Numerical Investigation of the Scale Effects of Rock Bridges

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Out Line

- Introduction
- Methodology
- Results discussion
- Conclusion

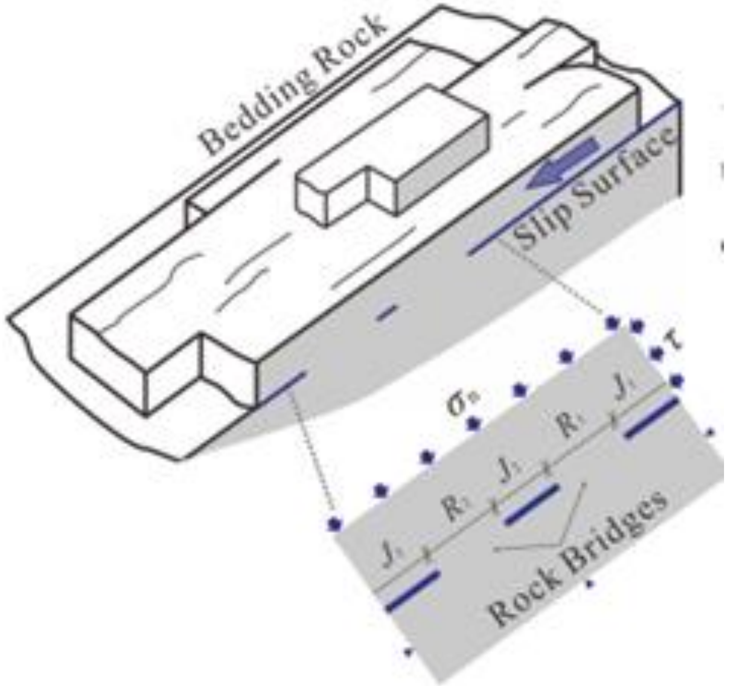
- The discontinuity within natural rock masses appears to have an important role in rock engineering
- Rock bridges have always been considered to provide key resistance to reduce the potential for damage in rock masses to develop.
- K is the ratio of the joint length to measure the discontinuity in the rock mass.
- Jennings' criterion was proposed to compute the combined strength of joints and rock bridges.

$$K = \frac{\sum J_i}{\sum J_i + \sum R_i} \quad (1)$$

K: the ratio of the joint length
ΣJ_i: the i length of the joint
ΣR_i: the i length of the rock bridge

$$\tau = K(c_j + \sigma \tan \phi_j) + (1 - K)(c_r + \sigma \tan \phi_r) \quad (2)$$

τ: shear stress
σ: normal stress
c_j: cohesion of joints
c_r: cohesion of rock bridges
φ_j: friction angle of joints
φ_r: friction angle of rock bridges



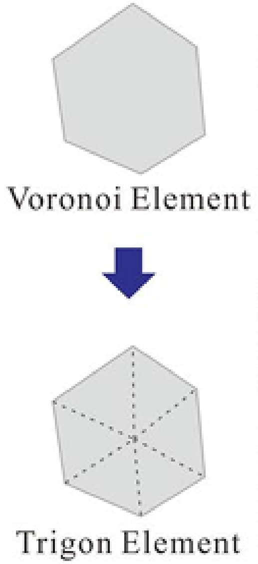
- This criterion assume simultaneous failure of rock bridges and joints and ignore the impact of joints on the stress field, progressive rock mass damage and changes in stresses within a rock mass.
- It is questionable to evaluate mechanical properties of rock bridges using only geometric parameters.
- The investigation of the scale effects of rock bridges in a laboratory is still difficult because of the high cost and high failure rate of sample with rock bridges.
- Thus, it is necessary to introduce numerical simulations into this research.

Discrete Element Modelling

The discrete element modelling (DEM) has been widely used in numerical simulations of rock behaviours because of its ability to explicitly represent fractures and bond failure of rocks.

Voronoi elements can facilitate more reasonable crack propagation in numerical models.

Transitioning from Voronoi elements to Trigon elements allows for reduced dependence on the computational grid.



Physical Prototype and Calibration

Granitic rock specimens collected from a quarry in China Qing dao City were used as physical prototypes.

The lengths of the rock bridges were set as 50 mm (K = 0.75), 100 mm (K = 0.50) and 150 mm (K = 0.25)

The modelling parameters shown in Table 1 have been calibrated for a range of macro parameters of both uniaxial compression tests and direct shear tests with these presented in Table 2, indicating that the simulation in UDEC agreed well with the prototype results.

