ROLE OF SELECTED PARAMETERS OF MATERIAL MODEL FOR CONCRETE IN ATENA PROGRAM

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Abstract

The article studies the effect of variations in selected parameters featured in various material models of concrete in Atena software. In particular, we focus on two material models, namely Microplane and 3D Nonlinear Cementitious 2 (fracture plastic) model. The numerical simulations at elemental and structural levels (dog-bone specimens) were performed with varied parameters related to tensile strength (K1 vs. tensile strength f_t) and influencing characteristic length (crack band c_b vs. fracture energy G_F).

Abstrakt

Článek se zabývá vlivem vybraných parametrů materiálových modelů betonu dostupných v programu Atena. Především jsme se zaměřili na materiálový model Microplane a 3D Nonlinear Cementitious 2 (lomově plastický). Numerické simulace na modelu obsahujícího jeden konečný prvek a na modelu vzorku ve tvaru psí kosti byly provedeny s různými parametry, které ovlivňují tahovou pevnost (parametr K1 a tahová pevnost f_t) a charakteristickou délku (šířka pásu trhlin c_b a lomová energie G_F).

1 Introduction

There is a plenty of material models for concrete (cracking) available in ATENA software. The most frequently used are probably the fracture-plastic (Non-linear cementitious NL-CEMII model) and the microplane model. Both these models can be specified by a set of parameters. The role of the most important parameters for tensile failure must be correctly understood when performing stochastic analyses with randomly varying parameters. Also the inverse identification of model parameters leading to agreement between model response and real experiments can be greatly simplified if the role of parameters is known. That is why we present a simple yet usable parametric study of the role of selected parameters in the two above mentioned material models.

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2 Effect of varied G_F and c_b

We have performed simple numerical experiments with two material models - Microplane and 3D Nonlinear Cementitious 2 (NLCEM) in ATENA software [2] using which we document the effects of varied G_F and c_b on tensile response of (i) one element and (ii) dog-bone specimens.

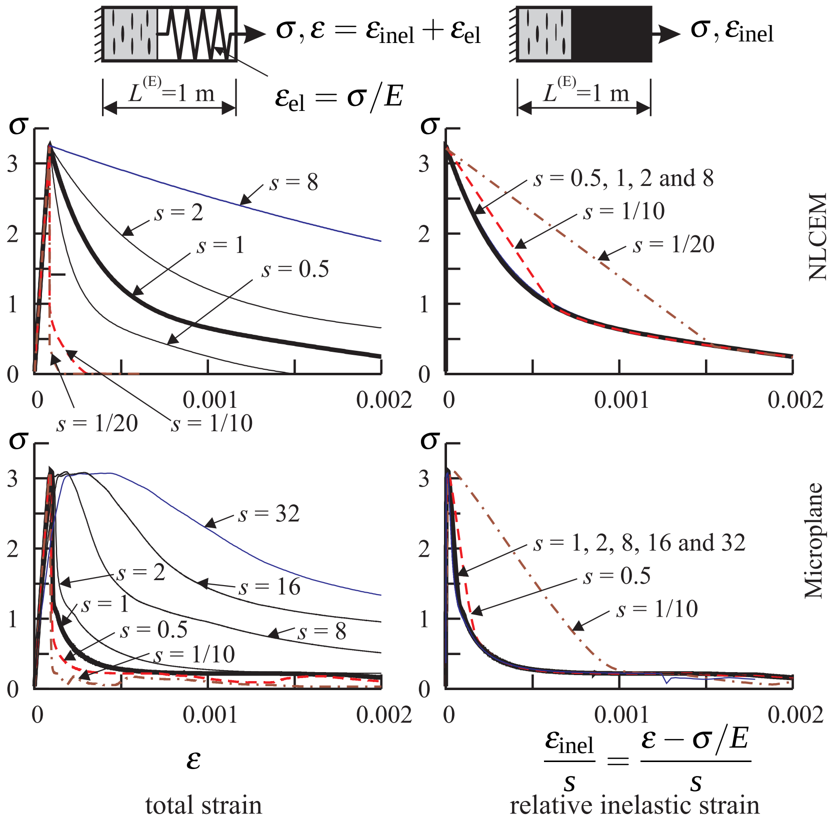

Figure 1: Effect of varying: fracture energy G_F in NLCEM model (top); and crack band width c_b in M4 model (bottom) in a single finite element under tension. Left: stress vs total strain curves; Right: stress vs scaled inelastic (fracturing) strain.

