The Importance of Rock Fracture Mechanics in Cap Rock Stability Research for CO2 Storage Field

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Jan 19th,2010

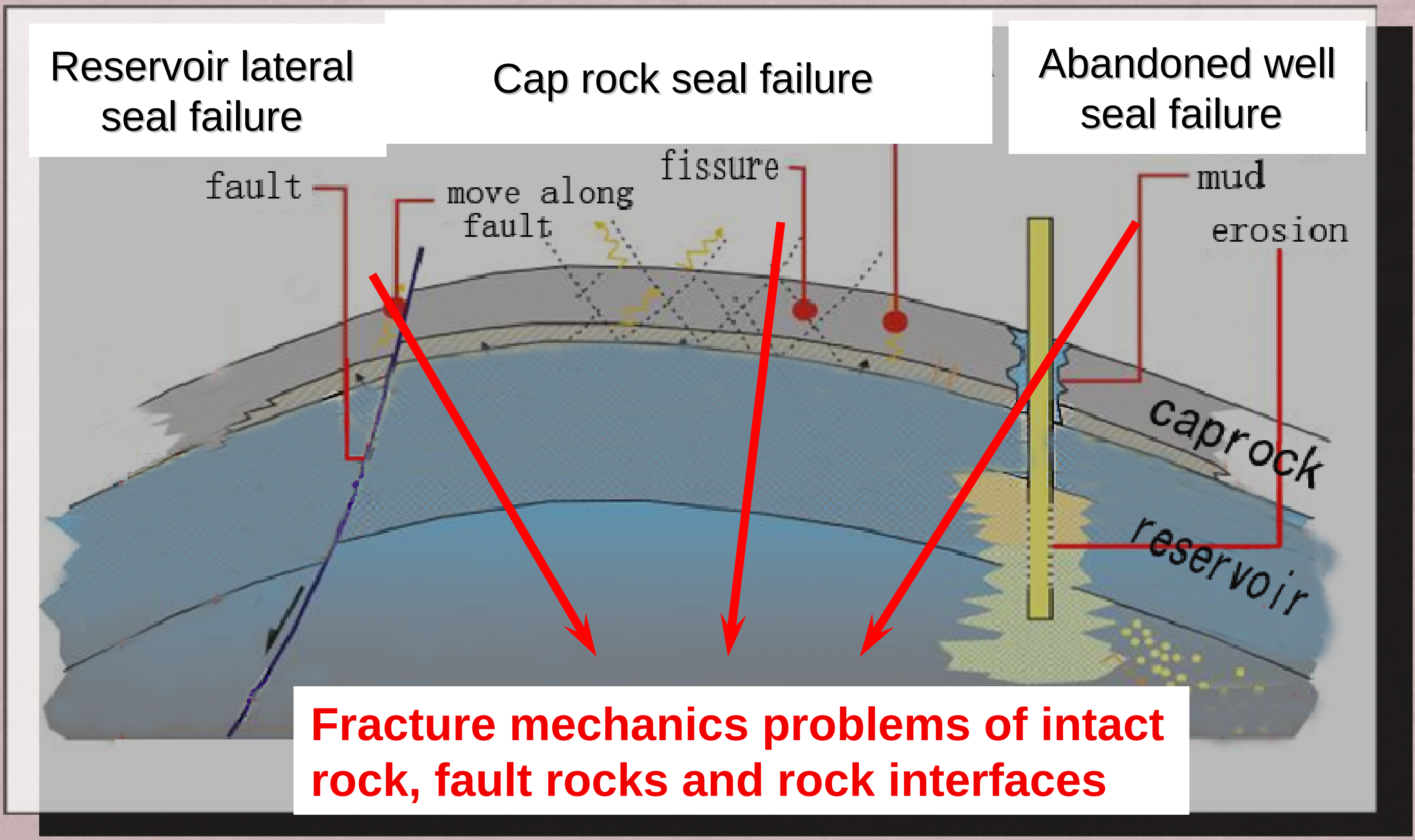
OUTLINE

- Key Geomechanical Issues in Cap Rock Stability Research for CO_2 storage;
- Three Aspects of Fracture mechanics for the cap rock stability Research;
- A Crucial Problem of Rock Fracture Mechanics;
- What have we prepared for solving this problem?
- Prospecting and Conclusions

