global constitutive model for RC panels is presented. It takes into account three sources of non-linearities: (i) concrete damage or micro-cracking, which causes a reduction of concrete stiffness through a damage variable $E_c(d)$, (ii) concrete macro-cracking with non-zero stresses at cracks $\underline{g}$ (with a normal g_n and a tangential g_t component respect to cracks) and (iii) bond stresses $\underline{\tau}_d$ caused by the relative displacement between concrete and steel bars (with τ_x^o and τ_y^o the average bond stress value for the x and y rebars).

An analytical stress homogenization procedure is performed on a RC tie limited by two consecutive cracks (see Fig 1), which is considered as the Representative Volume Element of the RC cracked panel. The geometry of the RVE depends on the crack orientation θ_r and spacing s_r (these values are considered as constant after the cracking onset in the panel). Crack displacement discontinuity $\underline{w}$ (with crack width w_n and tangential slip w_t components) is also taken into account in the RVE boundary. All the previous values are considered as averages in the RVE since a RC finite element in a global model may contain cracks having different widths or directions. A general form for the functions describing concrete stresses at cracks, bond-slip stresses (both used to take into account debonding) and the diminution of concrete stiffness due to damage is introduced.

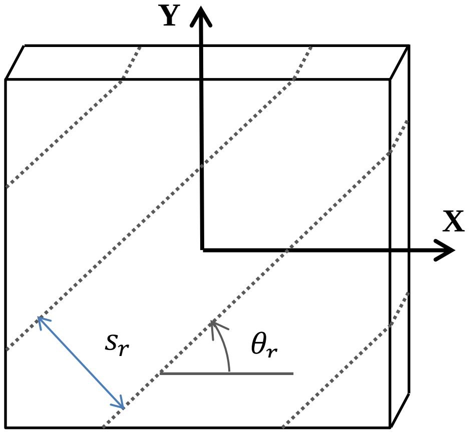

Fig. 1. Geometry of the cracked panel

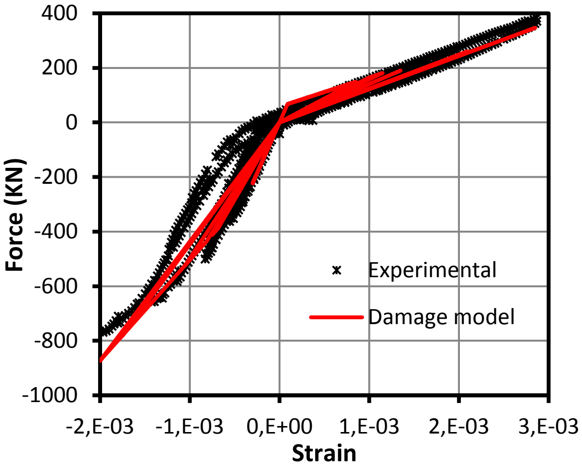

Fig. 2. Cyclic response for a one-dimensional RC member using a damage model

However, the analytical solution providing the dependence of the global stresses on the internal variables is known only for some particular cases. Hereafter we present the obtained constitutive law for the particular case of a one-dimensional RC element:

$$\sigma_{xx}^{o} = h \cdot \left(\rho_{sx} E_{sx} \varepsilon_{xx}^{o} + \rho_c g_n - \frac{2\tau_x^0 \rho_{sx} s_r}{\phi_x} \right) \tag{1}$$

with $\rho_{sx}, E_{sx}, \phi_x, \rho_c, h$ the steel reinforcement ratio, Young modulus and diameter, the concrete ratio and the panel width, respectively. The crack opening is calculated with:

$$w_n = s_r \cdot \left(\varepsilon_{xx}^{o} - \frac{g_n}{E_c} + \frac{2\rho_{sx} s_r \tau_x^{o}}{\rho_c \phi_x E_c} \right) \tag{2}$$

The simplest application of the previous model is the case where no crack opening is allowed and all the nonlinear effects are modeled by the concrete damage, see Fig. 2. Other more complex applications with crack opening models are also done.

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