International Numerical Modeling Contest of Rock Mechanics and Engineering (INCR)—2021

Problem A: Rock Fracturing

Purpose: The International Numerical Modeling Contest of Rock (INCR) is to encourage research students to conduct open, transparent, and extensive verification of existing numerical methods and software on rock mechanics problems, and provide a platform for sharing experimental and numerical results on rock mechanics problems and promote the application of numerical simulation in rock mechanics and engineering. This problem is on the rock fracturing problems. There are two stages of numerical modeling, one is calibration to obtain the basic numerical parameters of three types of rocks, and then to perform the prediction test based on the calibrated parameters. It is worth noting that we provided some basic parameters of three types of rocks according to these methods suggested by the International Society for Rock Mechanics (ISRM) for reference only. The team can change their parameters according to their own numerical tool. All details of these parameters should be recorded.

1. Stage-I

1.1 Calibration experiment

The dimension of cubic samples for three types of rocks (granite, marble, and red sandstone) is 50 mm in height and length, and 30 mm in width for compression tests (see Fig. 1). The loading rate is 1mm/min. The experiment setup and the failure pattern of the marble sample under the compression tests are given in Fig. 1, which is the same as other types of rocks. The compression tests directly yield the uniaxial compressive strength and the load-displacement curves for three types of rocks (see Fig. 2).

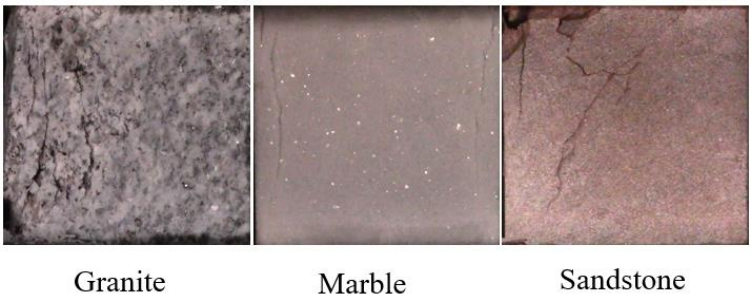


Fig.1 Compression test of the intact specimen

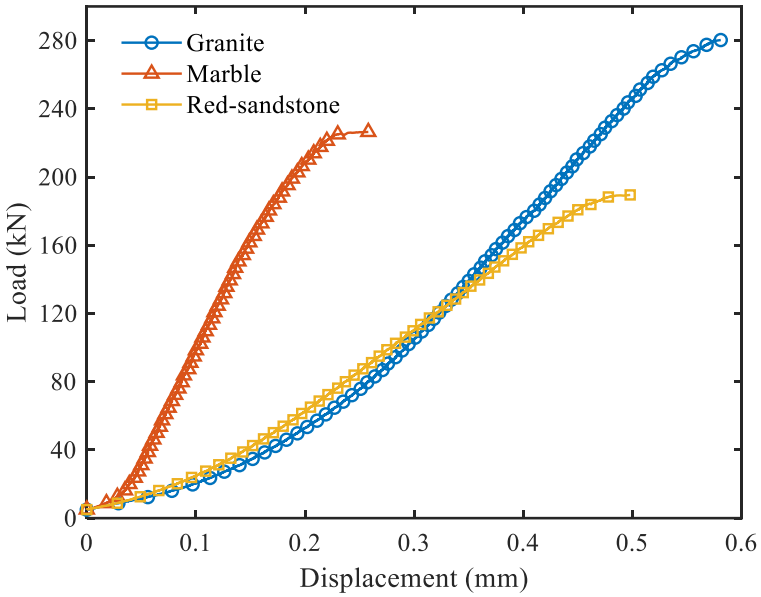


Fig.2 The load-displacement curves of three rocks in the compression test

The required calibration:

a. The numerical model description of three types of rocks in compression tests (the input parameters, the dimension, boundary conditions, loading rate, and element size/ particle size).

b. Modelling results of three types of rocks in compression tests (the failure modes and unconfined compressive loads).