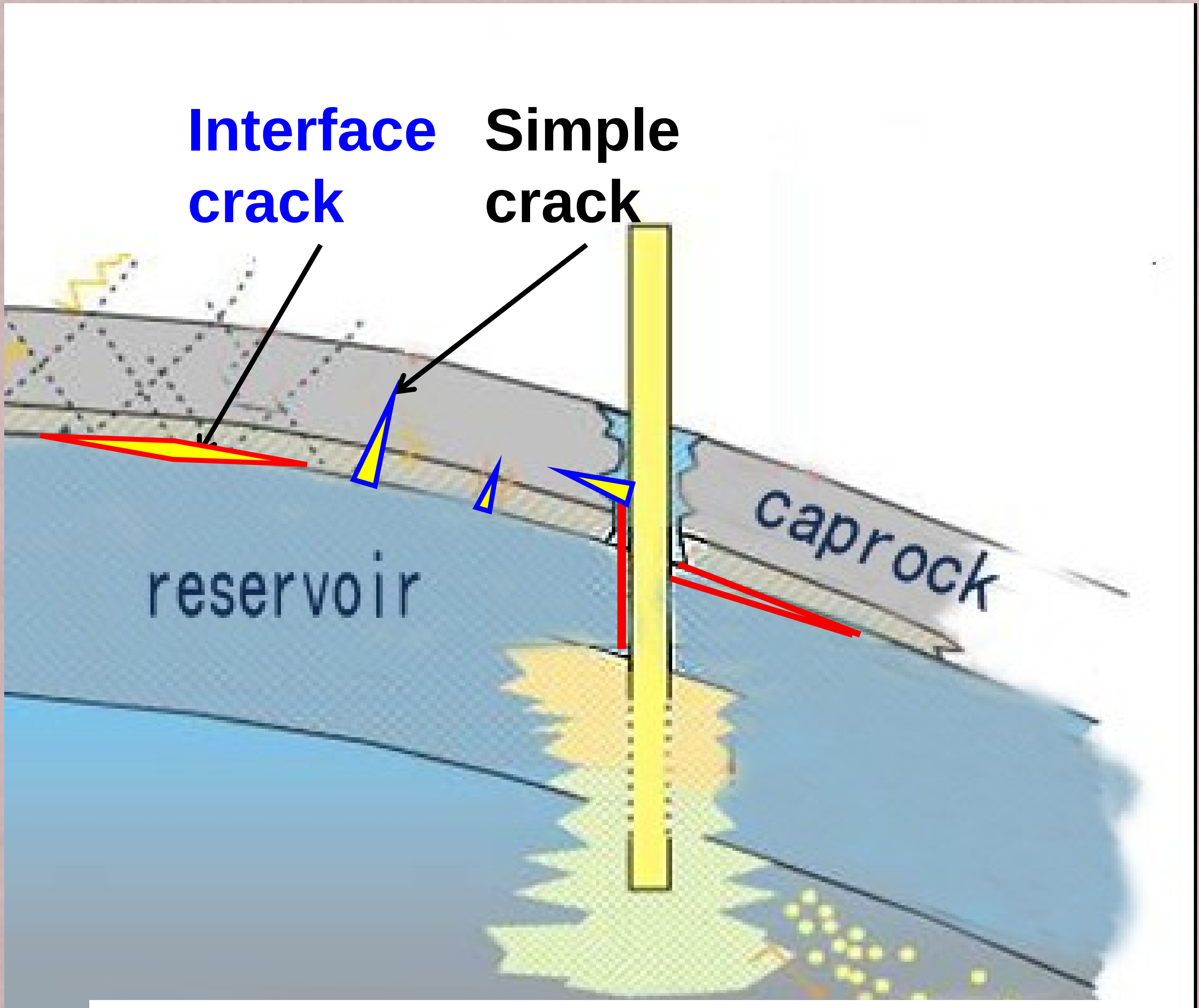
Key Geomechanical Issues in Cap Rock Stability Research for CO_2 storage

- Maximum sustainable pore fluid pressure in the reservoirs for the cap rock;
- Maximum sustainable pore fluid pressure in the reservoirs for the fault and reservoir seals;
- Stability of fault system and possibility of fault activation
- Human engineering activities influence on the stability or the seal of cap rock.
- Weakening of the physical and mechanical properties of seal rocks in the coupled fluid-stress-temperature field

