UDEC Simulation Results

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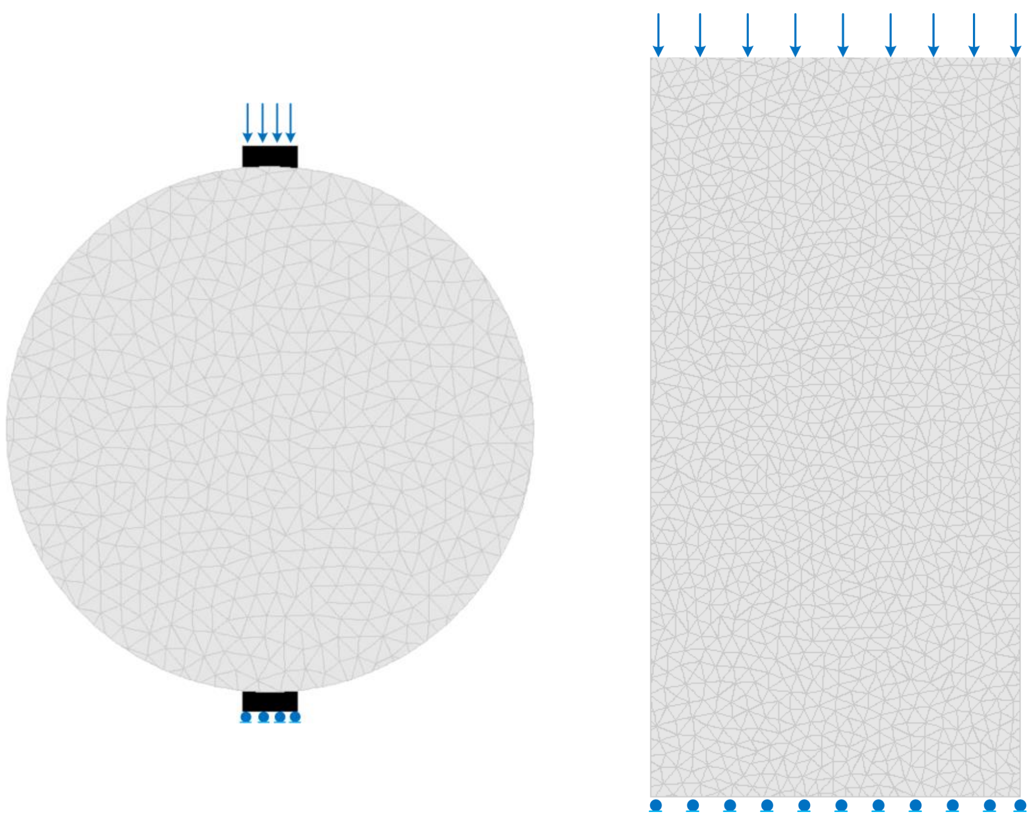
2. UDEC

2.1 UCS and BTS calibration

Figure 1 shows the setup of the BTS and UCS tests for UDEC simulation. The Brazilian sample is 50 mm in diameter and was loaded through two steel plates on both sides. The UCS sample is 100 mm in height and 50 mm in width and was loaded via a constant-velocity boundary at the top of the model. In both models, the bottom boundary is restrained by roller boundaries. The laboratory stress-strain curves have controlled the post-peak behavior, implying that the loading system was very stiff. As a result, no platens were included in the UCS model, which effectively simulates an infinitely stiff loading system. The loading velocity is 5 mm/s for the Brazilian tension test and 20 mm/s for the UCS test. Although these values are large in comparison to the realistic loading rates in laboratory tests, the time step itself is still extremely small in UDEC. A large number of solution steps are required for displacing the boundaries by unit distance. The velocities we used are small enough to mimic a quasi-static loading condition.



(a) BTS test (b) UCS test

Figure 1. The numerical setup of the BTS and UCS tests for UDEC

In the UDEC model, the rock is regarded as aggregate blocks bonded together via contacts. In this study, the elastic constitutive model and Coulomb slip model are applied to the block and contact, respectively. Each block in the model is elastic and will not fail. A block edge length of 2 mm is selected. The contact is simulated by a spring, and the force is divided into the normal stress and shear stress. The contact behavior depends on the stress state and the properties of the contact surface, and failure can occur in contact when the shear stress or tensile stress acting on the contact surface exceeds its contact strength.

The calibrated microscopic parameters of the three types of rocks are summarized in Table 1. Table 2 compares the simulated macro-mechanical results with the laboratory results. The failure diagrams are shown in Figure 2.