Parameters	Peak compressive load (kN)
Granite	
Marble	
Red-sandstone	

1.2 Prediction test

The overall dimension of three types of rocks for prediction models is 50 mm×50mm×30 mm subjected to uniaxial compression, and the details of four types of pre-existing crack samples are shown in Fig. 3. The loading rate is 1mm/min. The input parameters in the prediction model should be based on these calibrated parameters. The four types of pre-existing cracks for marble samples subjected to uniaxial compression are given in Fig.4.

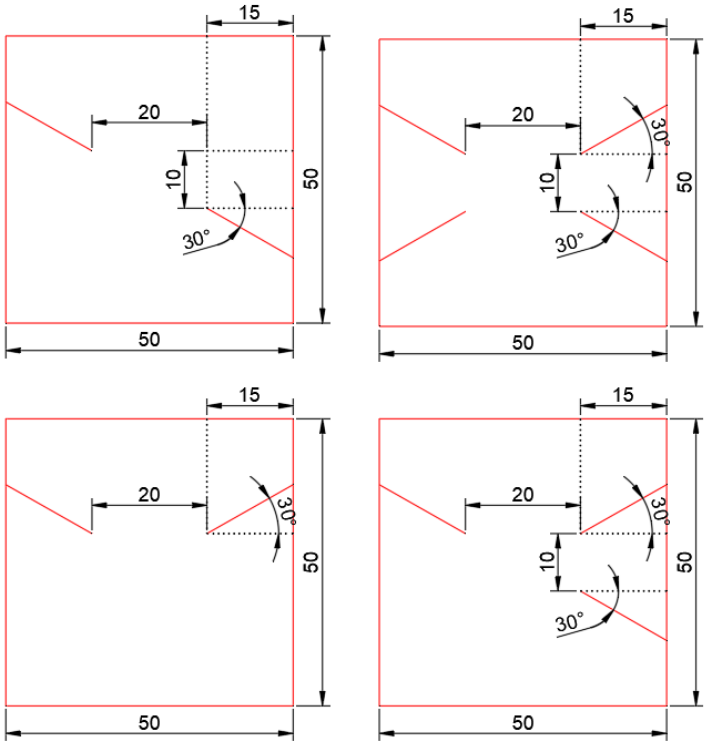


Fig.3 The dimension of four types of pre-existing crack samples in the compression test

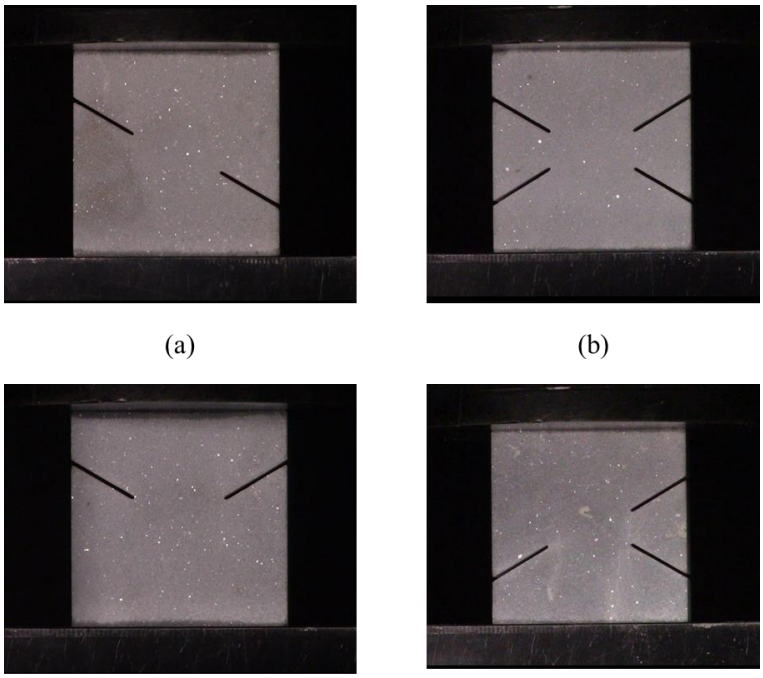


Fig.4 Samples with different pre-existing cracks in the compression test

The required numerical result:

a. Model description of three types of pre-cracked rocks subjected to uniaxial compression (the input parameters, the dimension, boundary conditions, loading rate, and element/ particle size).

b. Modelling results of three types of rocks subjected to uniaxial compression (the failure mode diagrams, peak compressive load).