Three Aspects of Fracture mechanics for the cap rock stability Research

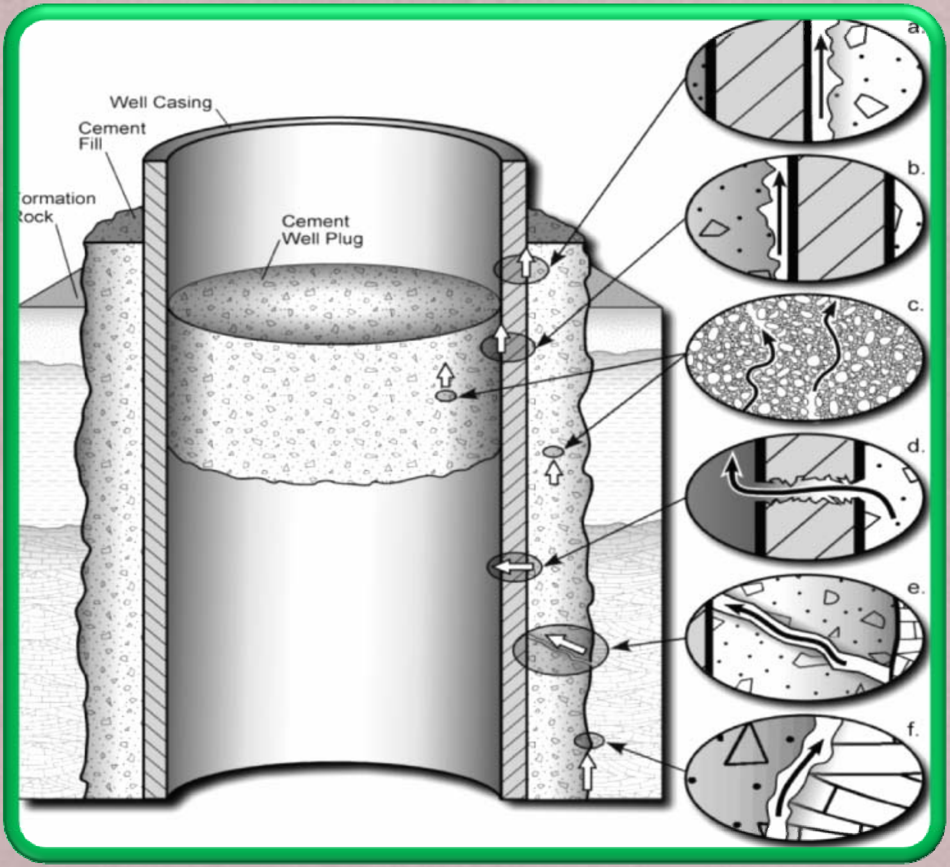


Two types of crack



Fracture of intact rock and rock interface

Rock Fracture Problems related to the Wells



POTENTIAL LEAK RISK IN CO_2 STORAGE
(Gasda et al. 2004)

Possible leakage pathways through an abandoned well:

a) Between casing and cement;

b) Between cement plug and casing;

c) Through the cement pore space;

d) Through casing;

e) Through fractures in cement;

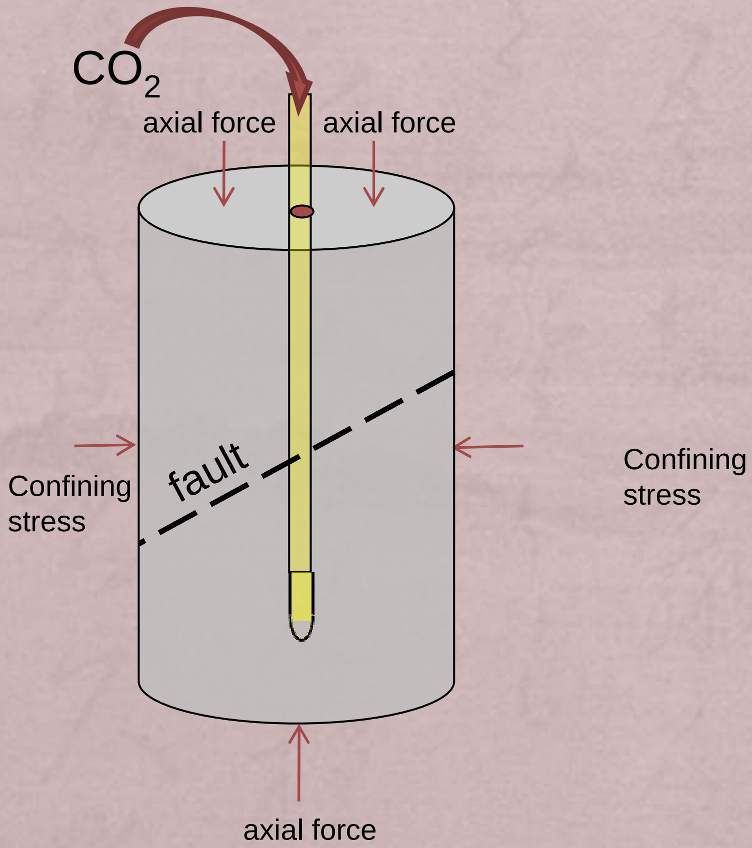
f) Between cement and rock

Fracture of concrete and rock;

