PNMM

Xing Li, Cheng Pan

Southeast University, Nanjing, Jiangsu, China

1. PNMM (Particle-based Numerical Manifold Method)

1.1. UCS test

Model description

The setup of the PNMM model for UCS tests is shown in **错误!未找到引用源。**. A 2D model is used. A rigid wall is located at the top of the specimen and moves downward with a constant velocity. The loading rate is set as 1.67 mm/s, namely 100 mm/min, to achieve an acceptable cost of simulation time. The bottom boundary of the model is fixed in the vertical direction. The left and right boundaries are free. The PNMM model consists of 20,604 particles, i.e. the average particle size is approximately 0.243 mm^2. The Johnson-Holmquist-Beissel (JHB) model is used for dynamic fracturing. The input parameters include: the density, Young's modulus, Bulk modulus, compressive strength (as the maximum strength), tensile strength. The strain rate coefficient *C* is set as 0.00965. The other material constants are assumed to be the same as those in (Li et al., 2018), due to the lack of laboratory data.

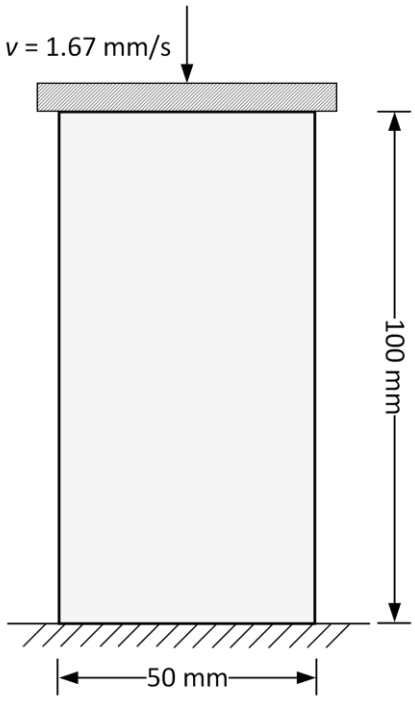


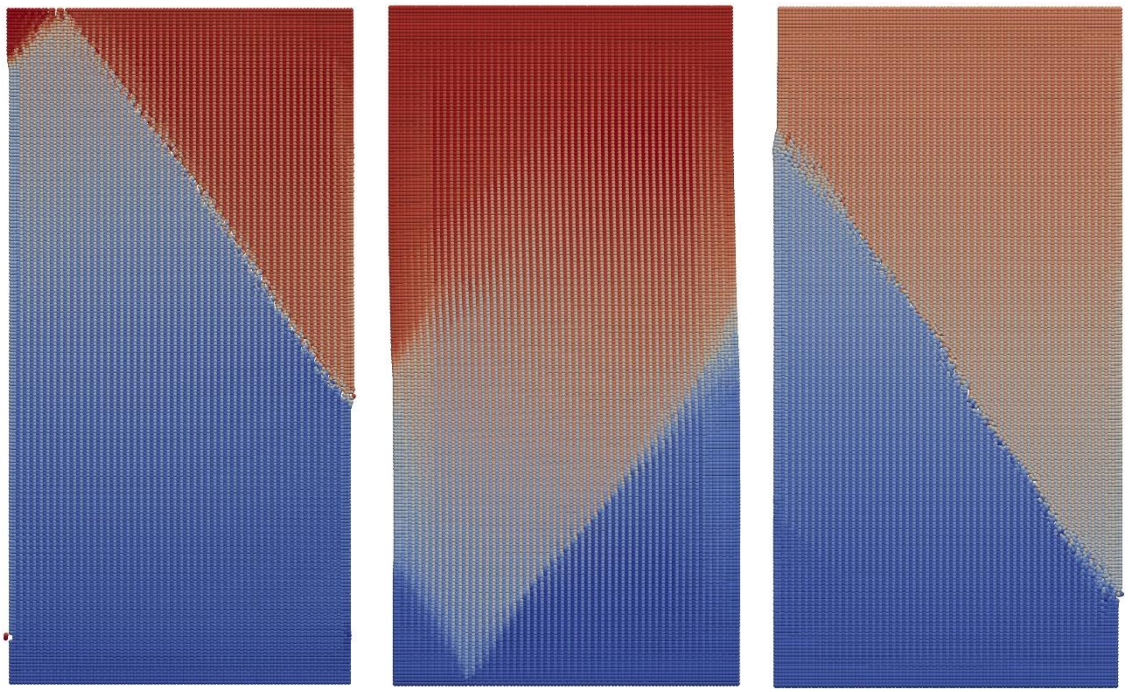
Figure 1. The numerical setup of the UCS test for PNMM

