Correlation of joint roughness coefficient and permeability of a fracture

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Presenter：Che-Wei Yeh(葉哲瑋)

Advisor：Prof. Jia-Jyun Dong

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Outline

- Introduction
- Methodology
- Result
- Conclusion

Introduction

The fluid transport in fractures has important applications in geosciences：

- Geothermal energy extraction
- Hazardous waste disposal
- Sequestration of greenhouse gases
- Enhanced oil recovery

Introduction

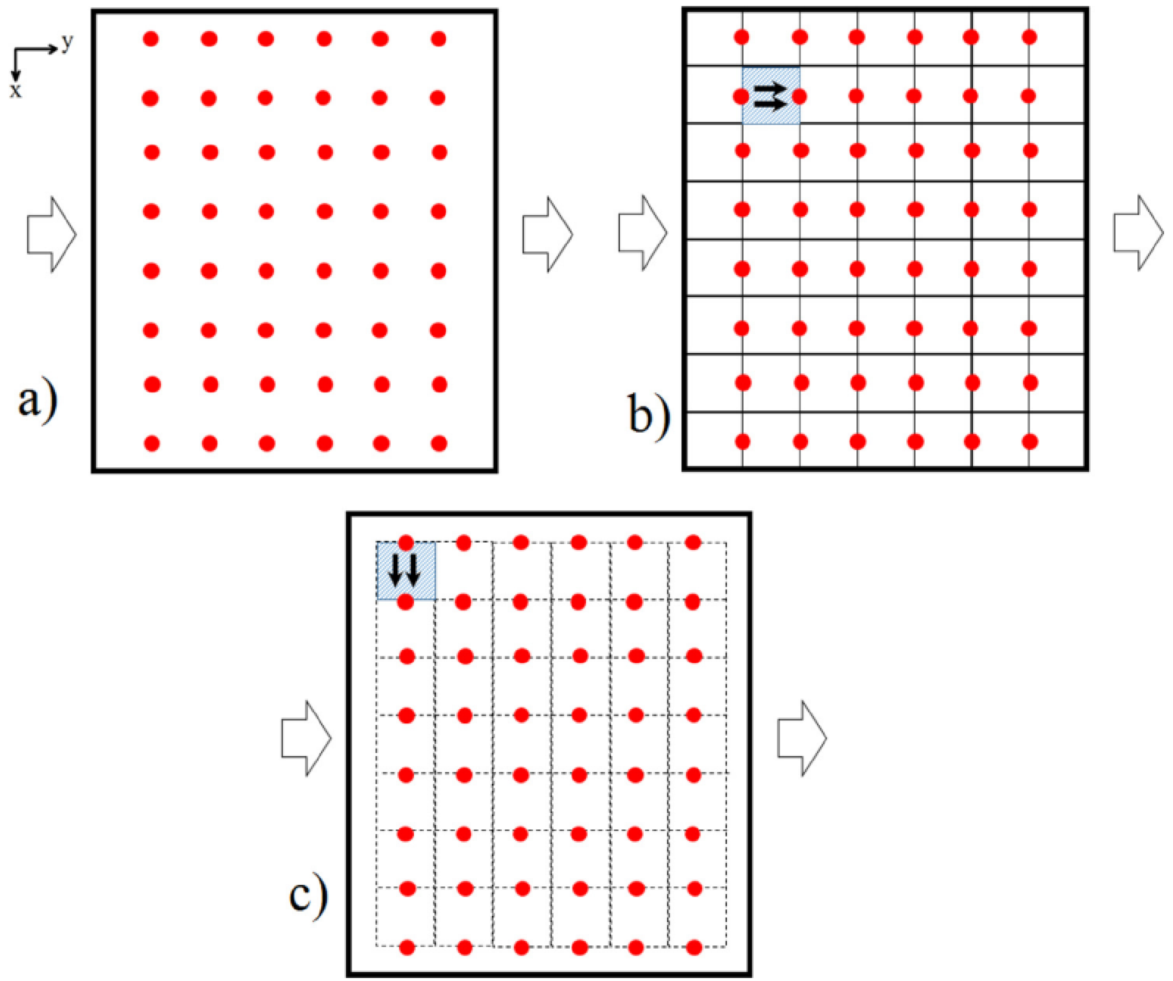
Previous modeling methods have shortcomings.

