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Numerical simulation of flexural property of self-compacting rock-filled concrete

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Abstract. By discretizing self-compacting rock-filled concrete (RFC) into self-compacting concrete (SCC), ROCK, and the interface between the two based on concrete damage and brittle fracture model, numerical simulation of the flexural property and failure mode of RFC was conducted and the simulated results were compared with tested results. Results showed that the model can well simulate the flexural test process of RFC, and the load-displacement curve and failure mode in simulation were well consistent with test results.

Key words. Self-compacting rock-filled concrete (RFC), numerical simulation, fracture resistance, crack propagation, failure mode..

1. Introduction

Rock-filled concrete (RFC), based on excellent fluidity of self-compacting concrete, is a concrete resulted by filling randomly stacked large rocks. Enjoying advantages of low cost, less cement consumption, and fast construction speed, it can be applied in construction of structures such as rock-fill concrete gravity dam, cofferdam, port [1]–[2].

Currently, most studies focus on test of RFC while studies on simulation of RFC are very few [3]–[4]. In this paper, based on test data, simulation was conducted by dividing RFC into self-compacting concrete (SCC), ROCK, and the interface between the two. Through bending simulation of a beam (500 mm × 500 mm × 1500 mm), the load-displacement curve and crack propagation law were obtained, which provides reference for numerical simulation of rock-fill concrete.

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2. Numerical simulation of bending test of rock-fill concrete

2.1. Abaqus-based numerical simulation

Due to the irregular shape and random pile of rock in RFC, it is very difficult to construct a 3D model of rock during simulation. Moreover, model analysis entails high requirement of computer [5], therefore in this paper a 2D model was established for simulation.

Abaqus provides three types of analyzing model including concrete damage plasticity model, concrete smeared cracking model and concrete brittle cracking model applied in Abaqus/Explicit. All the three models are based on the damage mechanics, of which the concrete damage plasticity model has wider application range due to its superiority and good convergence, and thus normally used for simulation of plastic failure of concrete [6].

In simulation of this paper, concrete damage plasticity model was used to simulate the plastic failure of the concrete, and the stress-strain curve was obtained. Regarding the four-point bending test of beam ($500\,\mathrm{mm} \times 500\,\mathrm{mm} \times 1500\,\mathrm{mm}$), concrete brittle cracking mode was used to simulation the brittle failure, and the failure mode of RFC beam was obtained.

2.2. Material constitutive model

As concrete damage model still showed good convergence after inputting concrete compressive and tensile constitutive models, therefore concrete damage model was used to obtain the tensile stress-strain curve and compressive stress-strain curve of bending tests of SCC and ROCK of RFC [6], while brittle fracture model was used for simulation of failure mode. The parameters during simulation are shown in Fig. 1.

2.3. Finite element model of bending specimen of rock-fill concrete

In bending test of rock-fill concrete beam, the least width of specimen should be 3 times larger than aggregate. In this paper, a specimen in dimension of $500\,\mathrm{mm} \times 500\,\mathrm{mm} \times 1500\,\mathrm{mm}$ was adopted for simulation. By dividing model into SCC group and ROCK group, model material characteristics were edited by concrete damage plastic model and calculated by arc length method, resulting in compressive stress-strain curve and tensile stress-strain curve of SCC and ROCK, respectively. Material characteristics are shown in Table 1. Mesh generation is shown as Fig. 2, where in model 1 of ROCK the concentration is higher, while model 2 of ROCK exhibits sparser distribution.

