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Finite element simulation of compressive strength of rock filled concrete based on Abaqus method

Wang Hui[1], He Shiqin[1], Zhu Zhongfeng[2]

Abstract. Based on Abaqus nonlinear finite element analysis software, the compressive strength of rock filled concrete cube and prism were simulated and analyzed. The rock filled concrete was divided into a type of three-component composite material composed of self-compacted concrete (SCC), rock and interfaces. The modelling, meshing and initial data export was completed by Patran software, and then analyzed with ABAQUS. The results show that compression test of rock filled concrete could be simulated with concrete damage model, and the compressive strength calculated from the load–displacement curve was in good agreement with the experimental results.

Key words. Rock filled concrete, compressive strength, finite element analysis..

1. Introduction

Rock Filled Concrete (RFC) technology is developed on the basis of self-compacting concrete (SCC), which features low carbon environmental protection, low hydration heat, simple process, low cost, fast construction speed [1]. Construction of rock-filled concrete is mainly divided into two processes: stone warehousing and pouring of self-compacting concrete. During the construction process, rock-fill body with particle size larger than 300 mm is placed in the surface of the storehouse, and then self-compacting concrete is poured into the rock-fill body. Due to its characteristics of good flowability, anti-separation and self-flowing, self-compacting concrete can fill voids in the rock-fill body well, thus forming complete, dense and high strength concrete [2].

The particle size of rock body in rock filled concrete is large, generally 150 $\sim$ 200 mm. According to the requirements that the specimen size should be 3 times of the rock body size, the size of specimen for research of mechanical properties of rock filled concrete is very large. Also, there is high requirement for test equipment

[1]School of Civil Engineering, North China University of Technology, Beijing, China, 100144
[2]School of Transportation, Southeast University, Nanjing, China, 210009

capacity and test condition, so it is difficult to study its mechanics and physical properties, and there is few related experimental research [3]–[4]. Numerical simulation of rock filled concrete performance, however, is a good way to study. Based on Abaqus finite element analysis software, compressive strength of 500 mm×500 mm×500 mm cube specimens and 450 mm×450 mm×900 mm prism specimens of rock filled concrete was numerically simulated. The specimen load-displacement curve and crack propagation forms were analyzed to provide a numerical method for the study of mechanical properties of rock filled concrete.

2. Numerical simulation of compressive strength of rock filled concrete

2.1. Finite element simulation of rock filled concrete

Because 3D modelling of rock filled concrete is very complicated [5], 2D finite element model was developed in this paper to simulate compressive strength of rock filled concrete cube and prism. MSC.Patran software was used for modelling and meshing. In modelling, RFCs were regarded as a type of three-component composite material composed of self-compacted concrete (SCC), rock and interfaces [6]. The rock outline in the specimen was randomly plotted by AutoCAD. The CAD-exported files were imported in MSC.Patran and meshing was done. The rock block was defined as ROCK group according to the CAD model, and the remainder was defined as SCC group. Then, Inp file was preliminarily analyzed and exported, and model material properties were defined by editing Inp file, and conferred to the corresponding rock and self-compacting concrete. Then the Abaqus software was used for finite element analysis, plastic damage of the concrete was analyzed by concrete plastic damage model, and the stress-strain curve was obtained.

2.2. Material constitutive model

The constitutive model was obtained from the relevant experimental data. For the rock, consider its plasticity descending branch, while plastic descending branch in the stress-strain curve is not taken into account for SCC. The load-displacement curves of rock and SCC were calculated and compared with the experimental data, as shown in Fig. 1. The simulation parameters of 500 mm×500 mm×500 mm cube and mm prism compressive strength are listed in Table 1.

Table 1. Material characteristics

SCC			ROCK		
Elasticity modulus (GPa)	Poisson's ratio	Compressive strength (MPa)	Elasticity modulus (GPa)	Poisson's ratio	Ultimate strength (MPa)
20.54	0.2	23	41.3	0.2	73