- Ignoring or underestimating important parameters
- Mass calculation

- Purpose

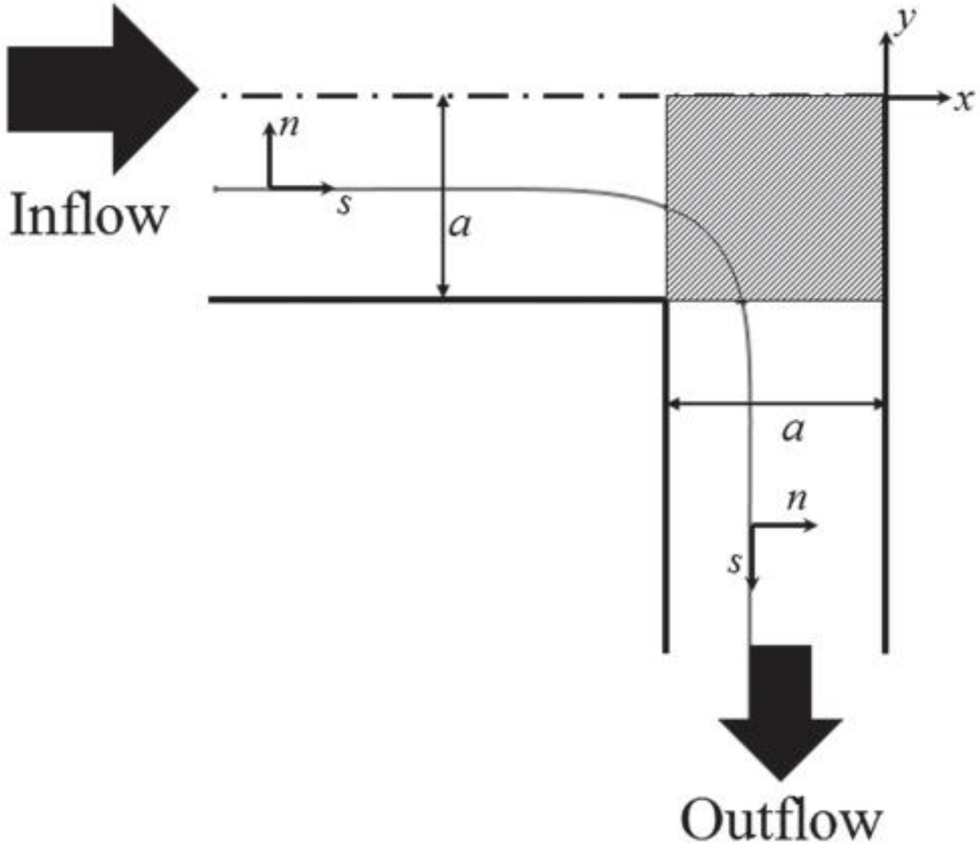
A new modeling approach for fluid transport between rough surfaces is presented in this paper, which addresses all shortcomings the previous modeling methods.

Methodology



The current model: (a) locations defined for fracture discretization; (b) cells defined for flow in the *y*-direction; (c) cells defined for flow in the *x*-direction

Methodology



The schematic of the stagnation-point flow

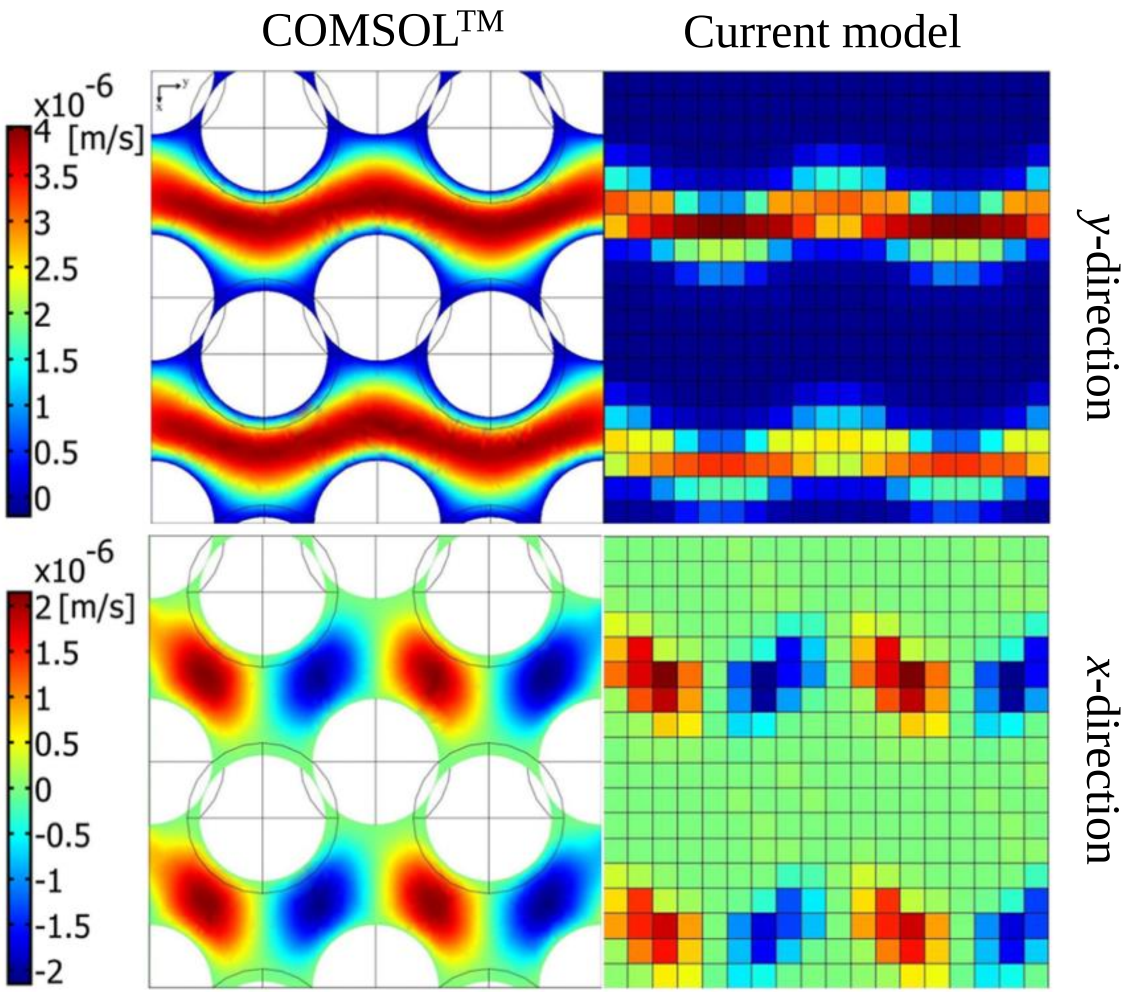
$$\frac{\Delta p}{v}$$

Δp ： pressure drop
v ： flow velocity (m/s)

Methodology

Comparison of permeability values predicted using COMSOL™ package and the current model.