2. Stage-II

2.1 Calibration experiment

The dimension of cubic samples for three types of rocks (granite, marble, and red-sandstone) is 50 mm in height and length, 30 mm in width for compression tests, and the details of pre-existing crack samples are shown in Fig. 5. The loading rate is 1mm/min. The compression tests directly yield peak compressive load and the load-displacement curves for three types of rocks (see Fig. 6).

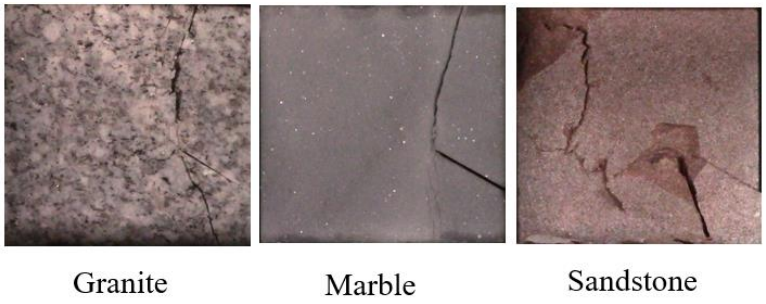


Fig.5 Compression test of specimens with pre-existing cracks

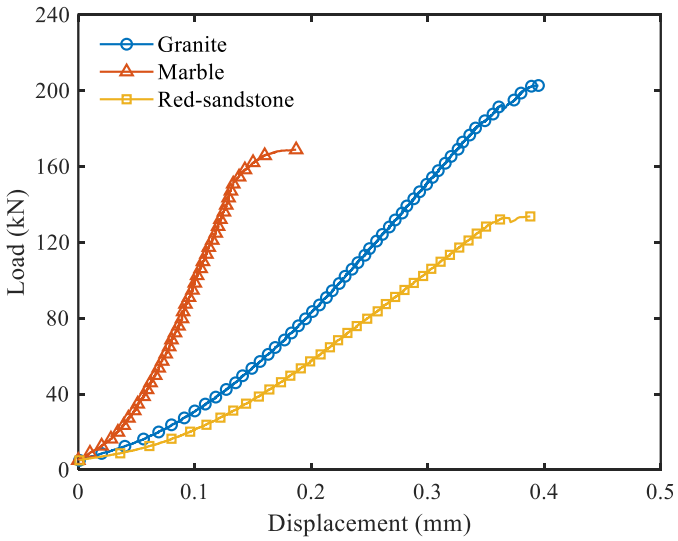


Fig.6 The load-displacement curves of three rocks with pre-existing cracks in the compression test

The required calibration:

a. The numerical model description of three types of rocks in compression tests (the input parameters, the dimension, boundary conditions, loading rate, and element size/ particle size).

b. Modelling results of three types of rocks in compression tests (the failure modes and unconfined compressive loads).

Parameters	Peak compressive load (kN)
Granite	
Marble	
Red-sandstone	

1.2 Prediction test

The overall dimension of three types of rocks for prediction models is 50 mm×50mm×30 mm subjected to uniaxial compression, and the details of four types of pre-existing crack samples are shown in Fig. 7. The loading rate is 1mm/min. The input parameters in the prediction model are based on the calibrated parameters. The testing machine employed in this compression test is the same as the compression test. The four types of pre-existing cracks for marble samples subjected to uniaxial compression are given in Fig.8.

