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IMPACT ANALYSIS OF STEEL FIBER REINFORCED CONCRETE PANELS USING AN ORTHOTROPIC CONSTITUTIVE MODEL

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ABSTRACT

An improved orthotropic constitutive model is proposed for use with steel fiber reinforced concrete (SFRC) subjected to dynamic multiaxial loads. The orthotropic model developed for plain concrete is modified to reflect the effect of the addition of steel fibers in the concrete matrix through the multi-axial experiments for SFRC. In the proposed model, stresses can be directly determined from the stress-strain relations with the current strengths which are obtained from dynamic biaxial strength envelope considering the triaxial stress state. The proposed orthotropic model is incorporated into LS-DYNA, and is verified through correlation studies between the numerical analysis and the experimental data for RC and SFRC panels under projectile impacts. The results show that the accuracy of simulation results is improved by the proposed numerical model.

1. INTRODUCTION

Steel fiber reinforced concrete (SFRC) has improved strength, toughness and ductility than concrete. SFRC is generally used for structures subjected to blast or impact loadings. Under high strain rate condition, material properties of SFRC and reinforcing steel are changed (Park et al. 2017; Abbass et al. 2018). This study adopted an orthotropic constitutive model to describe multiaxial behavior of SFRC. The proposed model is based on the orthotropic concrete model, which determines stresses in each principal coordinate by using uniaxial stress-strain relations with equivalent dynamic strengths determined from strain rate dependent biaxial strength envelope. Effect of steel fiber addition is reflected by using fiber reinforcing index. The proposed model is verified through a comparison with experimental data for failure strength envelope. The results show that the proposed model can be effectively used to describe the effects of fiber volume fraction and strain rate in failure strength envelope of SFRC. The proposed model is implemented as user defined model in LS-DYNA, and

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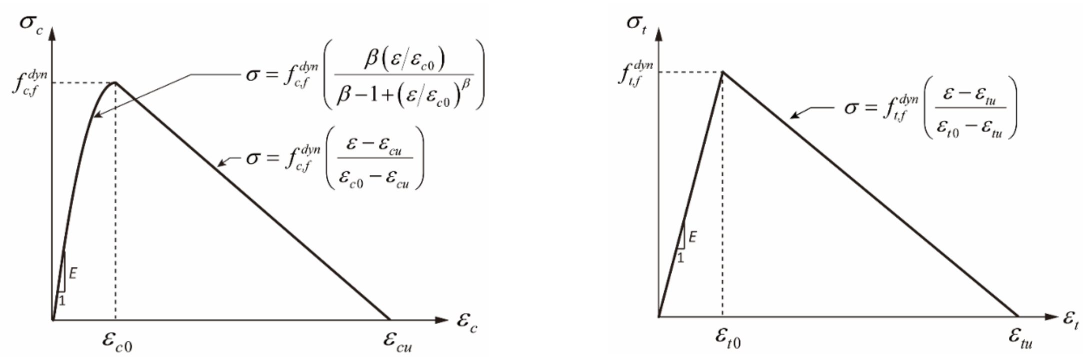
numerical analysis of SFRC slabs subjected to projectile impact are conducted. The numerical results show a good correlation with experimental data.

2. PROPOSED FAILURE SURFACE

The uniaxial stress-strain of SFRC for compression region is defined by Ezeldin and Balaguru (1992) up to the compressive strength and after that, a linear decrease is defined in Fig. 1(a). Equations of material parameter \beta and a strain at the compressive strength according to fiber reinforcement are proposed by Abbass et al. (2018). For tensile region, simple linear equations are defined in Fig. 1(b). Dynamic increase factor (DIF) of compressive strength for SFRC is based on the CEB-FIP 2010 model code of concrete, and DIF equation proposed by Park et al. (2017) is adopted for DIF of tensile strength.