Case		Permeability (m^2)		Logarithmic difference	Percentage difference (%)
No.	Code	COMSOL™	Presented model		
1	S1.5	2.64e − 6	3.17e − 6	− 0.08	− 20.0
2	S1.1	7.74e − 7	6.99e − 7	0.04	9.7
3	S0.9	3.68e − 7	3.10e − 7	0.07	15.8
4	P1.5	4.60e − 6	5.46e − 6	− 0.07	− 18.7
5	P1.1	2.49e − 6	2.90e − 6	− 0.07	− 16.5
6	P0.9	1.71e − 6	1.96e − 6	− 0.06	− 14.6
7	PT1.1	6.28e − 8	5.12e − 8	0.09	18.5
8	MT1.1	1.67e − 7	1.66e − 7	0.00	0.6
9	M1.1	1.57e − 6	1.55e − 6	0.01	1.3
10	D0.1	3.09e − 8	2.52e − 8	0.09	18.5
11	D0.5	7.28e − 7	7.75e − 7	0.00	0.9
12	D0.9	2.26e − 6	2.44e − 6	− 0.03	8.0



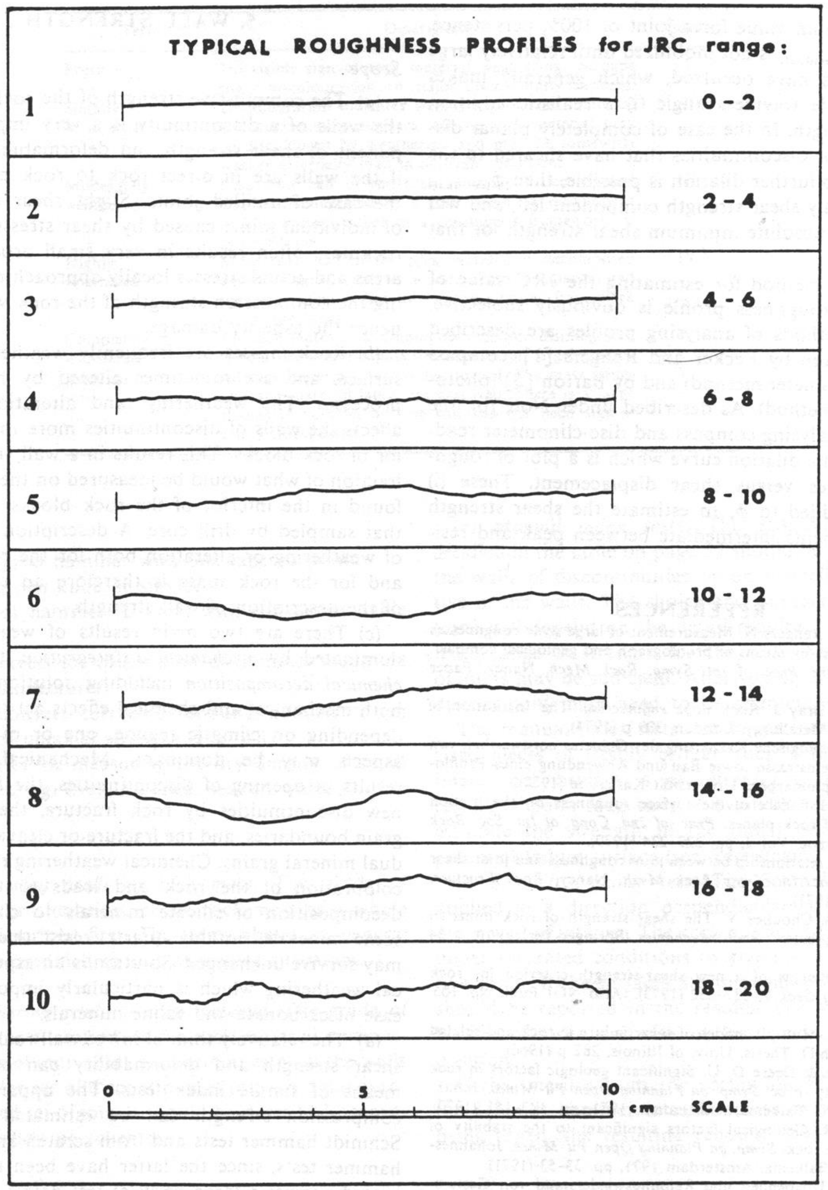
Colormaps of velocity distributions in the y (top) and x (bottom) directions predicted using COMSOL™ (left) and the current model (right) for case M1.1.