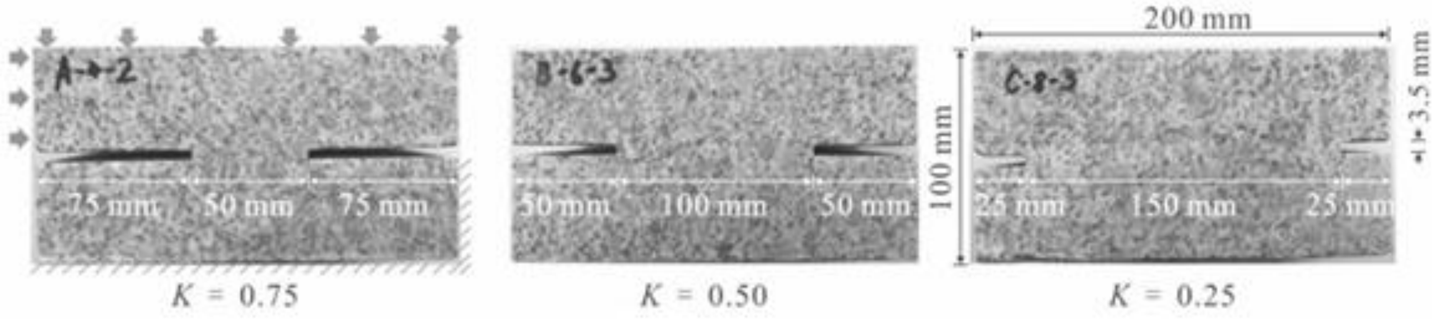


Table 1 Calibrated modelling properties used in UDEC to present the granite specimens

Properties	Values
Young's modulus of blocks, E^{block} (GPa)	27.20
Poisson's ratio of blocks, μ^{block}	0.12
Normal stiffness of contacts, k_n (GPa/m)	140,600
Shear stiffness of contacts, k_s (GPa/m)	56,240
Contact cohesion, c^{cont} (MPa)	24.80
Contact friction angle, ϕ^{cont} (°)	23.00
Contact tensile strength, σ_t^{cont} (MPa)	4.00

Table 2 Calibrated results of macroproperties

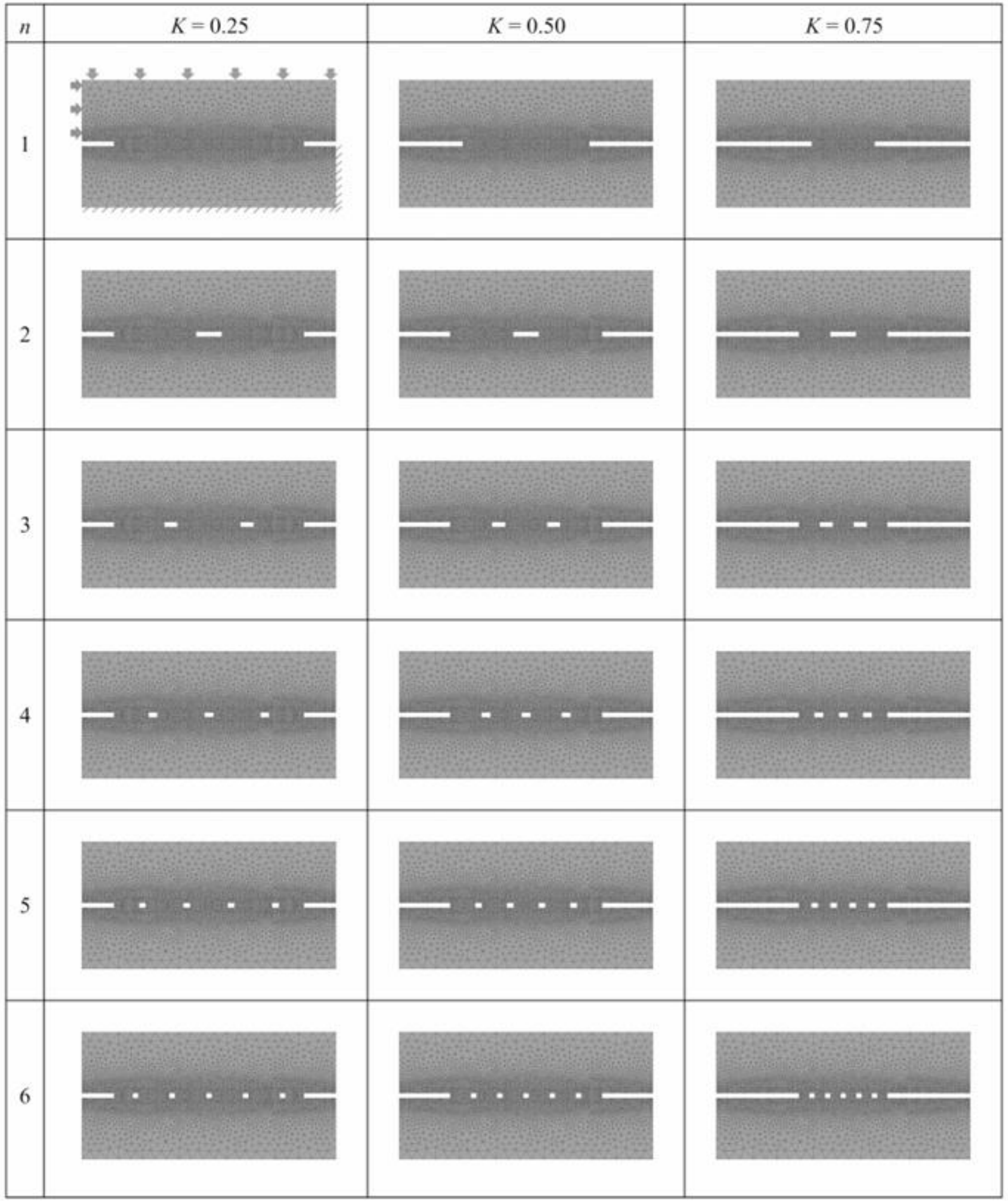
Properties	Experiment	Modelling
Young's modulus, E (GPa)	21.48	21.53
Poisson's ratio, μ	0.16	0.16
UCS (MPa)	87.80	87.75
Cohesion strength, c (MPa)	23.40	21.39
Internal friction angle, ϕ (°)	33.50	32.08
Shear strength (K=0.75) (MPa)	10.74	10.63
Shear strength (K=0.50) (MPa)	14.16	13.82
Shear strength (K=0.25) (MPa)	15.53	16.16