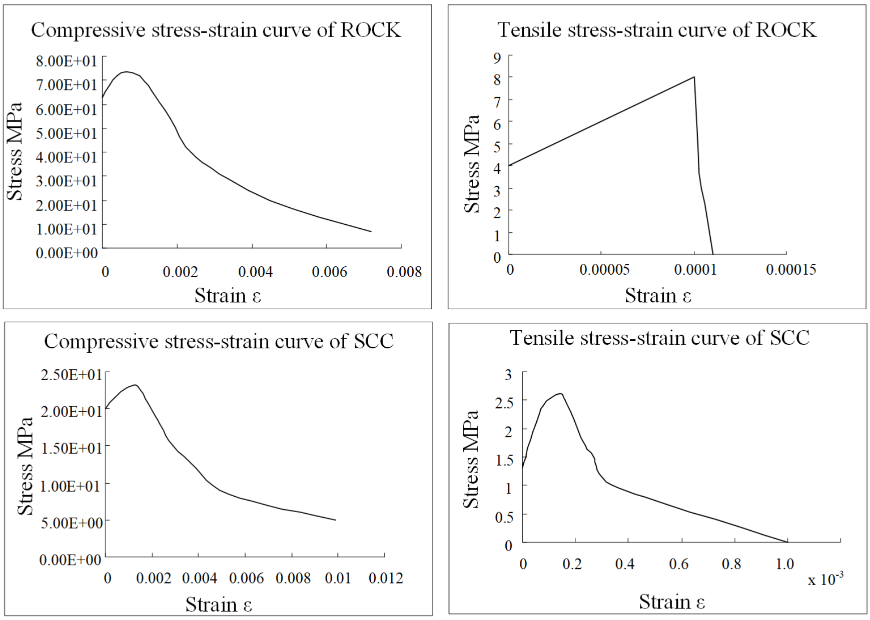

Fig. 1. Compressive and tensile constitutive relations of SCC and ROCK

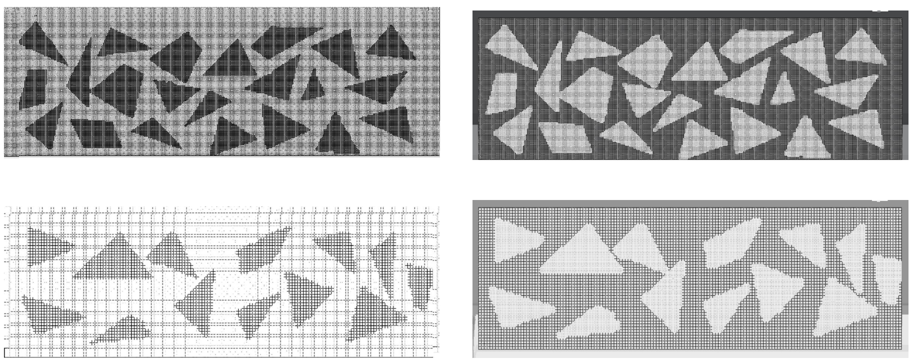

Fig. 2. Model 1 (top) and model 2 (bottom) of SCC group (left) and ROCK group (right)

3. Numerical simulation results and analysis

3.1. Failure mode

Stress distributions of two models are shown in Fig. 3.

Since the bending failure of concrete beam is dominant by tensile brittle failures, the compression area of concrete will not show failure before the occurrence of failure of tensile area. Therefore concrete brittle cracking model was used to simulate the

Table 1. Material characteristics

SCC	Elasticity modulus (GPa)	20.54
	Poisson's ratio	0.2
	Compression strength (MPa)	23
	Tensile strength (MPa)	2.61
ROCK	Elasticity modulus (GPa)	41.3
	Poisson's ratio	0.2
	Ultimate strength (MPa)	73
	Tensile strength (MPa)	8.1

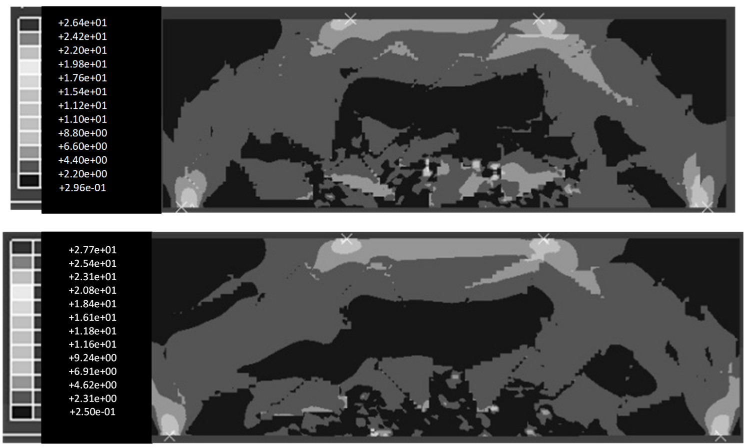

Fig. 3. Stress distributions of two models - model 1 (top) and model 2 (bottom)

brittle failure mode of concrete beam, as shown in Fig. 4.