Methodology

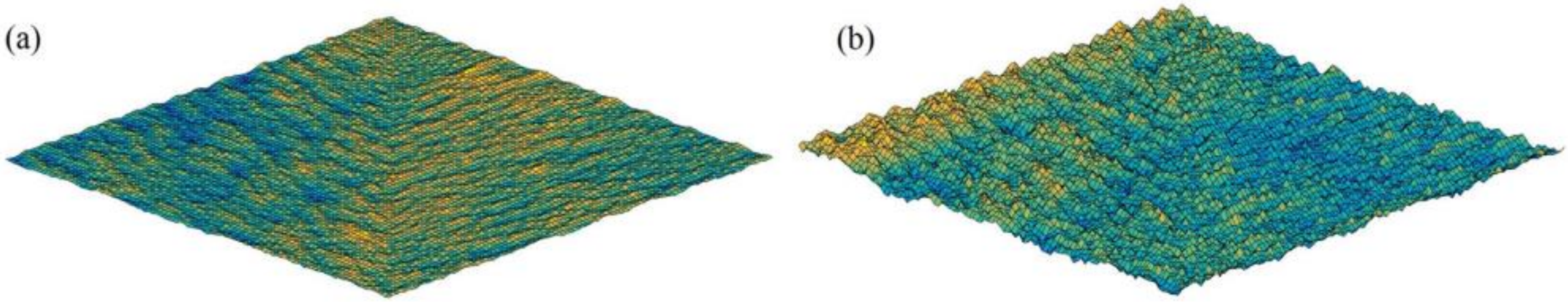
the correlation between the JRC and Z_2 parameter is the strongest and has form：

$$JRC = 60.32\, Z_2 - 4.5$$

JRC：joint roughness coefficient
Z_2 ： the root mean square of the first derivative of the profile



Methodology



Two sample surfaces reproduced by the compound model; (a) JRC = 1; (b) JRC = 10

Result

JRC	Mechanical aperture (mm)	Hydraulic aperture (mm)
5	1	0.0178854
11	1	0.00249183
15	1	0.00114755
19	1	0.0006355

$$k = \frac{e_m^2}{12}$$

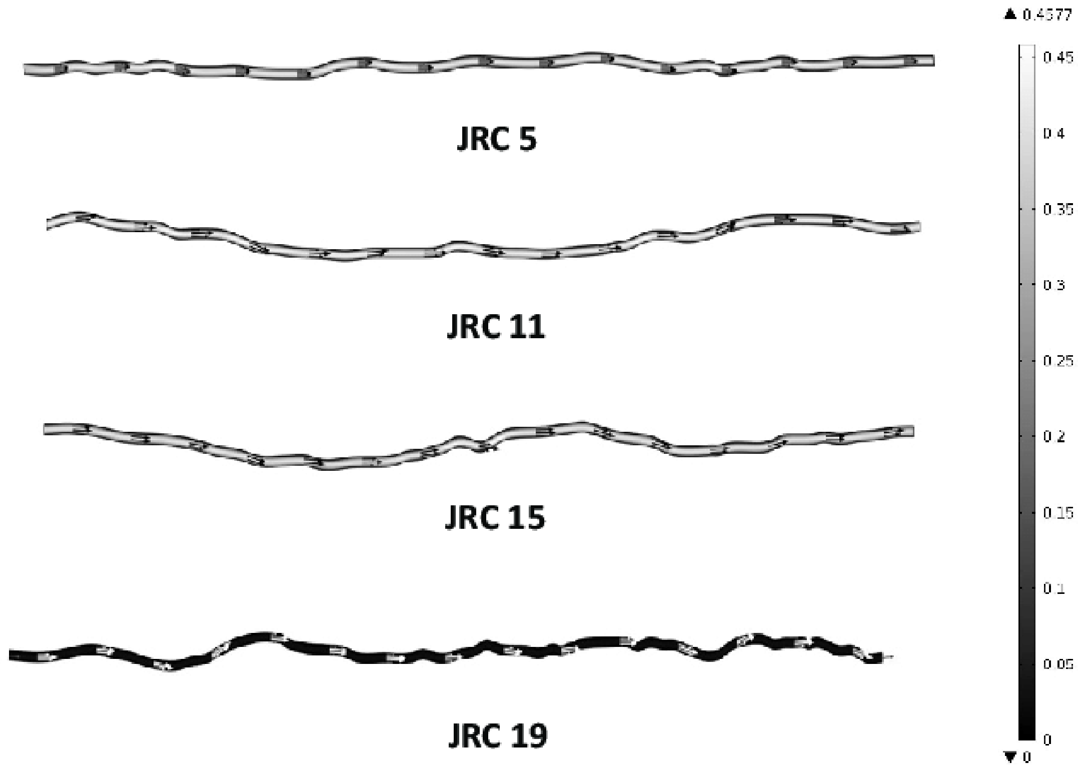
k ：permeability of a fracture
e_m ：aperture height (mechanical aperture)