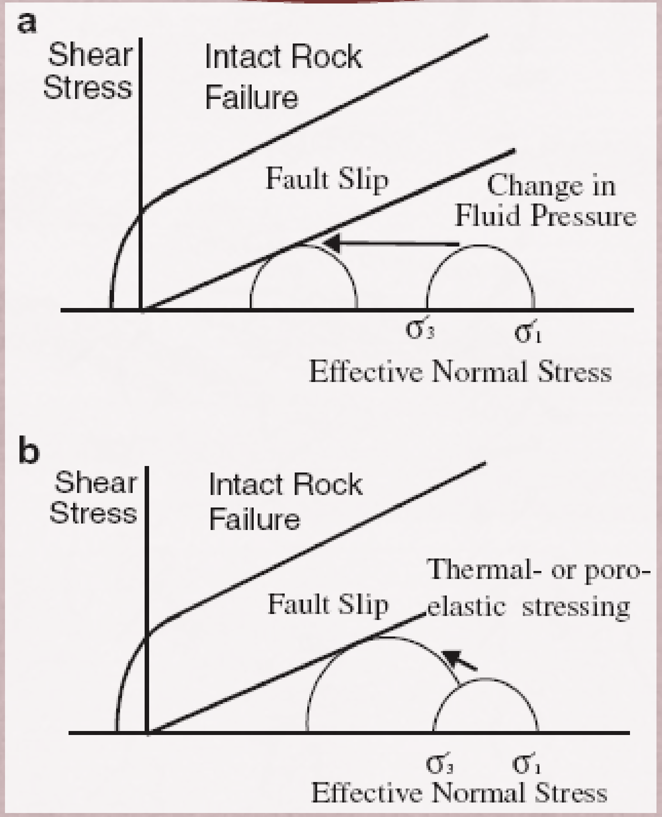
Interface fracture of concrete;

Interface fracture of concrete and rock.