Numerical Models and Monitoring

The constant K values were set from 1 to 6, indicating that the intact rock bridge was divided into equivalent lengths.
(n is numbers of rock bridges)

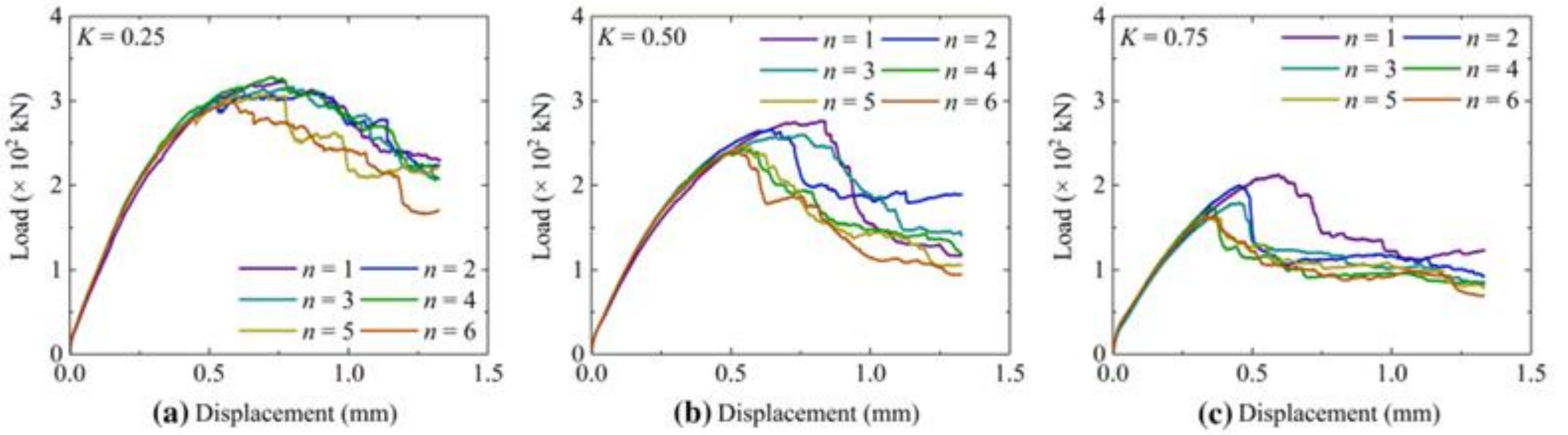
The dispersion of rock bridges became the only independent variable and was used to represent the scale

The failure process of the rock bridge was characterized by simulating acoustic emission (AE) by monitoring and analyzing the element velocity in the DEM.