mechanical aperture：Vertical distance between inner walls of joint planes

$$k = \frac{e_h^2}{12}$$

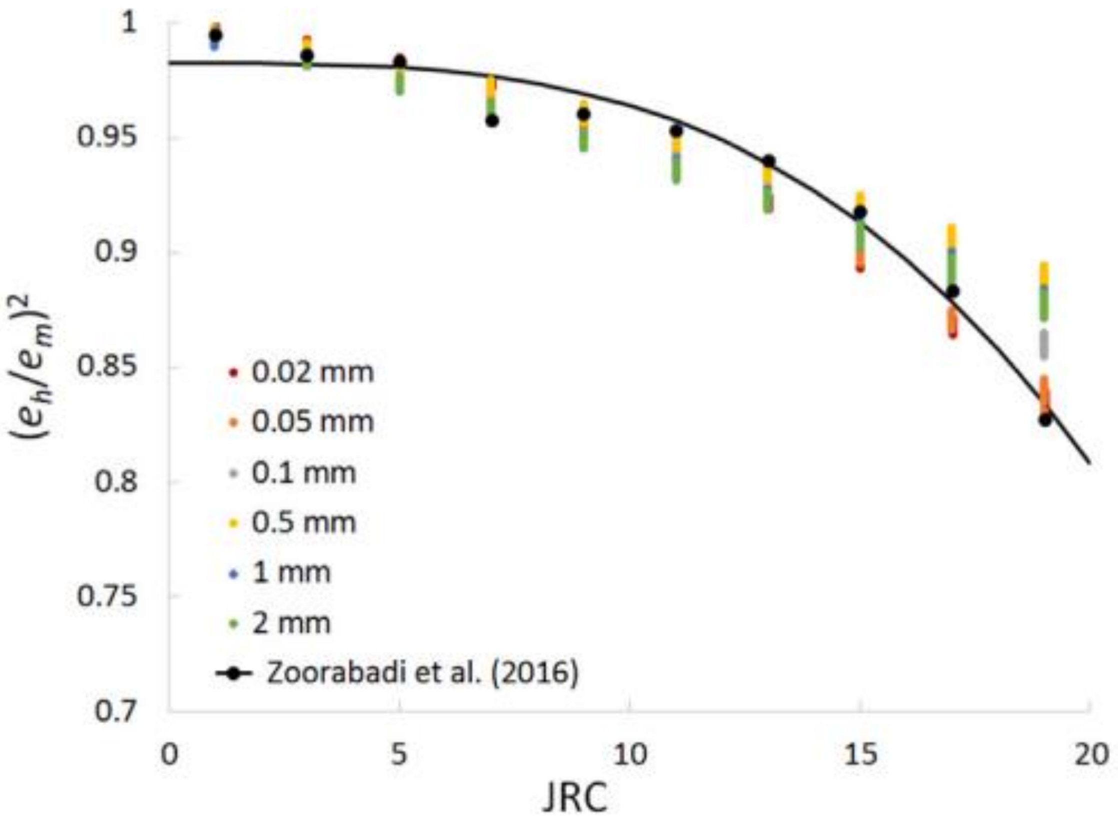
k ：permeability of a rough fracture
e_h ：hydraulic aperture

hydraulic aperture ：The equivalent inner width of a parallel plate passing a certain flow under a certain stress