(a) compression region (b) tension region

Figure 1. The stress-strain relations of SFRC

The static envelope of $\mathrm{R}(\alpha, I_f)$ is obtain from the linear product of envelope for plain concrete $\mathrm{R}(\alpha)$ proposed by Gang et al. (2017) and the parameter *k* where the parameter *k* represents the ratio of strength of SFRC to that of plain concrete and it can be determined from the experimental data for strengths of SFRC according to the fiber volume fractions. Then, biaxial strength envelope of SFRC is proposed considering strain rate effect $\mathrm{g}(\dot{\varepsilon})$ in Fig. 2. An effect of the third stress component is considered by multiplying the $\mathrm{h}(\sigma_3/f_c)$ equation in biaxial strength envelope, and the final biaxial envelope of SFRC $\mathrm{s}(\alpha, I_f, \dot{\varepsilon}, \sigma_3/f_c)$ is shown in Fig. 2.

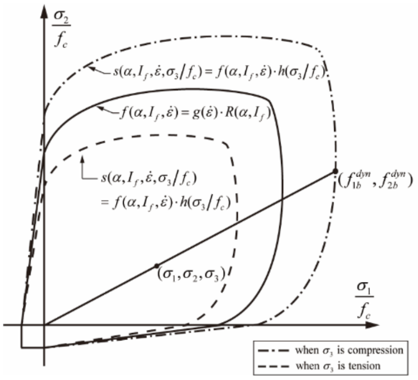
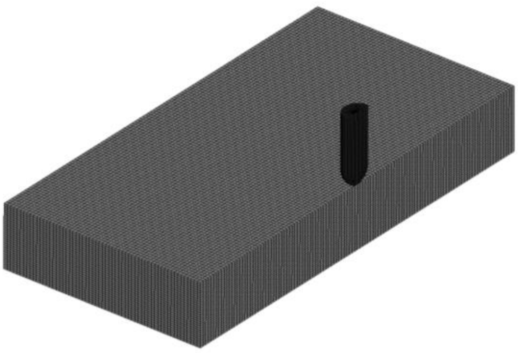


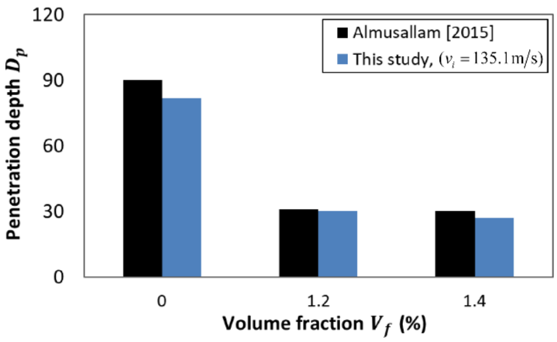
Figure 2. Dynamic biaxial envelope under triaxial stress state

3. NUMERICAL ANALYSIS

The proposed model is implemented as the user defined material model in LS-DYNA. To verify the numerical model, projectile experiment conducted by Almusallam (2015) is used for numerical simulations. All slabs have dimensions of $600 \times 600 \times 300$ mm, and the steel bars of 8 mm diameters were used for reinforcing slabs with a spacing of 100 mm. Experiments were conducted with three fiber volume fractions (0%, 1.2%, 1.4%) at the striking velocity of 135.1 m/s. Due to the symmetry of the geometry, the half of the target and projectile is modelled for numerical simulations Fig. 3(a). Figure 3(b) shows that the numerical results show a good agreement with experiment data by reflecting the decrease in the penetration depth with increasing volume fraction.



(a) finite element model



(b) comparison between numerical results and experimental data

Figure 3. Numerical simulation of projectile experiment

4. CONCLUSIONS

This paper introduces the orthotropic constitutive model for SFRC. The proposed model deals with the multiaxial strength envelope for SFRC, and strain rate effects for SFRC and steel are also taken into account. The proposed model is verified through a comparison with multiaxial dynamic compression test. Furthermore, the numerical simulation of SFRC slabs subjected to projectile impact have been compared with experimental results to testify the accuracy of the numerical model. As a result, the proposed model can be used to describe the nonlinear behavior of SFRC slabs under extreme loading.

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