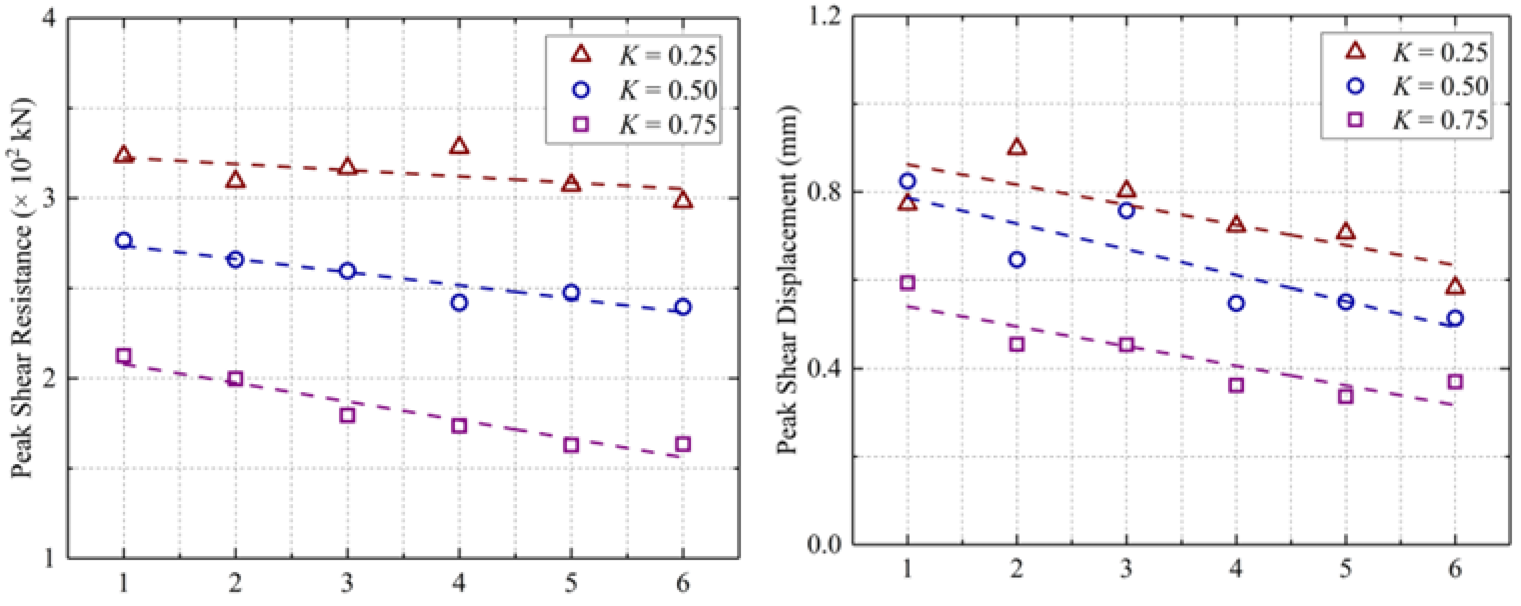
Peak Shear Resistance

The variation in shear load versus shear displacement of models with three constant K values and six different scales of rock bridges.



The peak shear resistance decreased with decreasing scale and the peak shear displacement also decreased with decreasing scale.

The results were consistent with the experimental studies of scale effects on shear behaviours of rock joints.