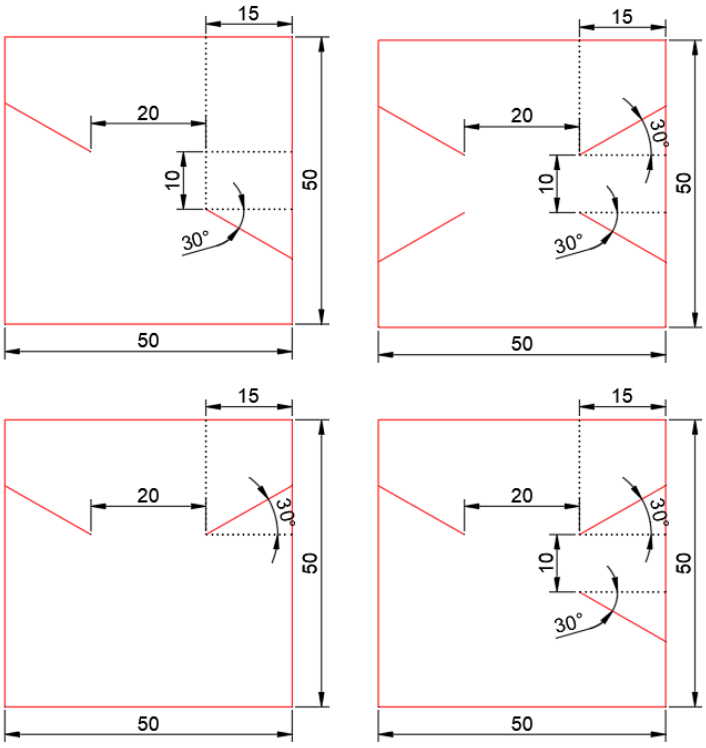
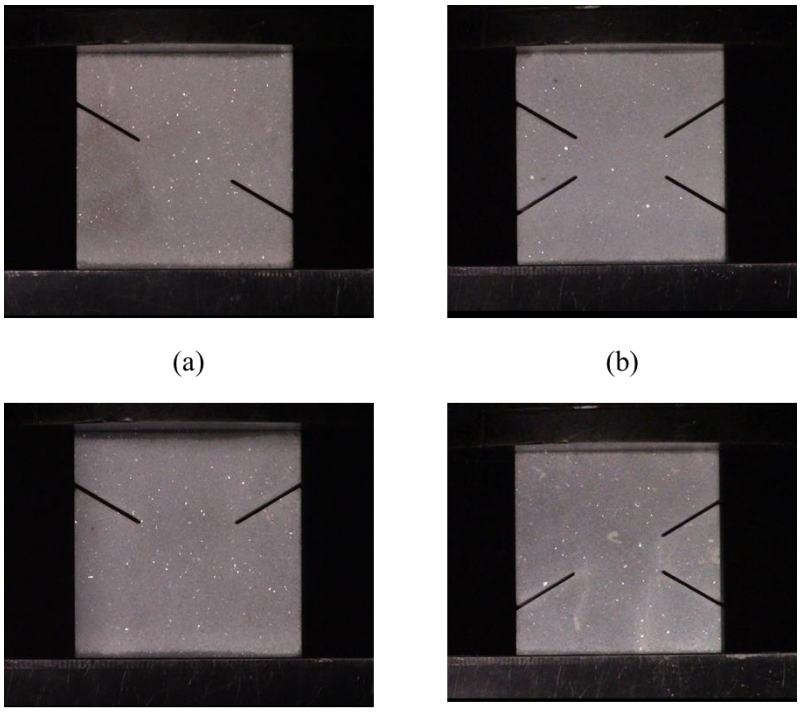


Fig.7 The dimension of four types of pre-existing crack samples in the compression test



(a) (b)

(c) (d)

Fig.8 Samples with different pre-existing cracks in the compression test

The required numerical result:

a. Model description of three types of pre-cracked rocks subjected to uniaxial compression (the input parameters, the dimension, boundary conditions, loading rate, and element/ particle size).

b. Modelling results of three types of rocks subjected to uniaxial compression (the failure mode diagrams, peak compressive load).