Table 1. Calibrated parameters for UDEC

Parameters	Rock types		
	Granite	Marble	Red-sandstone
Young's Modulus (GPa)	28.91	47.9	15.9
Poisson's Ratio	0.249	0.292	0.190
Density (kg/m^3)	2630	2850	2430
Normal contact stiffness (GPa/m)	63500	64600	30000
Shear contact stiffness (GPa/m)	40000	43000	15000
Contact friction angle (°)	54	53	57
Contact cohesion (MPa)	50	35.4	30
Contact tensile strength (MPa)	9.5	7.9	7.8
Residual friction angle (°)	32	32	34
Residual cohesion (MPa)	5	3.54	3
Residual tensile strength (MPa)	0	0	0

Table 2. UCS and BTS simulation results by UDEC

Parameters	Granite		Marble		Red-sandstone	
	Exp.	Sim.	Exp.	Sim.	Exp.	Sim.
Young's Modulus (GPa)	42.25	41.78	59.70	59.28	21.09	20.35
Poisson's Ratio (v)	0.265	0.263	0.274	0.274	0.225	0.218
UCS (MPa)	159.30	159.40	121.38	123.40	116.44	114.1

Peak load in BTS (kN)	/	14.13	/	12.07	/	11.32
BTS (MPa)	7.19	7.20	6.06	6.15	5.78	5.77