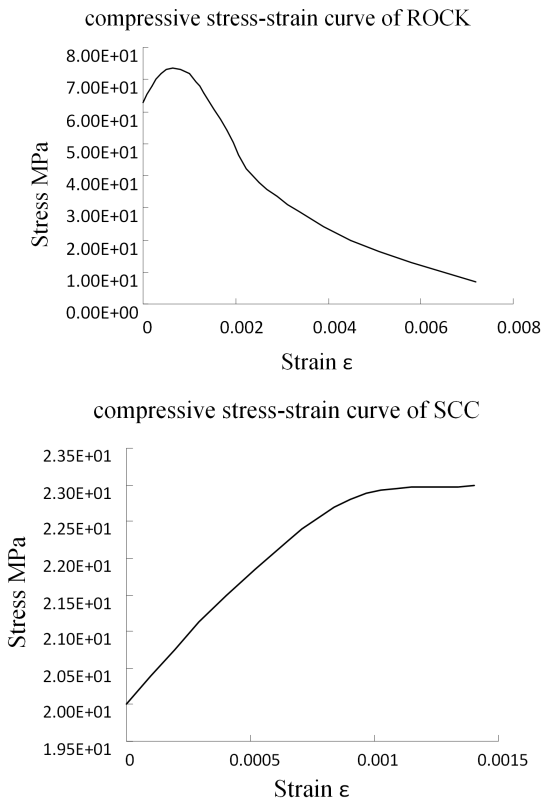

Fig. 1. Constitutive model of SCC (up) and ROCK (bottom) inputted by Abaqus simulation

2.3. Cubic compressive strength specimen modeling and meshing

In order to reflect the meso-scale properties of the concrete [7], the cubic compression model was separated into 40,000 meshing of 2.5 mm×2.5 mm units. The number of units and the computation is very large, and the computer analysis time is relatively long. The model meshing is shown in Fig. 2.

2.4. Prism compressive strength specimen modeling and meshing

The prism model was simulated by 450 mm×450 mm×900 mm prism model, and divided into 45,000 meshing of 3 mm×3 mm units. The meshing and grouping are shown in Fig. 3.

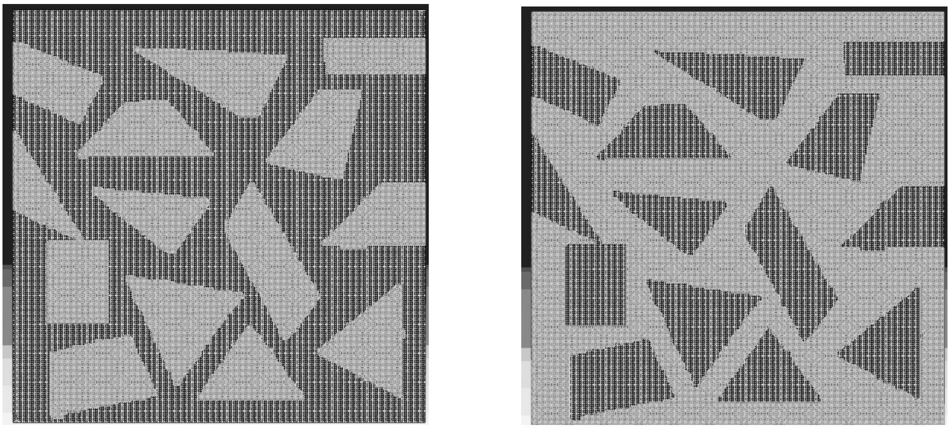

Fig. 2. Mesh generation of model: left–SCC Group (Grid Area); right–ROCK Group (Grid Area)

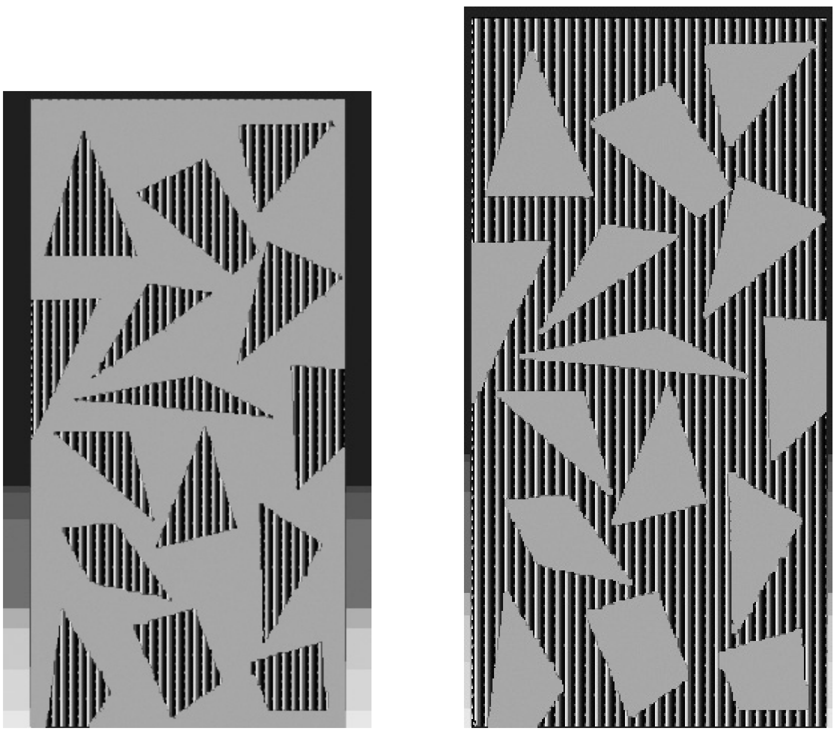

Fig. 3. Prism model meshing: left–SCC Group (Grid Area), right–ROCK Group (Grid Area)

3. Finite element simulation results and analysis

3.1. Stress distribution

The stress distribution of cube compressive strength specimen is shown in Fig. 4.