3.2. Stress-strain curve

The stress-strain curves of tensile area and compression area of SCC and ROCK were respectively obtained using concrete damage plasticity model. The stress status at difference location on the beam is analysed and the results obtained which was shown in Fig. 5 were compared with the constitutive model given in Fig. 1.

4. Conclusion

According to stress distribution figure of beam, the stress distribution of beam is in line with bending stress distribution and no serious local stress discontinuity occurs due to the addition of rock mass, which indicates that SCC and ROCK can

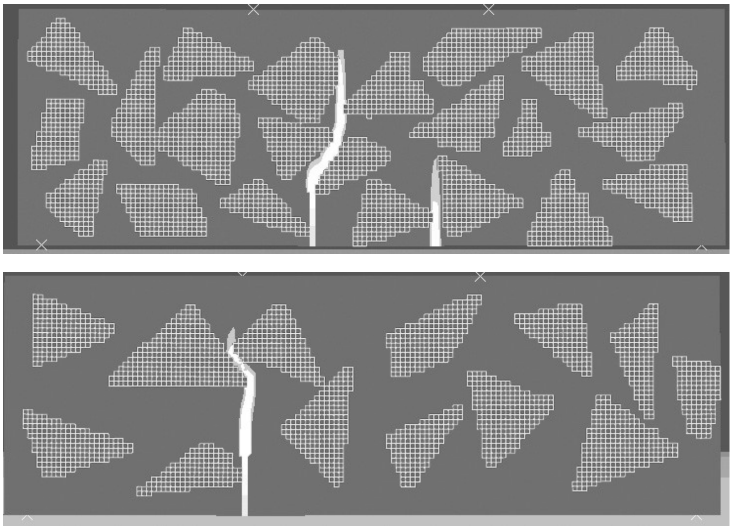

Fig. 4. Simulated failure mode of RFC beam - model 1 (top) and model 2 (bottom)

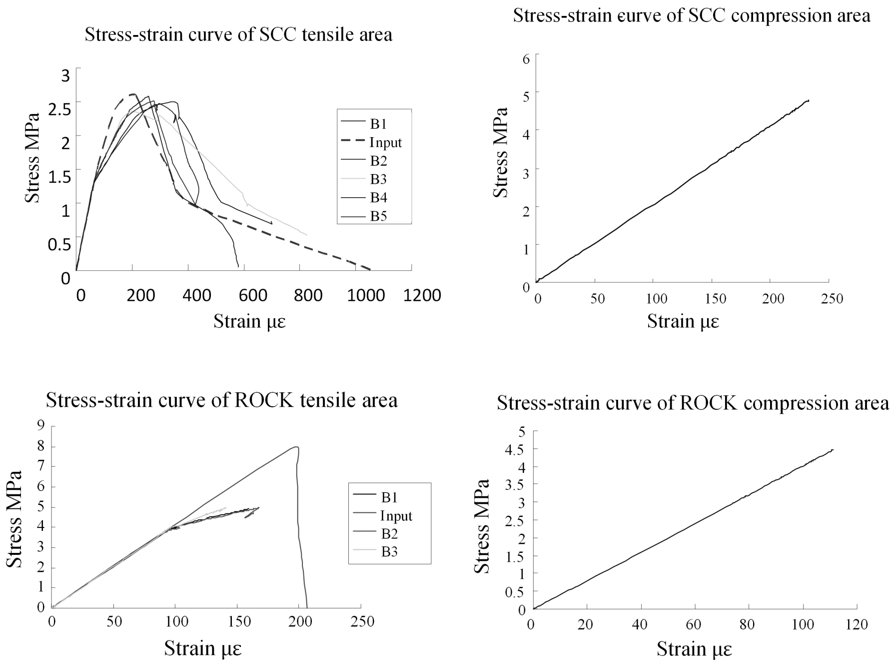

Fig. 5. Stress-strain curves of SCC and ROCK

work together.

It can be seen from the simulation figure of failure mode of beam that the beam failure occurs at area between loading points, which is consistent with test results; cracks first occur at tensile area of SCC, and then propagates along the interfaces of SCC and ROCK, and bypass rock mass along the interface when meeting ROCK.

According to stress-strain curves at tensile area and compression area of SCC and ROCK, the stress-strain curve of SCC tensile area has limited discreteness, while its peak strains are slightly larger than that of constitutive model. ROCK tensile area and the compression areas of ROCK and SCC are all in ascent plasticity stage.

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