Key Problem of Rock Failure After CO_2 injection



Mohr-coulomb

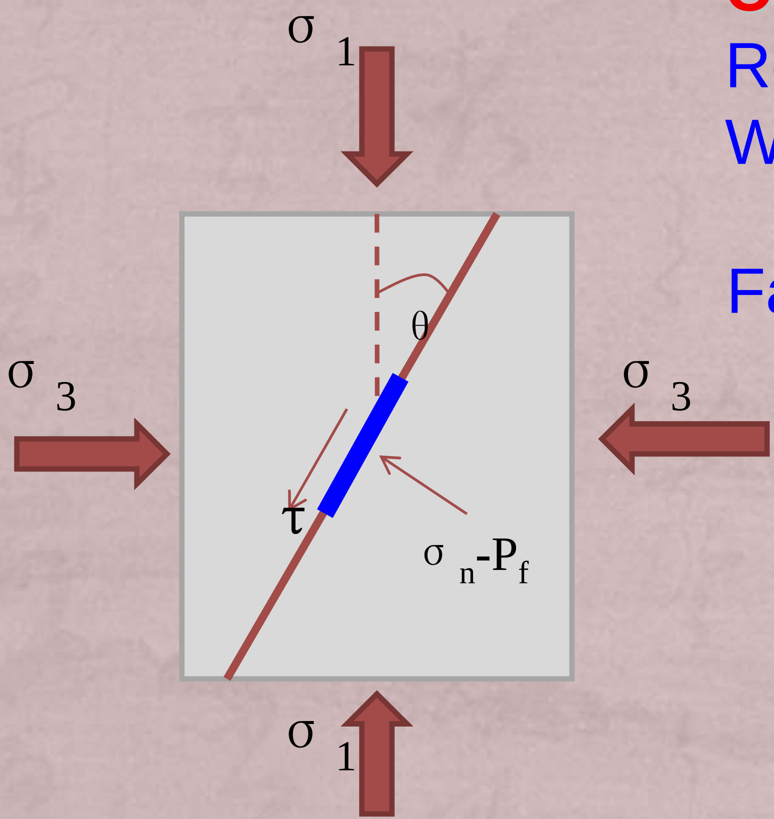


Crucial Rock Fracture Problem

Rock fracture toughness

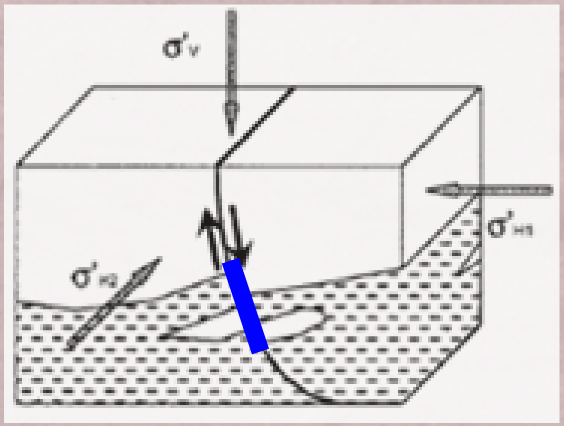
Weakening after CO2 injection

Fault activation → rock fracture



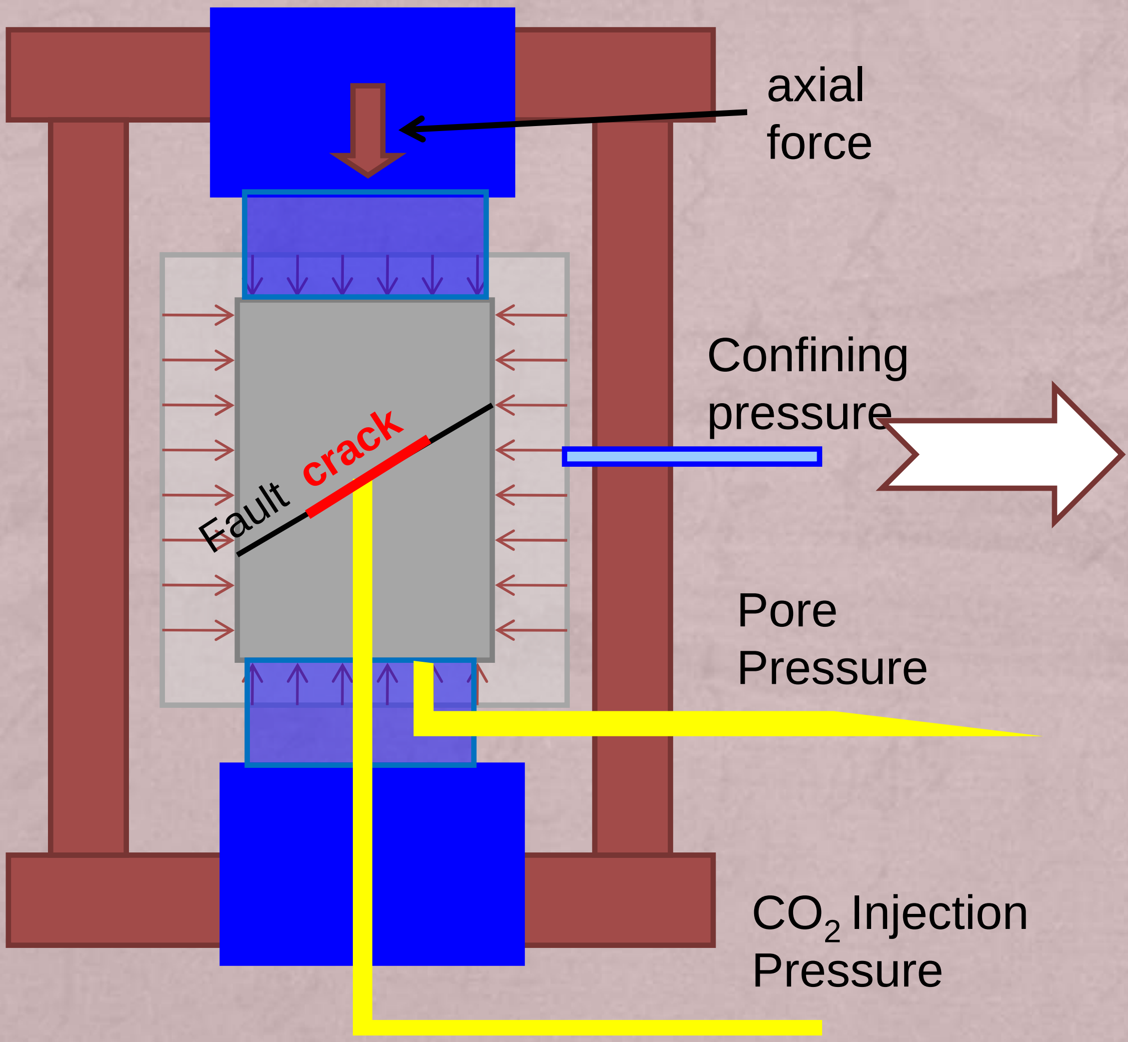
$$T_s = \frac{\tau}{\sigma_n - P_f}$$

Weakening of physical properties of rock
(Streit, J.E., et al., 2003)



Fault activation

Experimental Design for Crucial Rock Fracture Problem Study



schematic diagram of experimental device

Instron 1346 Testing Machine

Experimental study on Rock fracture toughness Weakening!

Why Rock Fracture Toughness so important ?

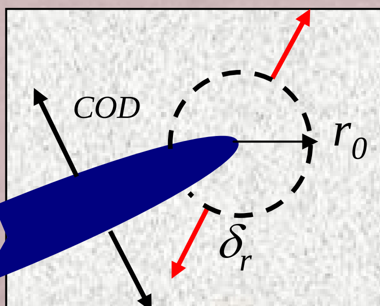
- Basic parameter and basic concept of rock fracture mechanics
- Material property of rock (conditional)
- Prerequisite for establishing a fracture criterion (just like strength theory)
- Prerequisite for more realisitc geomechanical accessment based on theoretical and numerical analysing

What have we prepared for solving this problem ? (How to Determine Rock Fracture Toughness Weakening?)

