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RATE DEPENDENT EFFECTS IN THE SIMULATION OF PROGRESSIVE COLLAPSE OF RC STRUCTURES

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ABSTRACT

Progressive Collapse (PC) is a situation where an initial local failure leads to a widespread damage in the structure to a disproportionate extent. This work deals with the modelling of reinforced concrete structures in the framework of PC simulations. The final objective is the development of a numerical tool for the PC calculation, so that prescriptive rules for the design of buildings against PC can be extracted. Since PC is a phenomenon which involves high strain rates in the structural members, a proper representation of the strain rate effects on the material behaviour is needed. A first estimate of the magnitude of the strain rates that can be observed in a building during PC has been obtained by means of a dynamic calculation, using an elastic constitutive law and the HHT-α solution scheme. Strain rates up to 0.2 s^{-1} have been obtained in this calculation, where the loss of one central column has been simulated dynamically. According to the CEB, these strain rates lead to a strength enhancement in concrete at the material level equal to 50% in tension and 35% in compression [1,2].

A multi-fibre beam element accounting for strain rate effects is used in this paper, where the longitudinal steel reinforcements are included. Perzyna's viscoplastic model [3,4] is adopted for the introduction of strain rate effects in the plastic domain for both concrete and steel fibres, leading to an increase in the ultimate stress. In the case of the concrete fibres, an exponential yield stress evolution is applied in order to model the negative slope in the stress-strain curve, representing the softening due to concrete cracking. In the elastic domain, the rate dependence is introduced via a strain rate dependent Young's modulus proposed by the CEB [1,5]. Additionally, since concrete presents different strength in tension and compression, a multi-surface plastic criterion is used in order to establish different values for the tensile and the compressive yield limits. As for the fibres corresponding to the steel reinforcements, the evolution of the yield stress has been modelled using a hardening power-law. The parameters of the constitutive laws for concrete and steel have been chosen in such a way that the dynamic increase factors (DIF) -i.e. the ratio of dynamic to static strength- obtained with the proposed constitutive models are in good agreement with the CEB recommendations [1,2,5]. Figure 1 depicts

the DIF for the compressive strength of concrete versus the strain rate.

The introduction of these constitutive laws for concrete and steel (1D stress-strain relations) in a multi-fibre beam model [6] provides strain rate dependent relations between the generalized stresses (N,M) and generalized strains ($\bar{\varepsilon}$,χ), to be applied at each integration point in a FEM calculation. First, the axial strains in each fibre are evaluated with the information from the macroscopic level ($\bar{\varepsilon}$ and χ from the FEM calculation). Then the microscopic stresses (i.e. the axial stresses in each fibre) are obtained by applying the 1D constitutive laws. Finally the macroscopic stresses (N,M) are evaluated by integrating the microscopic stresses through the cross-sectional area of the beam. Rate dependent M-χ relations obtained for a RC section are shown in Figure 2. From a computational point of view, this multi-level approach is very time consuming. Hence, the development of closed-form rate dependent relations for N-$\bar{\varepsilon}$ and M-χ appears to be of great interest. In the ongoing research work, closed-form M-χ relations as a function of $\dot{\chi}$ and $\bar{\varepsilon}$ are developed and compared with rate independent results. These relations are then used in structural computations, in order to compare the structural behaviour under PC using rate independent material laws with the one obtained with physically motivated rate dependent ones.

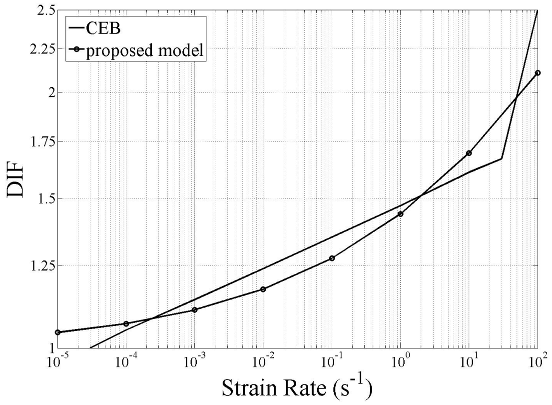

Figure 1: Rate effect on concrete compressive strength

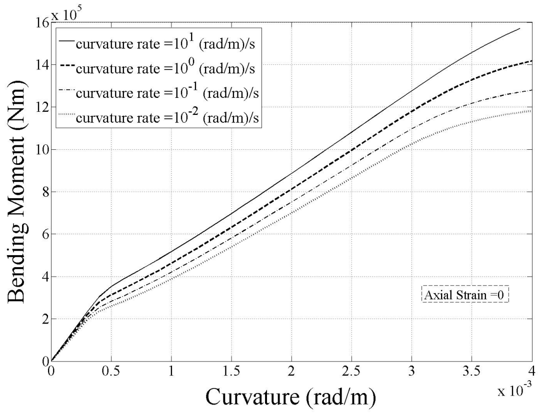

Figure 2: Rate dependent M-χ relations

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