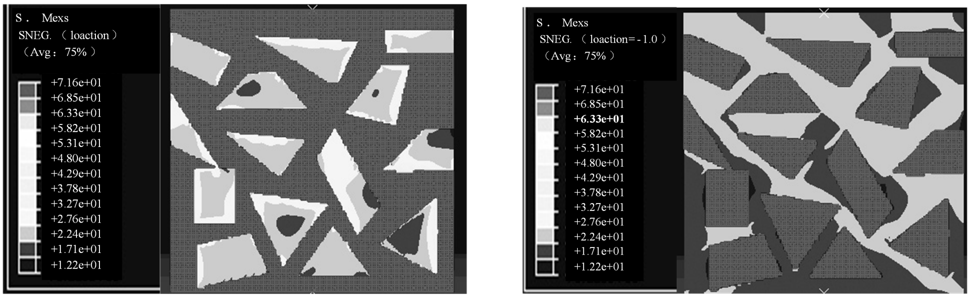

Fig. 4. Stress distribution of cube specimen: left–ROCK stress distribution, right–SCC stress distribution

Stress distribution of prism compressive strength specimen is shown in Fig. 5

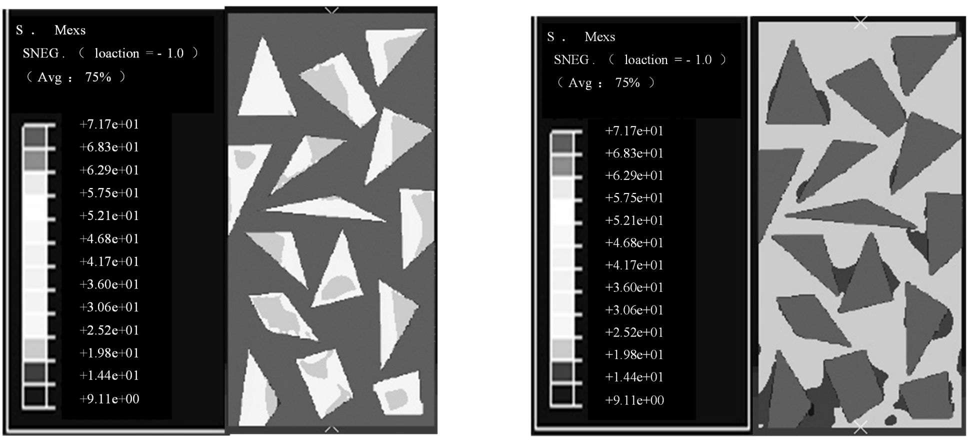

Fig. 5. Stress distribution of prism specimen: left–ROCK stress distribution, right–SCC stress distribution

3.2. Failure state and load displacement curve

Because concrete damage model analysis cannot show concrete crack propagation of specimen, this paper applied equivalent plastic strain to simulate crack propagation of the specimen. The equivalent plastic displacement of cube compressive strength specimen is shown in Fig. 6 and the resulting load displacement curve is shown in Fig. 7. As can be known from Figure Fig. 7, the maximum load is 5, 940 kN and the compressive strength is 23.76 MPa, which is close to the experimental result.