From theories to techniques and experiments

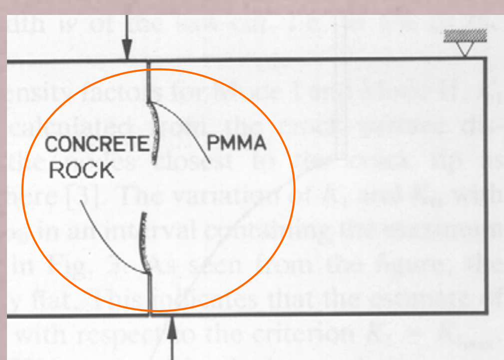
Achievements on Rock Fracture Mechanics

Generalised COD Fracture Criterion



$$\delta_r = \frac{1}{4\mu}\sqrt{\frac{r}{2\pi}}\,\{K_I\,[(2k-1)\,(\cos\frac{\theta}{2} + \sin\frac{\theta}{2}) - \cos\frac{3\theta}{2} + \sin\frac{3\theta}{2}] + K_{II}\,[(2k-1)\cdot(\cos\frac{\theta}{2} - \sin\frac{\theta}{2}) + 3(\cos\frac{3\theta}{2} + \sin\frac{3\theta}{2})]\} + \frac{\sigma_{ox}}{8\mu}\,[1 + k - 4\cos^2\theta]\cdot r$$

True Mixed Mode Fracture Criterion



$$\lambda K_{I\theta} + K_{II\theta} <= K_{IIc\theta}$$

$$K_{I\theta} = K_I a_{11} + K_{II} a_{12}$$

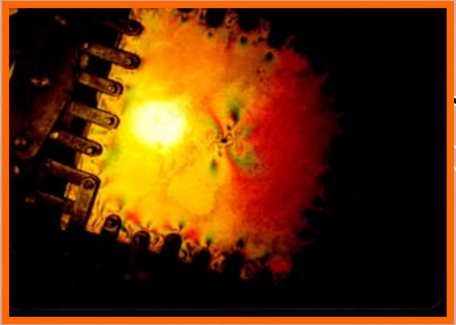
$$K_{II\theta} = K_I a_{21} + K_{II} a_{22}$$

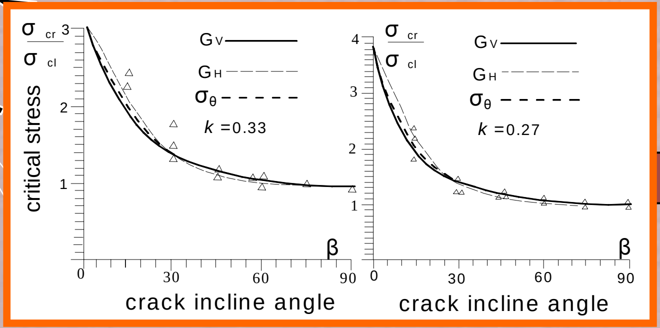
Achievements on Energy Gradiant Fracture Criterion G_V

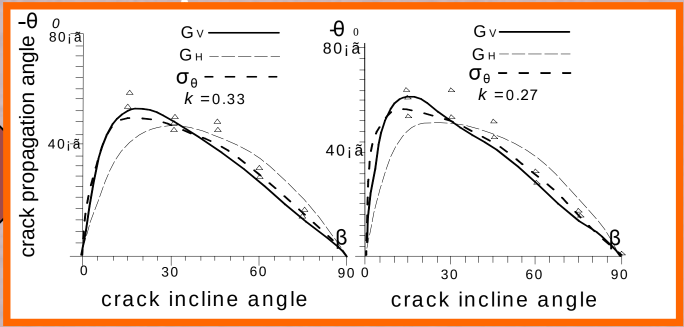
$$G_V = |\mathrm{Grad}(E)| = \sqrt{\left(\frac{\partial E}{\partial a_x}\right)^2 + \left(\frac{\partial E}{\partial a_y}\right)^2} = G_C$$

$$\theta_0 = \mathrm{arctg}\left(\frac{\partial E}{\partial a_y} \Big/ \frac{\partial E}{\partial a_x} \right)$$