Modelling results

The simulated UCS of the three rocks is summarized in Table 1. The failure diagrams are presented in Figure 2.

Table 1. UCS simulation results by PNMM

	UCS (MPa)
Granite	160.7
Marble	122.2
Red-sandstone	118.0



a. Granite b. Marble c. Sandstone

Figure 2. UCS failure diagrams by PNMM (displacement contour, blue color indicates small displacement, red color indicates large displacement)

1.2 BTS test

Model description

The setup of the PNMM model for BTS tests is shown in Figure 3. The PNMM consists of 12,281 particles. The average particle size is 0.16 mm^2.The bottom of the model is fixed in the vertical direction. The loading rate and input parameters are the same as that in the UCS test.

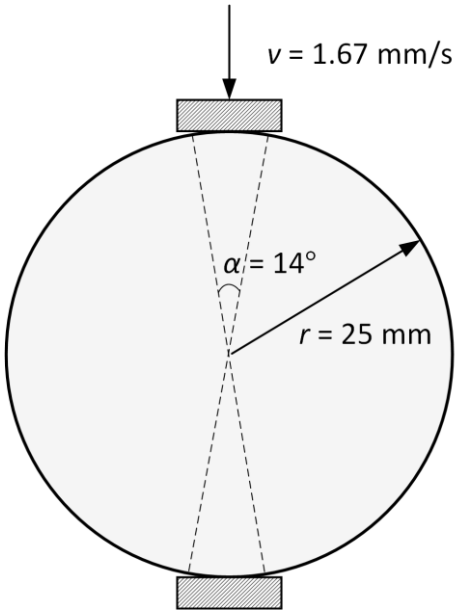


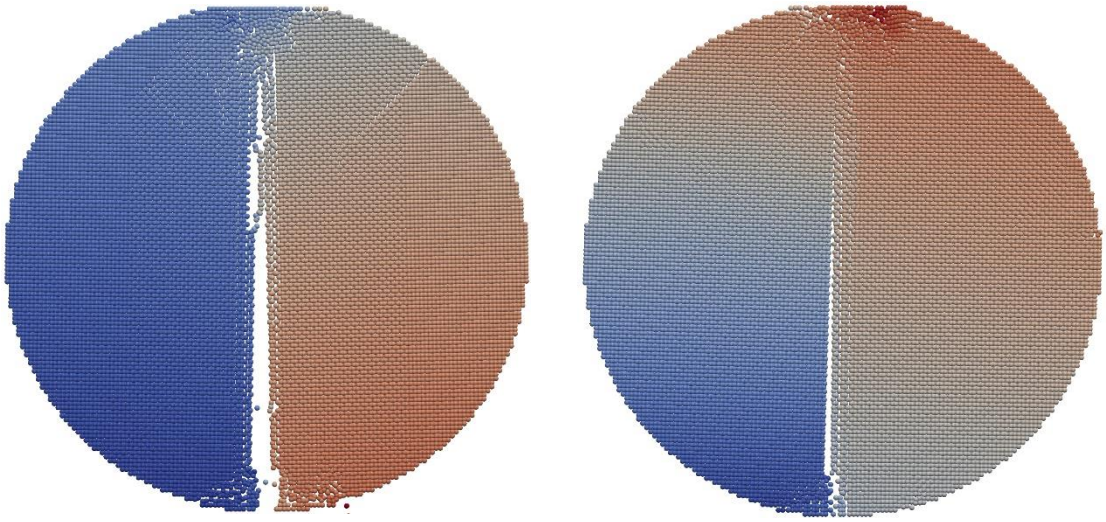
Figure 3. The numerical setup of the BTS test for PNMM