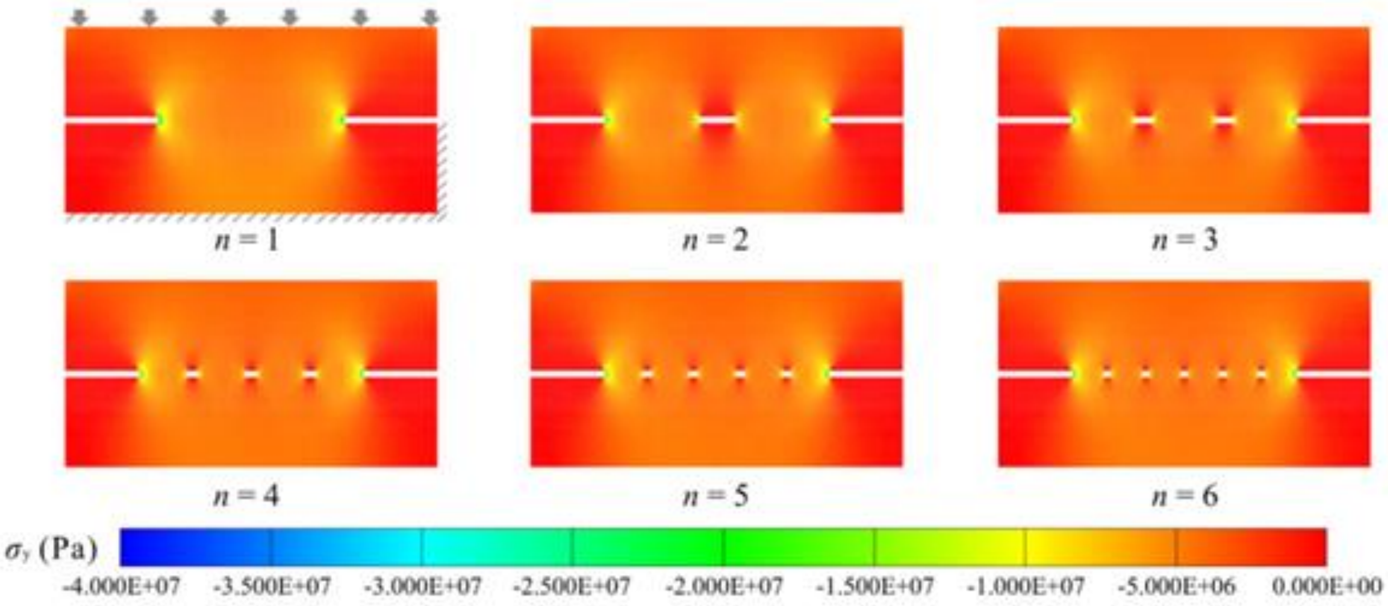


Shear Stress Field

Numerical simulations with a K value of 0.50 were taken as an example. When the numerical models were subjected to a constant normal compression without shear load and were stable.

The scale effects of rock bridges on the normal stress (σ_y) field were appreciable.

The end rock bridges bore the key normal compression, while the inside ones shared it almost equally.

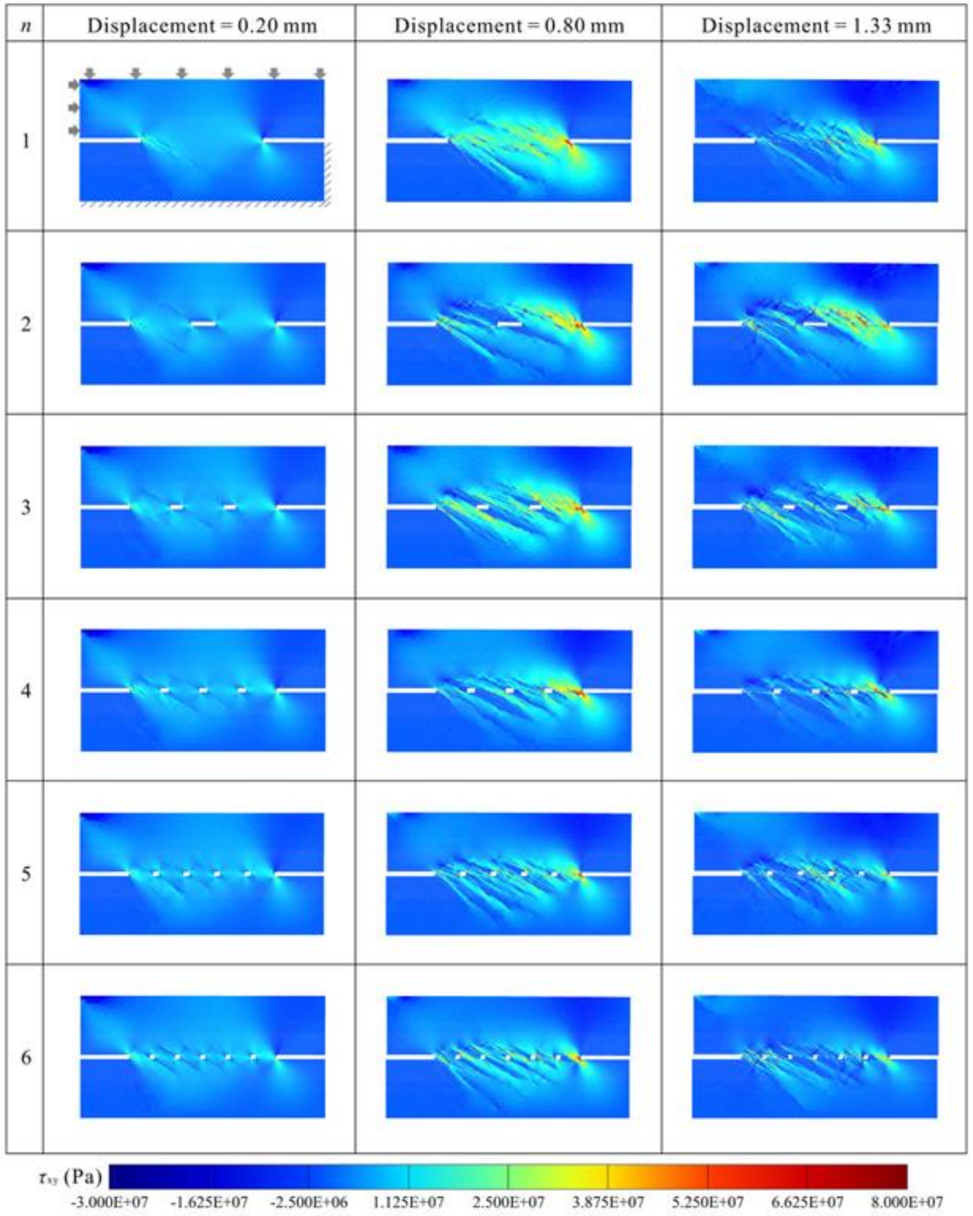


Shear Stress Field

The shear stress (τ_{xy}) field states of the pre-peak stages (displacement of 0.20 mm), approximate peak stages (displacement of 0.80 mm) and post-peak stages (displacement of 1.33 mm).