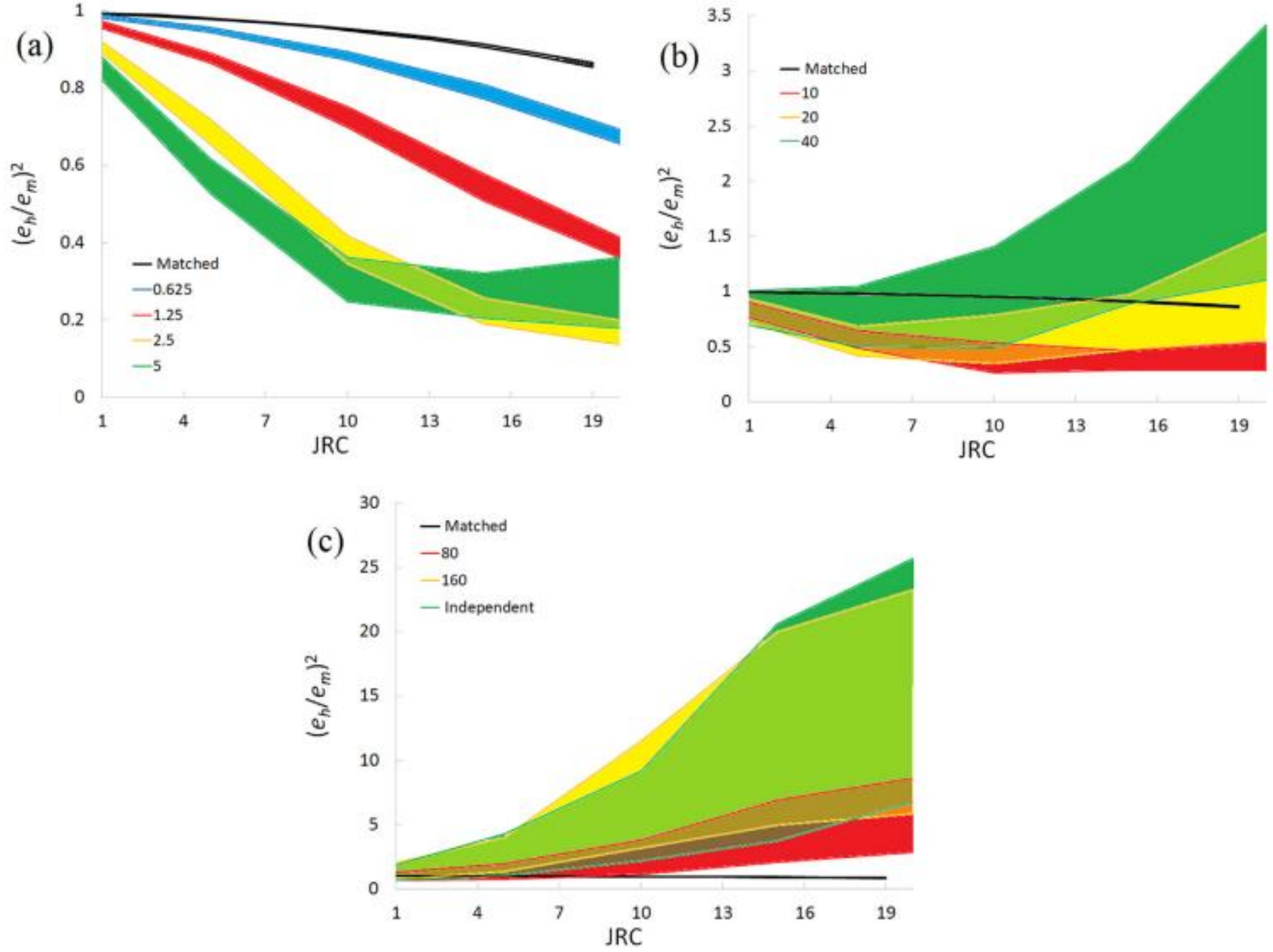
$$e_h = \frac{e_m^2}{JRC^{2.5}}$$

Result

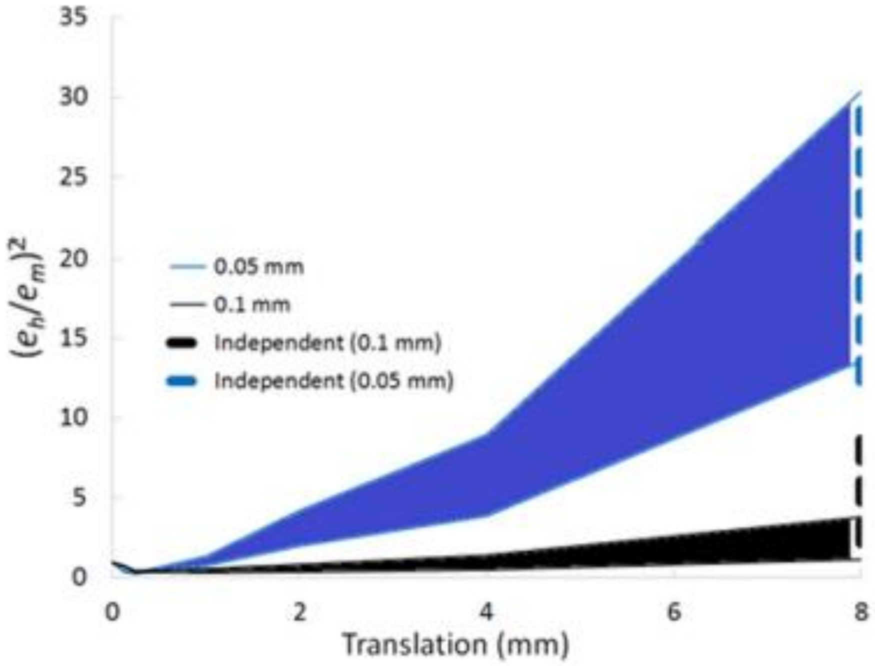


Correlation between the JRC and permeability ratio in different aperture sizes for exactly matched surfaces. In each case, 100 different samples are reproduced and the resulting ranges are shown.

Result – Translated surfaces



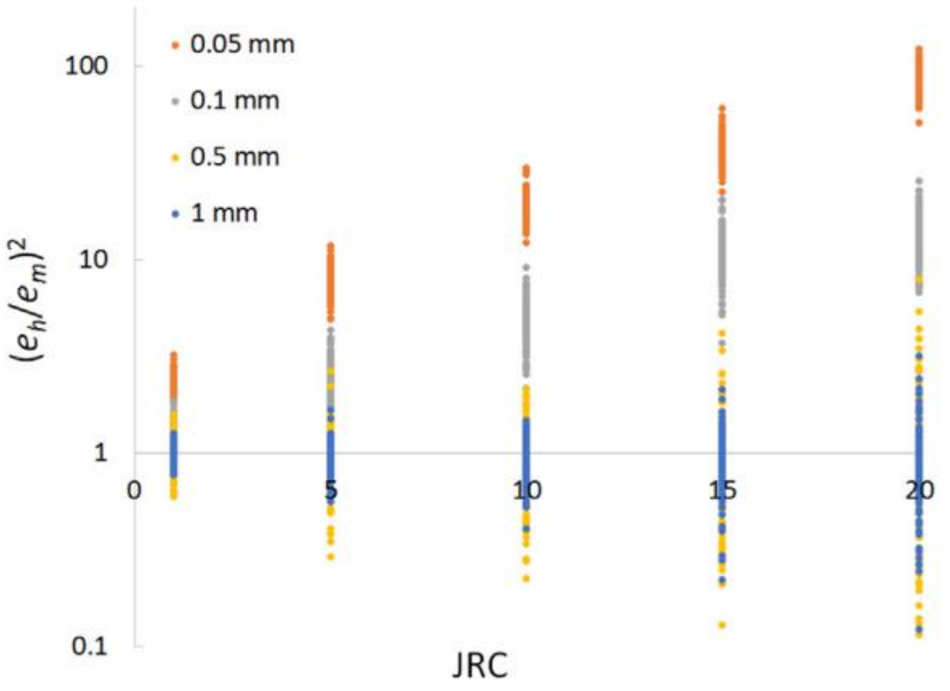
The effect of translation of the surfaces for different JRC values (aperture size of 0.1 mm); (a) translation to aperture ratio of 0–5; (b) translation to aperture ratio of 10–40; (c) translation to aperture ratio of 80–160.