Modelling results

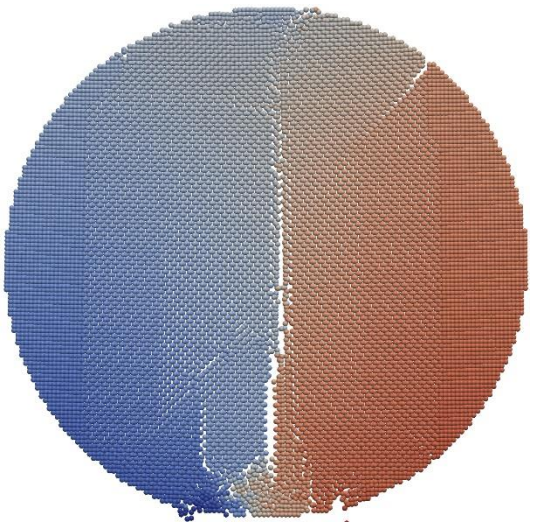
The simulated peak load in BTS tests of the three rocks is summarized in Table 2. The failure diagrams are presented in Figure 4.

Table 2. BTS simulation results by PNMM

	Peak load (kN)
Granite	14.4
Marble	12.3
Red-sandstone	11.2



(a) Granite (b) Marble



(c) Sandstone

Figure 4. BTS failure diagrams by PNMM (displacement contour, blue color indicates leftward displacement, red color indicates rightward displacement)

1.3 Prediction test

Model description

The setup of the PNMM model for the prediction test is shown in Figure 5. The boundary conditions and input parameters are similar to those in the UCS test. The PNMM model for this test consists of 39,524 particles. The average particle size is 0.245mm^2.