During the pre-peak stages, τ_{xy} distribution of rock bridges was not uniform, and significant stress concentration appeared at the upper tips of the left joints and the lower tips of the right joints.

When the numerical models lay in post-peak stages, the bearing capacity dropped significantly, and the concentrated values and areas also decreased with decreasing scale.

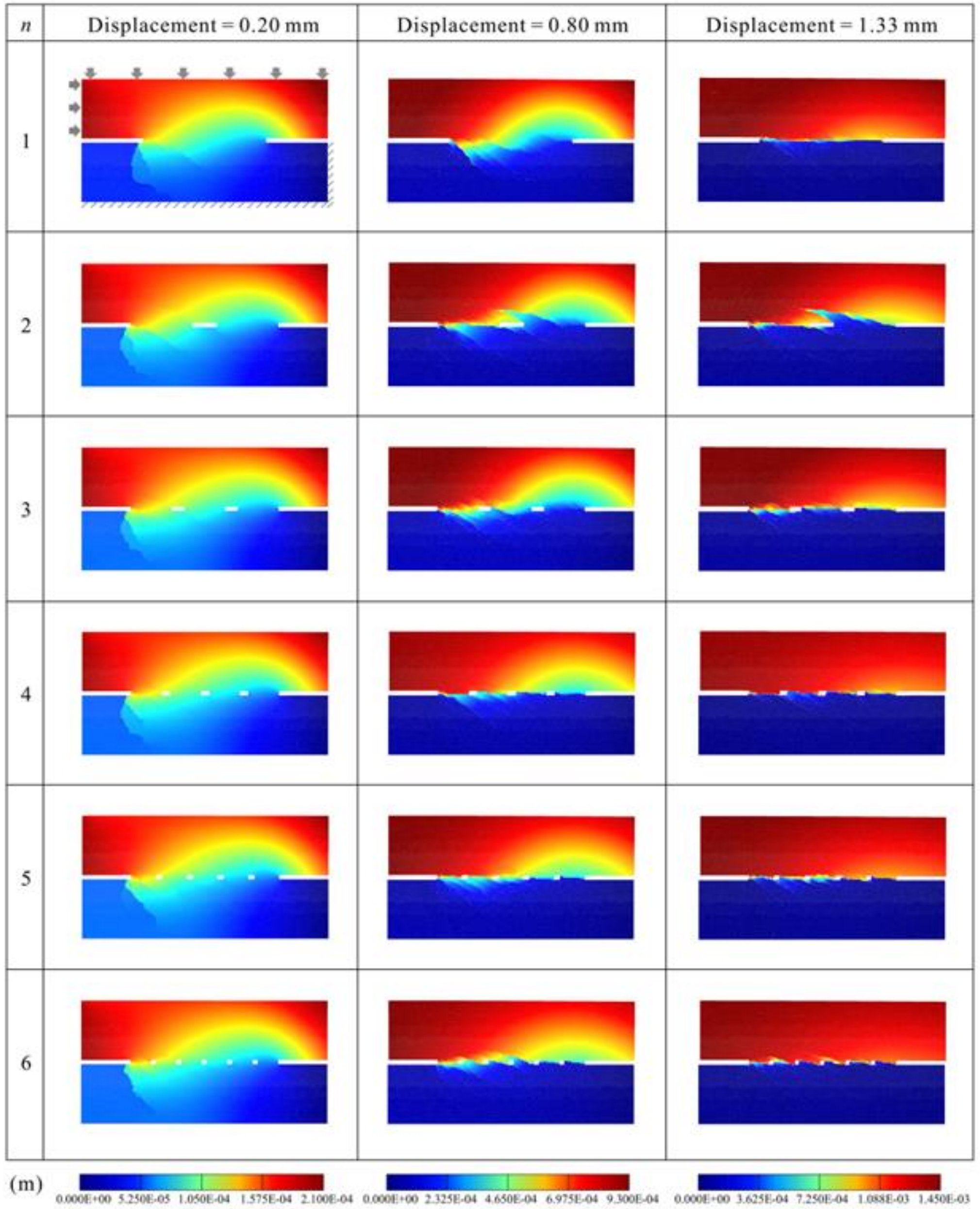


Displacement Field

At the pre-peak stages, an intuitive result was the arc distribution of displacement.

At the approximate peak stages, it moved further away from the load, and the displacement field on the left side of the arc varied significantly, indicating the failure of the left rock bridges. Another change was that the area of the arc decreased, while the reduction increased with decreasing scale.