The effect of aperture size in different translations for JRC value of 10.

Result — Independent surfaces

1. For large apertures, the cubic law can predict the average permeability with an acceptable accuracy.
2. For small aperture sizes and moderate to high JRCs, the cubic law underestimates the permeability up to 2 orders of magnitude.
3. The JRC effect is significantly controlled by the aperture size.



Correlation between the JRC and permeability ratio for different aperture sizes with independent surfaces.

Result – Sample size effect

The average and standard deviations of permeability ratios for 1000 samples with an aperture size of 0.1 mm and independent surfaces.

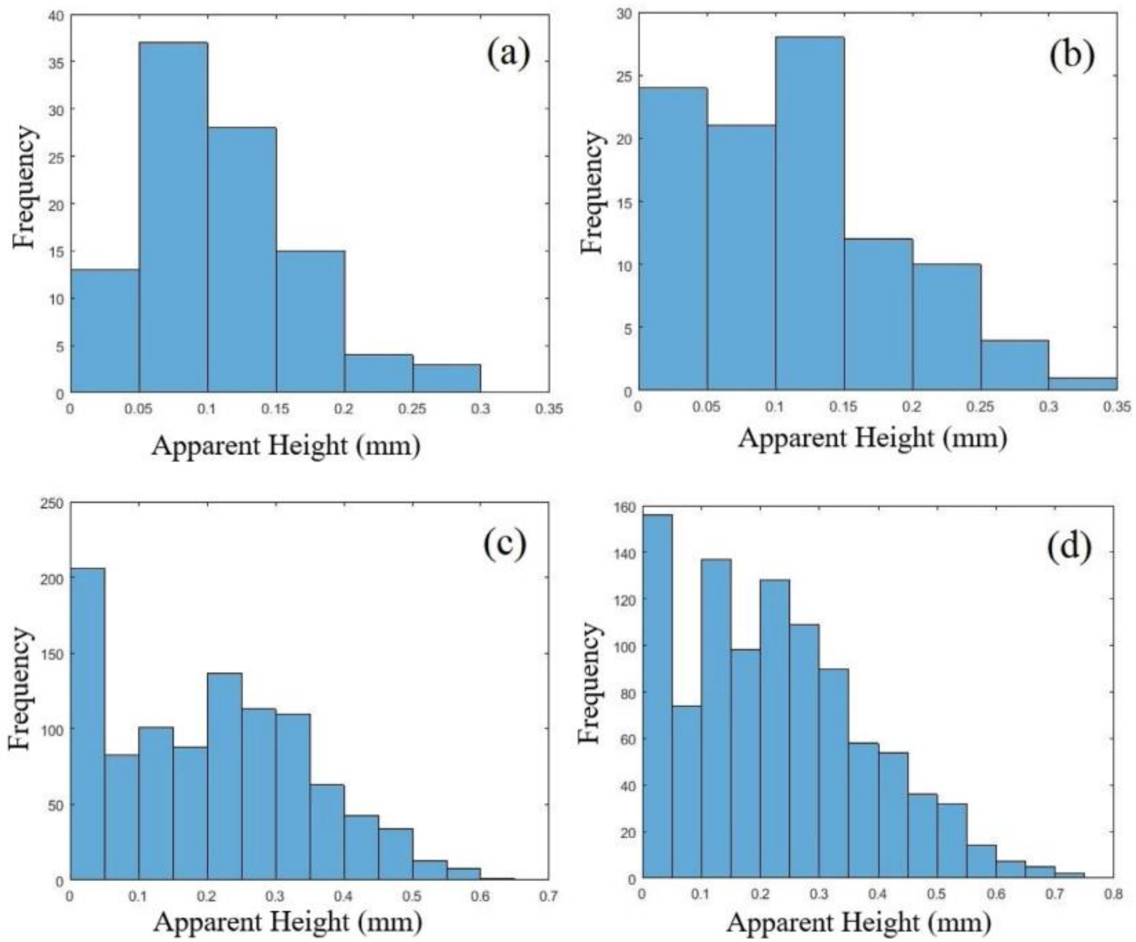
JRC	Average	Standard deviation Sample size				
		$2.5 \times 2.5\,cm^2$	$10 \times 10\,cm^2$	$20 \times 20\,cm^2$	$50 \times 50\,cm^2$	$1 \times 1\,m^2$
1	1.24	0.233	0.0582	0.0291	0.0116	0.00582
5	2.36	0.576	0.144	0.0721	0.0288	0.0144
10	4.83	1.25	0.311	0.156	0.0623	0.0311
15	9.13	2.72	0.679	0.340	0.136	0.0679
20	14.7	4.29	1.07	0.537	0.215	0.107

Result－Sample size effect

First sample　　Second sample

Sample size：2.5×2.5 cm^2

Sample size：25×25 cm^2



Histograms of apparent height distributions of one side of samples with an aperture size of 0.1 mm and a JRC value of 10 for independent surfaces; (a) sample size 2.5 × 2.5 cm2 , first sample; (b) sample size 2.5 × 2.5 cm2 , second sample; (c) sample size 25 × 25 cm2 , first sample; (d) sample size 25 × 25 cm2 , second sample.