Appendix A

Table 1. Mechanical parameters of three types of rocks (reference only)

Parameters	Rock types		
	Granite	Marble	Red-sandstone
Peak compressive load (kN)	312.63	233.84	228.44
Compressive strength (MPa)	159.30	121.38	116.44
Tensile strength, (MPa)	7.19	6.06	5.78
Young's modulus (Gpa)	42.25	59.70	21.09
Poisson's ratio	0.265	0.274	0.225
Cohesion, C (MPa)	29.00	21.50	19.10
Friction angle, Φ (°)	50.18	51.11	53.74
Density (g/cm^3)	2.63	2.85	2.43

Appendix B

Table 2. Fig.2 data

Granite		Marble		Red-sandstone	
Displacement(mm)	Load(kN)	Displacement(mm)	Load(kN)	Displacement(mm)	Load(kN)
0	4.9531	0	4.9796	0	4.9909
0.029	8.7369	0.017	8.6915	0.028	8.771
0.056	12.3316	0.028	12.5435	0.049	12.5322
0.078	16.0133	0.035	16.1306	0.066	16.1836
0.097	19.7745	0.039	19.9258	0.083	20.1567
0.113	23.5659	0.044	23.7362	0.096	23.8648
0.126	27.2363	0.047	27.3422	0.109	27.5806
0.14	31.058	0.05	31.1261	0.121	31.2926
0.152	34.7321	0.053	34.8305	0.132	35.1483
0.163	38.5311	0.056	38.4441	0.143	38.8073
0.173	42.3415	0.058	42.2658	0.152	42.5458
0.183	45.974	0.061	46.0723	0.162	46.4659
0.193	49.7086	0.064	49.8146	0.171	50.1124
0.202	53.4575	0.067	53.5518	0.18	53.9069
0.211	57.1325	0.069	57.1434	0.189	57.6363
0.219	60.8292	0.072	61.0032	0.197	61.3584
0.227	64.7507	0.075	64.6347	0.205	65.0768
0.235	68.2879	0.078	68.5199	0.213	68.6467
0.243	72.0934	0.081	72.1405	0.221	72.4123
0.251	75.8299	0.084	75.9351	0.23	76.2141
0.257	79.5847	0.087	79.784	0.237	79.9797
0.264	83.0784	0.089	83.5677	0.245	83.8576
0.271	86.8331	0.092	87.3442	0.253	87.5544
0.276	90.6132	0.095	90.9394	0.261	91.1605
0.283	94.3607	0.098	94.7449	0.268	94.9841
0.289	98.2857	0.1	98.4814	0.275	98.7279
0.295	102.0518	0.104	102.0339	0.283	102.5082
0.301	105.8249	0.106	105.9506	0.292	106.1411
0.307	109.4326	0.109	109.6374	0.299	109.8458
0.313	113.2631	0.112	113.2883	0.306	113.5722
0.318	116.8493	0.115	116.9464	0.314	117.3416
0.323	120.5146	0.117	120.6906	0.322	120.9566
0.329	124.4349	0.12	124.4457	0.33	124.7835
0.334	128.0355	0.123	128.2403	0.338	128.4631
0.34	131.8624	0.126	131.8517	0.345	132.229
0.345	135.56	0.128	135.5672	0.352	135.9984
0.35	139.1067	0.131	139.2899	0.36	139.6457

0.355	142.9696	0.134	143.0558	0.368	143.5265
0.361	146.8468	0.136	146.7282	0.374	147.2169
0.365	150.5803	0.139	150.451	0.382	150.8642
0.371	154.1126	0.143	154.206	0.39	154.666
0.375	157.7383	0.146	157.9467	0.398	158.4498
0.381	161.515	0.149	161.6515	0.405	162.054
0.386	165.3383	0.153	165.3778	0.414	165.7983
0.392	168.9389	0.156	169.1293	0.423	169.6755
0.397	172.9131	0.16	172.7874	0.432	173.4234
0.403	176.4957	0.164	176.564	0.441	177.1282
0.41	180.2077	0.167	180.3155	0.45	180.7934
0.415	183.8837	0.171	184.0418	0.462	183.8693
0.42	187.7107	0.176	187.7933	0.478	188.2892
0.425	191.6238	0.179	191.4334		
0.43	195.2388	0.184	195.1525		
0.435	198.8753	0.188	199.0226		
0.44	202.6348	0.193	202.6637		
0.445	206.231	0.197	206.325		
0.449	210.3116	0.203	210.1236		
0.455	214.0054	0.208	213.8174		
0.461	217.8943	0.214	217.5365		
0.465	221.3026	0.22	221.2159		
0.471	225.1373	0.23	224.8807		
0.475	228.9179				
0.481	232.731				
0.486	236.291				
0.492	240.0932				
0.496	243.7545				
0.503	247.564				
0.507	251.2939				
0.514	255.1287				
0.519	258.7755				
0.527	262.5813				
0.535	266.398				
0.545	270.2002				
0.556	273.7422				
0.568	277.483				