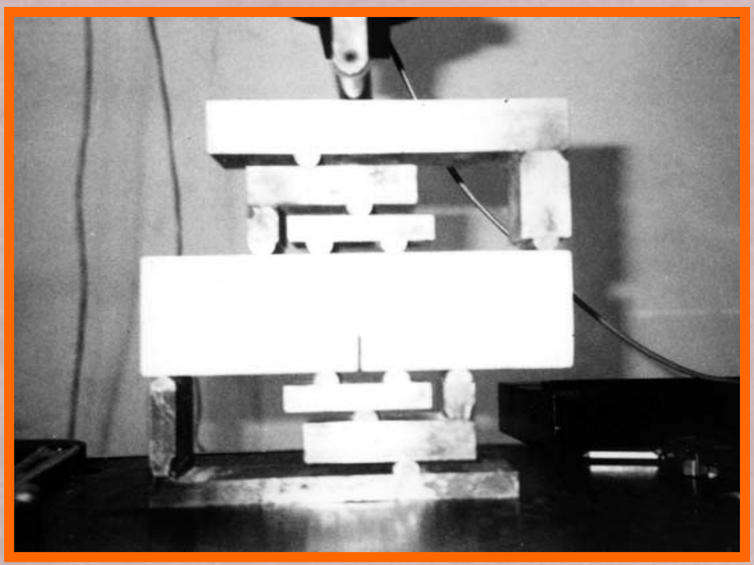
$$E(a_x, a_y) = \frac{(1+\kappa)\pi a^2 \sigma^2}{32\mu}\left[(1+k2)-(1-k2)\cos 2\beta\right]+E0$$



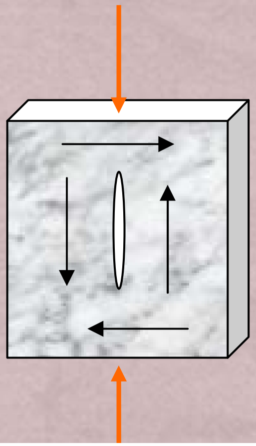




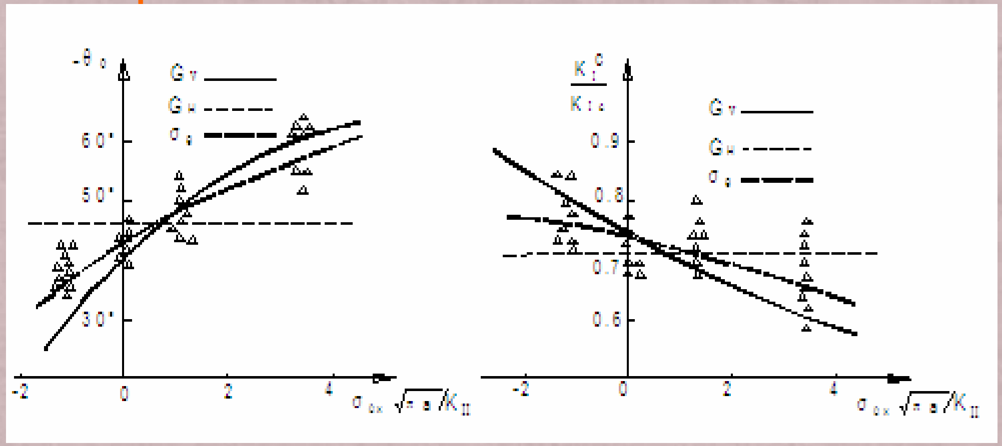
Nonsingular Effects on Rock Fracture



Specially designed compression shearing rock fracture experiment



k	0	2-√3	1/3	2-√3
β	60^0	45^0	30^0	0^0
K_I / K_{II}	√3	√3	√3	√3
$\sqrt{\pi a}\sigma_{ox} / K_{II}$	-2√3 / 2	0	2√3 / 2	2√3