Fig. 2 presents stress-strain (force-displacement) diagrams of one square finite element of unit size loaded in uniaxial tension. The top row shows the situation with NLCEM model, in which the original fracture energy $G_F = 2000$ N/m is multiplied by several factors s ranging from 1/20 to 10 (f_t and E were kept constant at values mentioned above). The bottom row shows a similar numerical experiment in microplane model with original crack band width $c_b = 30$ mm multiplied by factors s ranging from 1/10 to 32 (again, the other parameters were kept as before). It is known [see e.g. 1] that when using the crack band technology, the finite element can be imagined to consist of an inelastic part with softening behavior and a perfectly elastic spring coupled in a series (see Fig. 2 top left). It can be seen that both the initial (spring) stiffness E and tensile strength are not affected by variations of G_F or c_b. The area below the curves is almost perfectly proportional to the scaling factor s (see the right hand side plots in Fig. 2 of stress against scaled inelastic strains, that collapse into one curve). There is one condition, though, for the scalability of fracture energy, that is thoroughly described in sec. 8.6.4 of Bažant and Planas [1]: the finite element can not be arbitrarily large compared to the characteristic length (or c_b). Or, equivalently in NLCEM model, the fracture energy of a single finite element must be greater than the elastic strain energy accumulated in the spring at the peak stress: $G_\mathrm{F}^{(\mathrm{E})} > f_\mathrm{t}^2/(2E)$. The problem is that snap-back behavior can not be captured by the nodal displacement controlled computation. Therefore, one can see that when s is small in the two material models, the finite elements dissipate more energy than they should. If no other criterion (such as those recommended in Bažant and Planas [1], sec. 8.6) can be implemented in the finite element program used, caution must be paid that the element fracture energy of the crack band is greater that the elastic energy of the spring. The finite element fracture energy in our case is simply $G_\mathrm{F}^{(\mathrm{E})} = G_\mathrm{F}/L^{(\mathrm{E})}$, where $L^{(\mathrm{E})}$ is the width of elements perpendicular to the direction of cracking. It is important to check this criterion in models processed in ATENA as the software makes no checks of it. Another consequence is the possibility to simplify analyses of structures of various sizes as the structural size can be mimicked by change of material parameters in the reference size [5].

Let us focus on the effect of varied G_F and c_b at a structural level. We study a particular structure, namely do bone specimen [5]. Since the dog bone specimens are not loaded just by uniform tension, stress redistribution can take place. It was concluded that varying fracture energy (or crack band width) is in fact equivalent to varying the proportion between structural size and characteristic length (characterizing the material heterogeneity scale). In order to document this numerically using the dog bone specimens models, we have varied the fracture energy G_F by multiplying it with parameter s ($s = 2,4,8,16,32$ and their inverses, the largest to the smallest ratio equals 1:1024) and plotted the nominal strength of specimens as a representative parameter against the structural size (which was kept constant). If we, however, shift the points towards the size D/s, the points fall exactly on the size effect curve computed with a constant G_F and varied size D, see Fig. 2. The nominal strength dependence on size in the studied case of dog-bone specimens for instance, can be fitted very well with the following formula [1]:

$$\sigma_\mathrm{N}^{\mathrm{det}}(D) = \sigma_{\mathrm{N},\infty}\left(1 + \frac{D_b}{D + l_p}\right) \tag{1}$$

where, aside from $D_b \approx 300$ mm, l_p is a second deterministic characteristic length controlling the center of transition to the left ‘plastic’ horizontal asymptote. The value of l_p can be deduced from the ratio of ‘ideal-plastic’ limiting strength and ‘elastic-brittle’ limiting strength $\eta_p = (1 + D_b/l_p) \approx 1.42$; therefore $l_p \approx 714$ mm (which happens to be quite close to the Irwin’s characteristic length $\ell_\mathrm{ch} = E\ G_\mathrm{F}/f_\mathrm{t}^2 \approx 720$ mm). Formula (1) gives the transition from perfectly plastic behavior for $D/l_p \to 0$ (corresponding to an elastic body in which the crack is filled with a perfectly plastic glue), through quasibrittle behavior, to perfectly brittle behavior for $D/D_b \to \infty$.

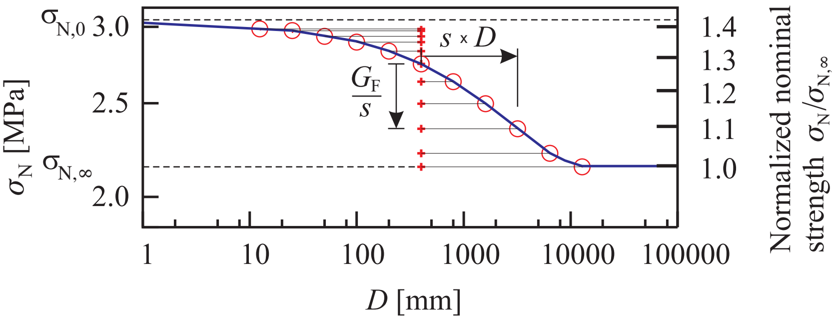

Figure 2: Strength scaling using varying fracture energy G_F (or c_b) in a logarithmic size effect plot.