Result－Contact area

Contact area percentages of 100 samples with different aperture sizes and JRC values for independent surfaces.

JRC	Aperture size (mm)			
	0.05	0.1	0.5	1
	Contact Area Percentage (%) Average, Median, Skewness			
1	1.17, 0.32, 3.46	0.208, 0, 4.53	0, 0, –	0, 0, –
5	5.18, 3.44, 1.76	1.89, 0.62, 3.02	0, 0, –	0, 0, –
10	6.99, 4.16, 3.04	3.51, 2.07, 2.85	0.0481, 0, 5.93	0, 0, –
15	9.64, 6.34, 2.87	4.60, 3, 1.97	0.371, 0.09, 4.06	0, 0, –
20	7.13, 4.71, 3.59	6.39, 3.92, 2.97	1.29, 0.29, 4.23	0.0092, 0, 8.21

Conclusion

- Even a translation of 62.5 μm for an aperture size of 0.1 mm has a noticeable effect on the permeability range.
- For large aperture sizes, the cubic law can predict the permeability with a reasonable accuracy.
- While for small aperture sizes and moderate to high JRC values, the cubic law underestimates the permeability up to 2 orders of magnitude.
- The aperture estimation error could be considerably increased for larger sample sizes.

Thank you for your attention

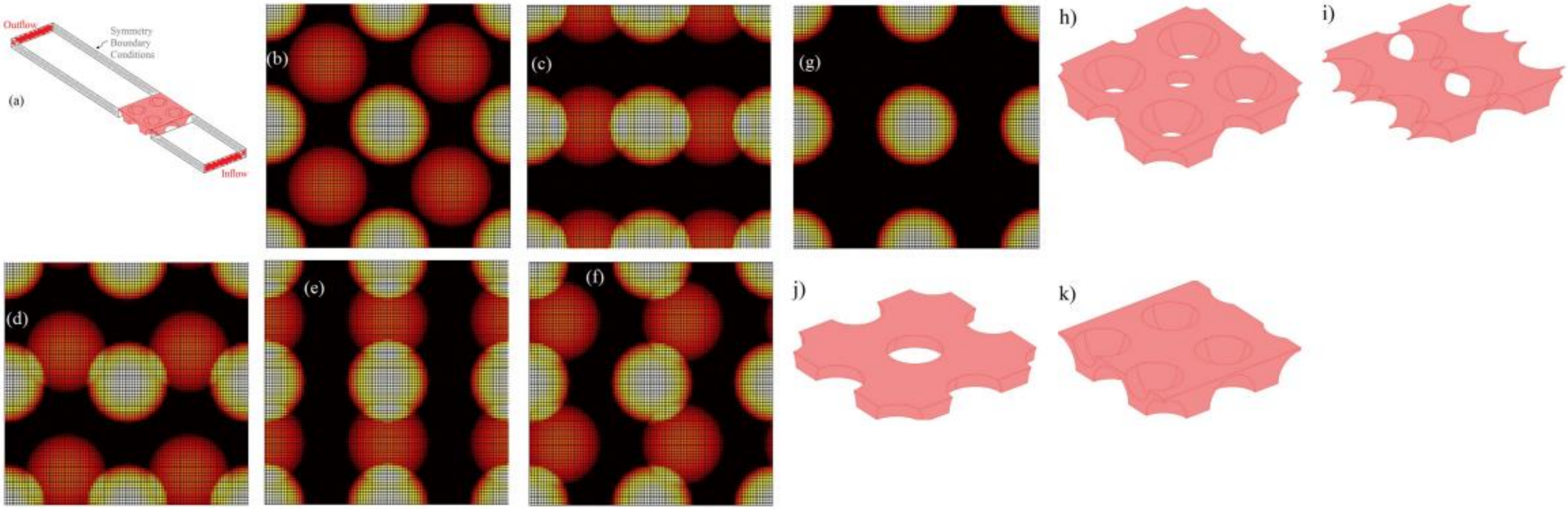


Fig. 3. Cases used for model verification: **(a)** The sample geometry used in COMSOL™; **(b)** Staggered (S) arrangement; **(c)** Parallel (P) arrangement; **(d)** Middle (M) arrangement; **(e)** transverse parallel (PT) arrangement; **(f)** transverse middle (MT) arrangement; **(g)** Smooth top plate case (D). In subfigures (b–f), the asperities on the bottom plates are shown with brighter colors. **(h)** 3D geometry of the case S0.9; **(i)** 3D geometry of the case P0.9; **(j)** 3D geometry of the case D0.5; **(k)** 3D geometry of the case M1.1.