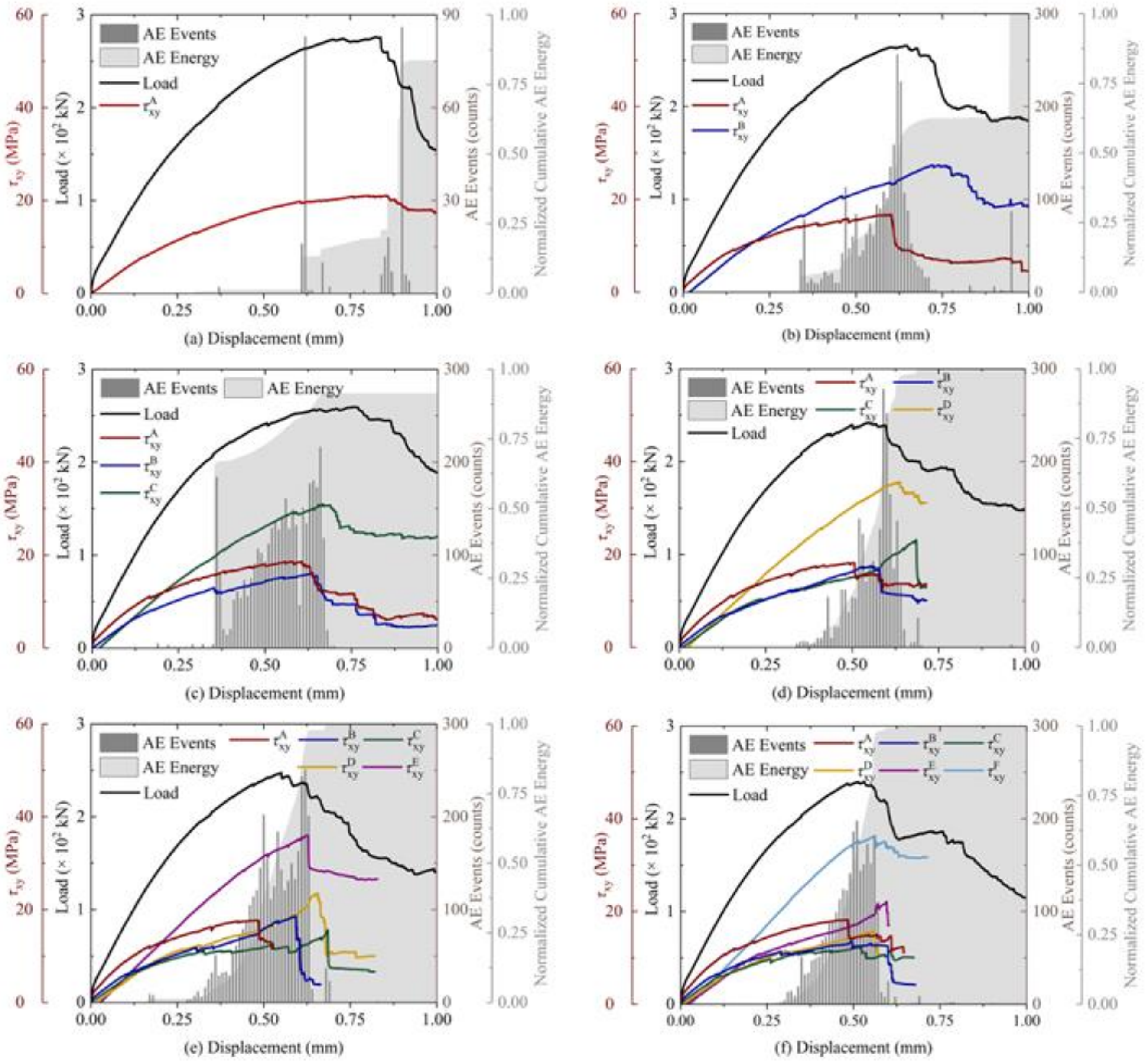
At the post-peak stages, the arc was invisible, and the displacement fields strongly separated along the rock bridges, indicating that the cracks had a largescale coalesce. Formed rough macro fractures provided residual shear resistance, and the roughness basically decreased with decreasing scale.



AE Characterization

AE signals accompanied by fracturing events are always operated in the form of waveform analysis to acquire AE parameters (AE events and AE energy) to quantify the failure process of rocks.

Several sudden increases in AE events and cumulative AE energy can be observed, which the last increase was the strongest, corresponding to the peak stress point and significant drops in τ_{xy} curves of the final rock bridges. With decreasing scale, the shear resistant zone was more crushed, leading to a superposition of the precursors.