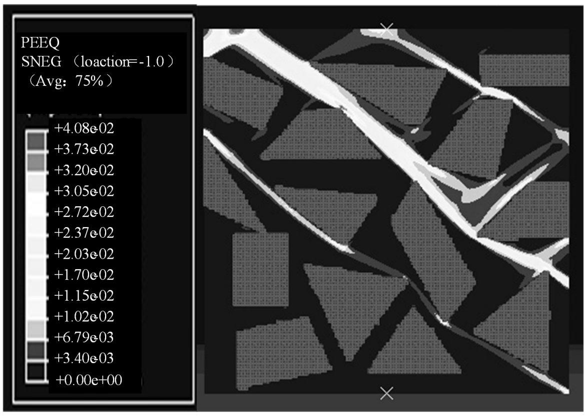

Fig. 6. Equivalent plastic displacement diagram

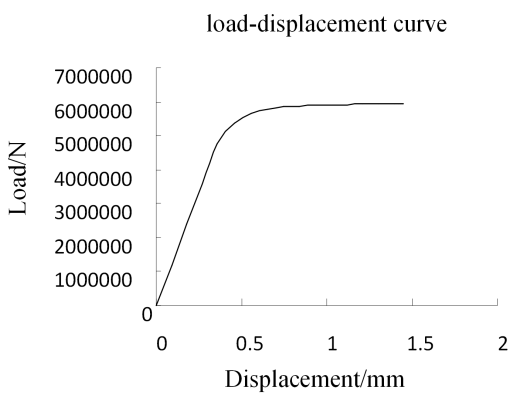

Fig. 7. Load-displacement curve of cubic specimen

The equivalent plastic displacement of the prism specimen is shown in Fig. 8, and the resulting load displacement curve is shown in Fig. 9. As can be known from Fig. 9, the maximum load of specimen is 4.790 kN and the compressive strength is 23.65 MPa, which is higher than the experimental result.

4. Conclusion

The stress distribution diagram for compression failure analysis of cube model and prism model shows that SCC and ROCK can work together, and there is no obvious discontinuity in stress distribution.

The cubic compressive and prismatic compressive failure modes are mainly cracking failure in SCC.

The results of cubic compressive strength of rock filled concrete are close to the

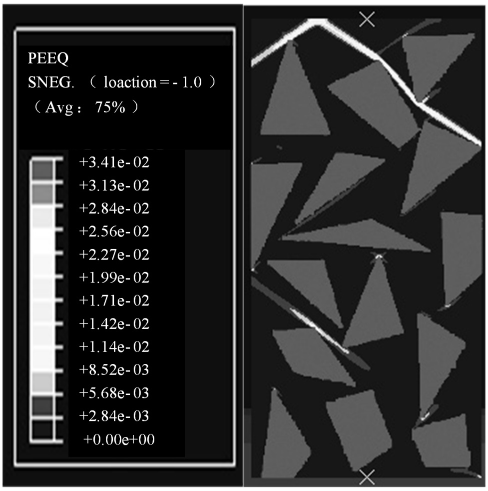

Fig. 8. Equivalent plastic displacement diagram

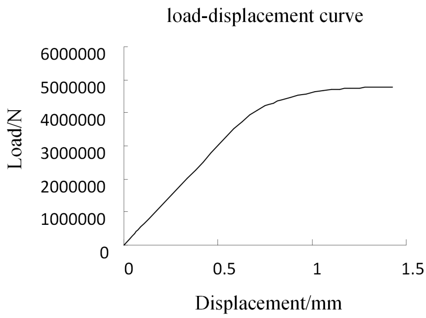

Fig. 9. Load-displacement curve of prism specimen

experimental results. Due to there is error in boundary conditions and experimental conditions in prism compressive strength calculation, the calculated value is higher than the experimental results.

References

[1] C. Liu, C. R. Ahn, X. H. An, et al.: *Life-cycle assessment of concrete dam construction: Comparison of environmental impact of rock-filled and conventional concrete*. Journal of Construction Engineering & Management, *139* (2013), A4013009-1-A4013009-11.

[2] X. An, Q. Wu, F. Jin, M. Huang, H. Zhou, C. Chen, C. Liu: *Rock-filled concrete, the new norm of SCC in hydraulic engineering in China*. Cement and Concrete Composites, *54* (2014), 89–99.

[3] Y. Xie, D. J. Corr, F. Jin, H. Zhou, S. P. Shah: *Experimental study of the interfa-*

cial transition zone (ITZ) of model rock-filled concrete (RFC). Cement and Concrete Composites *55* (2015), 223–231.

[4] Y. Xie, D. J. Corr, M. Chaouche, F. Jin, S. P. Shah: *Experimental study of filling capacity of self-compacting concrete and its influence on the properties of rock-filled concrete*. Cement and Concrete Research *56* (2014), 121–128.

[5] G. Lilliu, J. G. M. van Mier: *3D lattice type fracture model for concrete*. Engineering Fracture Mechanics *70* (2003), Nos. 7–8, 927–941.

[6] E. P. Prado, J. G. M. van Mier: *Effect of particle structure on mode I fracture process in concrete*. Engineering Fracture Mechanics *70* (2003) No. 14, 1793–1807.

[7] C. Qin, C. Zhang: *Numerical study of dynamic behavior of concrete by meso-scale particle element modeling*. International Journal of Impact Engineering *38* (2011), No. 12, 1011–1021.

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