Appendix C

Table 3. Fig.6 data

Granite		Marble		Red-sandstone	
Displacement(mm)	Load(kN)	Displacement(mm)	Load(kN)	Displacement(mm)	Load(kN)
0.001	5.0174	0	5.0325	0.001	5.0023
0.02	8.6537	0.01	8.8429	0.036	8.7332
0.04	12.4376	0.02	12.5738	0.061	12.5662
0.056	16.2631	0.028	16.3047	0.08	16.4068
0.069	19.975	0.034	19.8918	0.096	20.1339
0.08	23.7475	0.039	23.4713	0.11	23.7778
0.091	27.3838	0.043	27.3044	0.122	27.5352
0.1	31.0618	0.048	31.2245	0.133	31.2585
0.109	34.6753	0.051	34.7397	0.144	34.9062
0.118	38.3608	0.056	38.6976	0.155	38.6522
0.127	42.3944	0.059	42.3415	0.164	42.3869
0.135	45.8983	0.062	45.9702	0.174	46.201
0.141	49.6178	0.066	49.8259	0.182	49.6519
0.149	53.5083	0.069	53.7148	0.191	53.5155
0.156	57.1434	0.072	57.321	0.199	57.205
0.163	60.8981	0.075	61.1518	0.208	60.8655
0.169	64.5296	0.078	64.9319	0.216	64.6347
0.177	68.4691	0.08	68.5887	0.223	68.3531
0.183	72.1767	0.083	72.3036	0.231	72.184
0.189	75.9677	0.086	75.8698	0.239	75.8118
0.195	79.6354	0.089	79.7188	0.248	79.6934
0.201	83.4735	0.09	83.4119	0.257	83.5786
0.207	86.9382	0.092	87.4021	0.264	87.4166
0.213	90.8343	0.095	90.9612	0.272	91.1714
0.218	94.4404	0.098	94.7956	0.28	94.85
0.224	98.2604	0.1	98.5141	0.288	98.5576
0.229	102.0482	0.102	102.4974	0.296	102.2207
0.235	105.7961	0.105	106.1554	0.303	106.0117
0.24	109.2458	0.107	109.8423	0.311	109.7345
0.246	113.1482	0.11	113.7159	0.319	113.3566
0.25	116.6517	0.112	117.3632	0.327	117.2194
0.256	120.626	0.115	121.0967	0.335	120.9314
0.261	124.1331	0.118	124.8302	0.342	124.5787
0.267	128.0678	0.12	128.4092	0.35	128.2798
0.272	131.7475	0.122	132.0888	0.362	132.0349
0.278	135.4163	0.125	135.984		
0.282	139.1354	0.127	139.6026		

0.288	142.9229	0.129	143.4475		
0.293	146.6348	0.131	147.0373		
0.299	150.5624	0.133	150.76		
0.304	154.1881	0.138	154.4684		
0.309	157.7599	0.143	158.2773		
0.315	161.6587	0.15	162.0468		
0.32	165.2664	0.16	165.7084		
0.326	169.0682				
0.33	172.8197				
0.336	176.5353				
0.341	180.2436				
0.349	184.0742				
0.356	187.6065				
0.361	191.3472				
0.374	194.9836				
0.38	198.6597				
0.389	202.277				