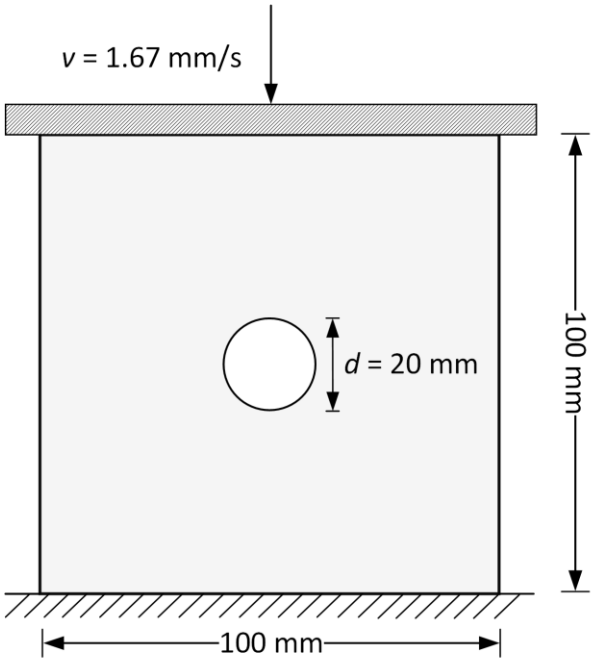


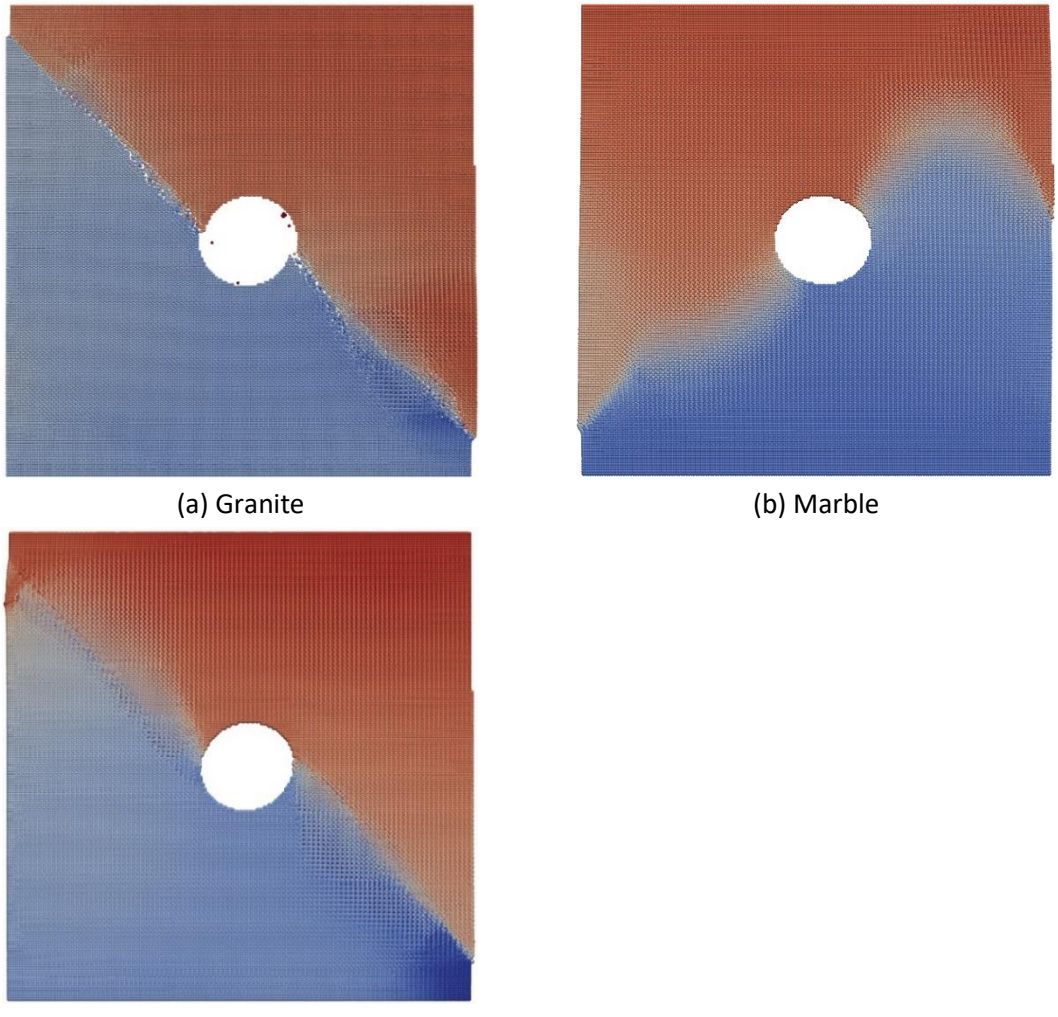
Figure 5. The numerical setup of the prediction test for PNMM

Modelling results

The simulated peak load in BTS tests of the three rocks is summarized in Table 3. The failure diagrams are presented in Figure 6. For all cases, a primary fracture is initiated at the left and right side of the circular hole and propagates diagonally. Therefore, the rock specimen is separated into two pieces. For the Marble case, there are more micro-cracks generated and therefore the propagation path of the primary fractures are influenced.

Table 3. Peak loads of the prediction test by PNMM

	Peak load (kN)
Granite	478.9
Marble	346.7
Red-sandstone	291.4



(a) Granite

(b) Marble

(c) Sandstone

Figure 6. Failure diagrams of the prediction test by PNMM (displacement contour, blue color indicates small displacement, red color indicates large displacement)