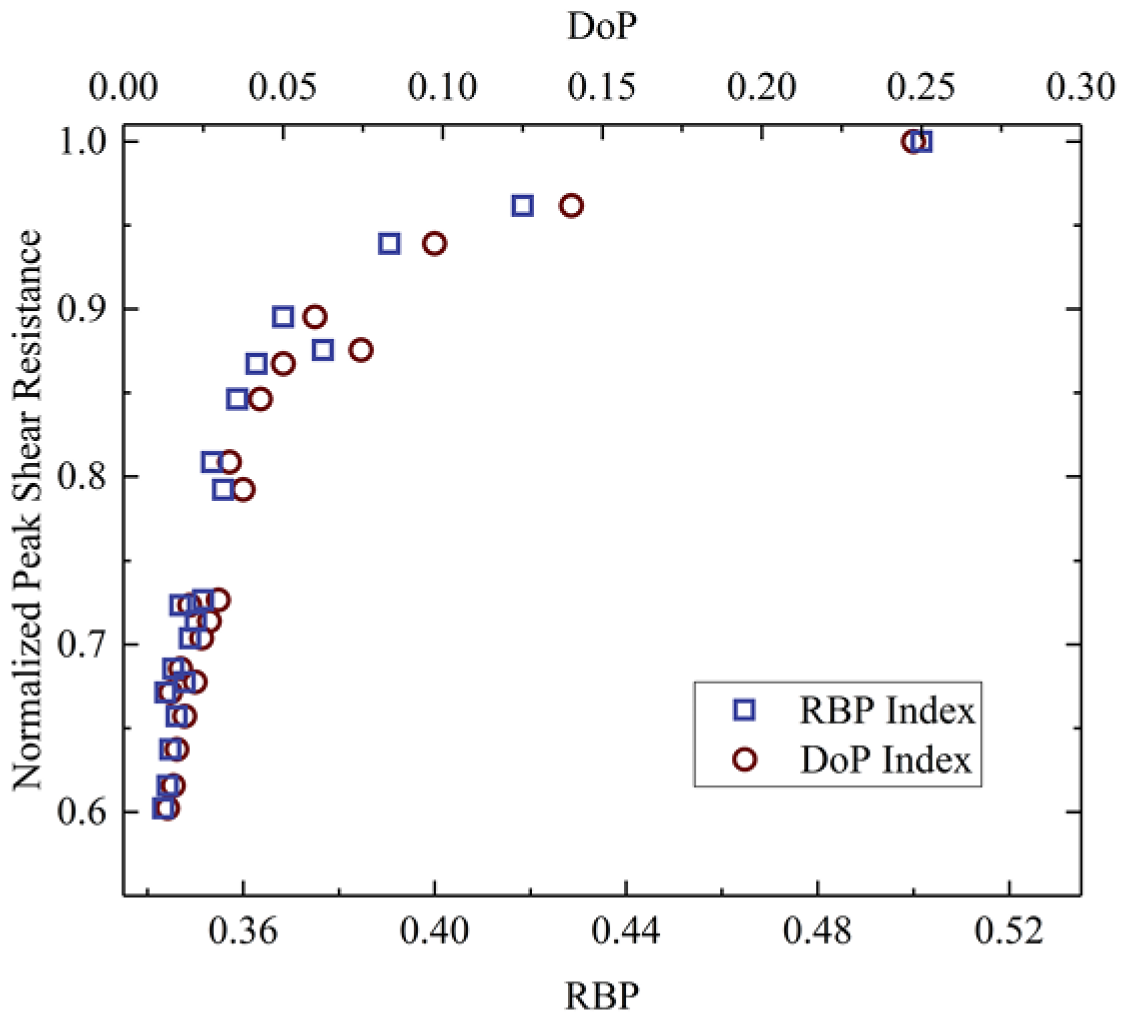


RBP and DoP index

The rock bridge potential index reveals that rock bridge strength is a manifestation of overall rock mass strength.

The DoP index consider the impact of discontinuous joint tips on stress distribution characteristics.

Although the span was different, both indices showed consistent feasibility in evaluating the scale effects.



- It is necessary to consider failure mechanisms in addition to geometric parameters when defining rock bridges.
- Shear resistance decreased with decreasing scale, and the reduction increased with increasing joint persistence.
- Rock bridges at the end bore the initial key resistance, and the stress concentration area and value decreased with decreasing scale.
- The uneven distribution of the displacement field of rock bridges was in an arc manner moving and degrading away from the load, illustrating the subsequent failure of multiple rock bridges. The relative degradation area of this arc increased with decreasing scale.
- Propagation of wing cracks was not sensitive to the scale, while the asperity of macro shear fractures mainly formed by secondary cracks basically decreased with decreasing scale.
- Dispersion of rock bridges might lead to the overlap of the precursors identified by intense AE events and abrupt AE energy.
- A unit with joint persistence of 0.20 might be a scale threshold to identify a rock bridge.

Thanks for your attention