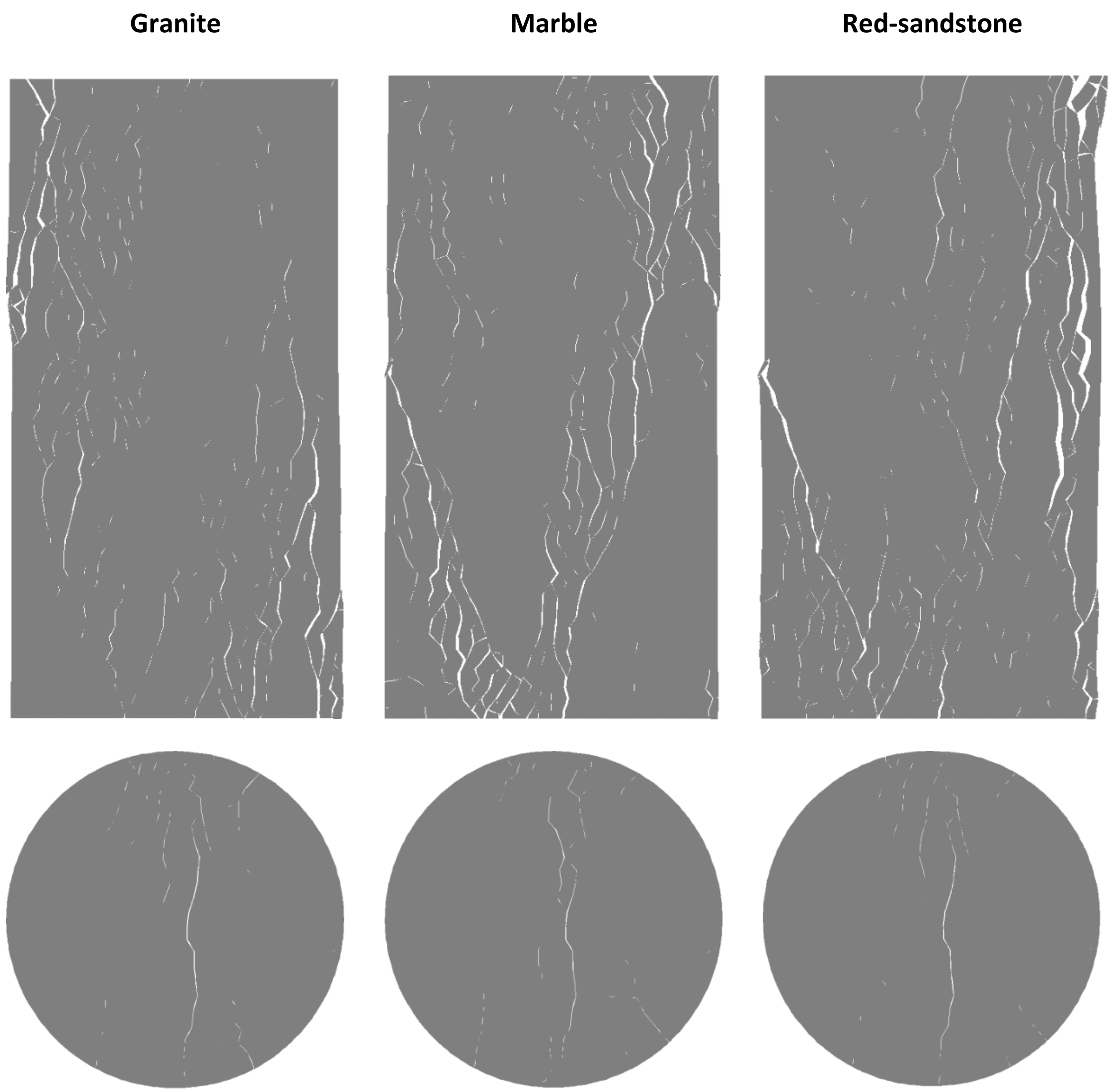


Figure 2. UCS and BTS failure diagrams by UDEC

2.2 Prediction test

The setup of the UDEC model for the prediction test is shown in Figure 3. The height and the width of the specimen are both 100 mm, and the diameter of the circular hole is 20 mm. The model is discretized into triangular blocks with an average edge length of 2 mm. A constant-velocity boundary is applied to the top boundary of the model, and the bottom of the model is fixed by a roller boundary. The loading velocity is 20mm/s, which is consistent with that in the UCS test. The input parameters are the same as those listed in Table 1.

The failure diagrams of three rocks are shown in Figure 4, and the corresponding peak compressive loads are listed in Table 3.

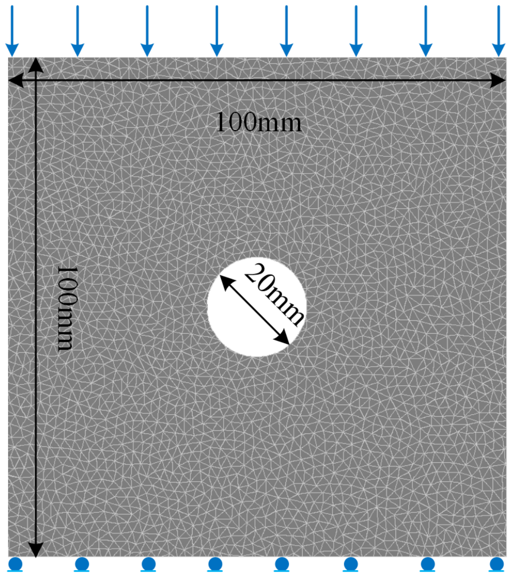
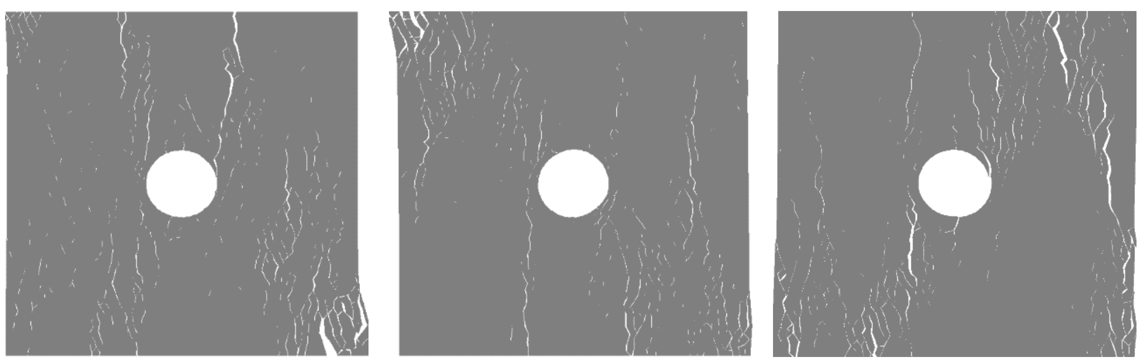


Figure 3. The numerical setup of the prediction test for UDEC



(a) Granite (b) Marble (c) Red-sandstone

Figure 4. Failure diagrams of the prediction test by UDEC

Table 3. Peak loads of the prediction test by UDEC

	Peak compressive load (KN)	Compressive strength (MPa)
Granite	534	106.8
Marble	405.5	81.1
Red-sandstone	318.5	63.7

Reference

Li, X., Li, X.F., Zhang, Q.B., Zhao, J., 2018. A numerical study of spalling and related rockburst under dynamic disturbance using a particle-based numerical manifold method (PNMM). Tunnelling and Underground Space Technology 81, 438-449.