It is an occasional practise to study a random model response of structures with varied (randomized) fracture energy (keeping an identical crack opening law curve shape). If the size effect relation such as the one in Eq. (1) is known, the probabilistic distribution of random strength σ_N for a given size D can be written analytically just using a random variable transformation. The situation is more complicated when randomizing the tensile strength and material toughness simultaneously.

3 Effect of varied f_t and K1

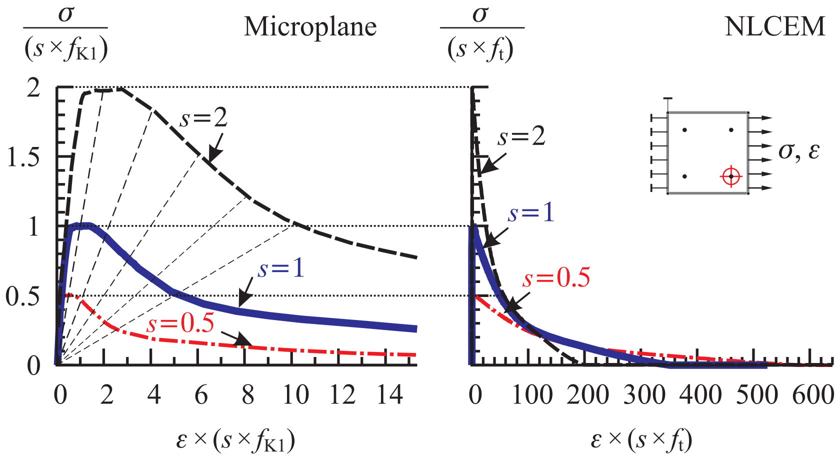

Figure 3: Effect of varying strength K1 [f_t] in microplane (left) [NLCEM (right)] models, respectively, on uniaxial tensile response of a single finite element.

Let us now study what happens if f_t is randomized only in NLCEM model of one finite element under uniaxial tension. Fig. 3 right studies such a situation, where we have multiplied the original tensile strength by $s = 1/2, 1$ and 2. Since the fracture energy is not scaled, the initial softening slope of σ–ε diagram depends on the peak stress f_t to keep the same area under the curve. We can write that if $f_t \propto s$ then $G_F = \text{const}$. Therefore, if $s > 1$ the same element becomes stronger but 'more brittle' and dissipates the original amount of energy. The initial softening slope is in perfect negative dependence on f_t, while G_F is independent of f_t. One would have to multiply G_F by s^2 to achieve it because the characteristic length $\ell_{ch} \propto s^{-2}$.

A somewhat different situation is when strength parameter K1 is varied in the microplane model. Fig. 3 left shows results when a single element has K1 multiplied by $s = 1/2, 1$ and 2. The tensile strength of one element scales linearly with s, but the whole σ–ε is scaled radially, keeping the instantaneous softening slopes equal at corresponding loading stages. In other words, if $f_t \propto s$ then $G_F \propto s^2$ and the characteristic length $\ell_{ch} = \text{const}$. This can be viewed as a perfect positive dependence between f_t and G_F.

Note that, there can be imagined another alternative in which, with $f_t \propto s$ the energy $G_F \propto s$. The softening curve would have to decrease towards an identical strain value irrespective the peak stress f_t. The characteristic length $\ell_{ch} \propto s^{-1}$. This would also imply a perfect positive dependence between f_t and G_F.

These illustrations are important when randomizing both peak stress and fracture energy simultaneously. The most frequent combination in academic studies is the simultaneous randomization of G_F and tensile strength f_t. For example, it was shown previously by Vořechovský [3], Vořechovský and Novák [4] that a strong positive correlation between these two parameters, when they are both randomly varying spatially, increases the slope of size effect curve in the transitional region between the two asymptotic limits (positive correlation, in fact, speeds up the convergence towards the classical Weibull statistical size effect).

4 Conclusions

The paper clarified the roles of selected parameters in NLCEM and Microplane material models. The obtained results might be important for modeling of concrete structures, inverse identification material parameters as well as studies with randomized material parameters.

Acknowledgements

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