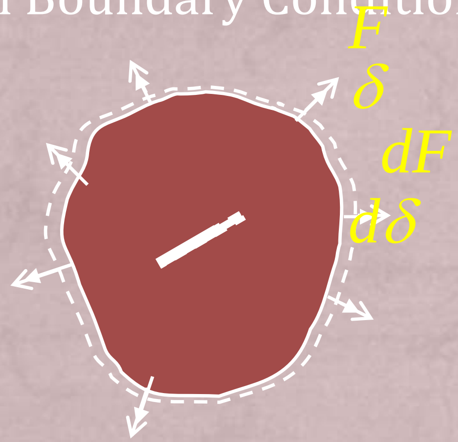


Different in-sito stress sysstem effect on rock crack with different orientation

Achievements on ISRM Sugessted Methods for Determining Rock K_{1C}

Theoretical foundation

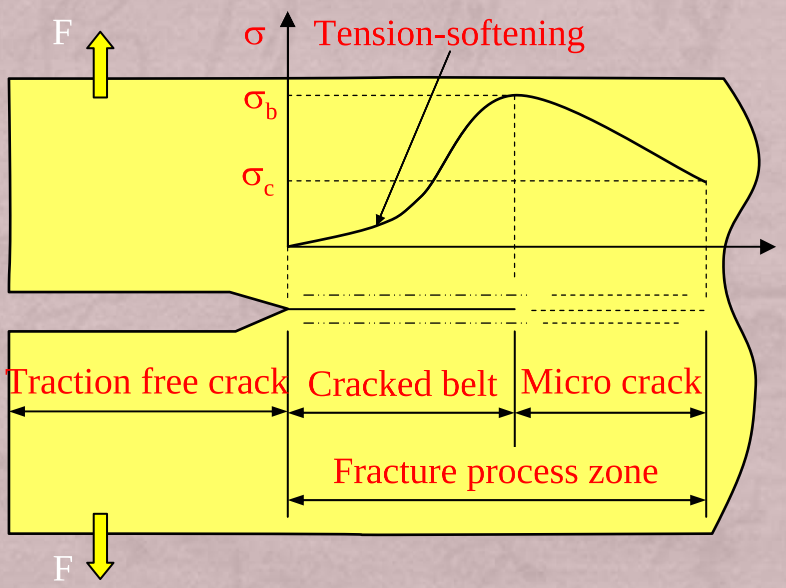
Energy Release Rate Under General Boundary Condition

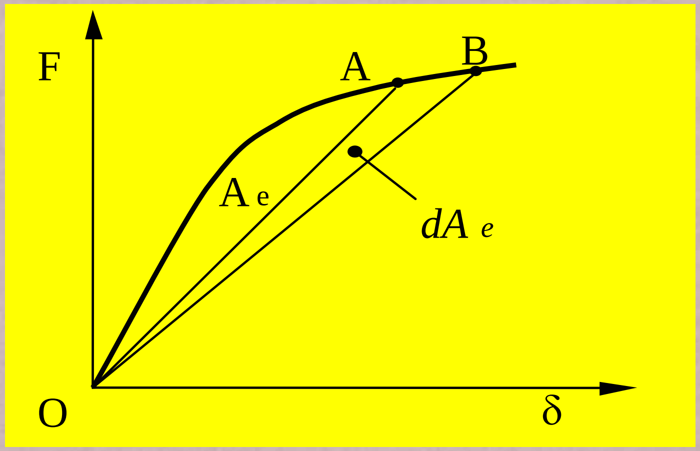


$$-\Pi_{AO} = A_e = \frac{1}{2}\int_O^A (F d\delta - \delta dF)$$

$$G_I = \frac{dU}{Bda} = \frac{K_I^2}{E}$$

$$G_I = \frac{dA_e}{Bda} = \frac{K_I^2}{E'}$$





Experimental comparison

Table 1 Physical parameters of each tested rock

Rock Name	Tensile Strength (Mpa)	Elastic Modulus (Gpa)	Poisson's Ratio	Grain Size (mm)	Porosity Ratio	Isotropic Property
Hunan marble	6.4	51.6	0.14-0.2	<0.4	<1%	excellent
Bohus granite	12.3	52.8-57.6	0.15-0.23	0.4-0.6	<1%	good
Ogino tuff	4.7	12.4	Not test	0.19	18%	excellent
Kallax gabbra	18.8	98.4	0.27-0.3	<1mm	Not test	excellent

Table 4 Statistic analysis on nonlinear correction of fracture toughness values for Bohus granite and Ogino tuff

Rock (Specimen)	D (mm)	F_{max} (kN)	K_{max} (MPa√m)	K_{ISRM} (MPa√m)	K_{ED} (MPa√m)	K_{W} (MPa√m)	K_{AED} (MPa√m)
Bohus Granite (SR)	50.0	0.867 ±0.058	1.826 ±0.141	2.138 ±.026	2.117 ±0.174	2.396 ±0.274	2.126 ±0.266
Bohus Granite (CB)	50.0	1.652 ±0.133	1.608 ±0.075	1.591 ±.386	1.881 ±0.097	2.491 ±0.131	2.236 ±0.116
$Mean_{SR}$ $-Mean_{CB}$			0.218	0.268	0.236	-0.095	-0.110
Ogino Tuff (SR)	68.5	0.557 ±0.014	0.738 ±0.015	0.857 ±0.051	0.802 ±0.017	0.836 ±0.046	0.862 ±0.027
Ogino Tuff (CB)	68.5	1.241 ±0.023	0.782 ±0.013	0.907 ±0.067	0.863 ±0.078	0.818 ±0.066	0.850 ±0.103
$Mean_{SR}$ $-Mean_{CB}$			-0.046	-0.051	-0.061	0.018	0.012

Prospecting and Conclusion

- Geomechanics and especailly rock fracture mechanics are crucial in the cap rock stability research;
- Physical simulation or experimental methods for fracture pressure prediction of cap rock should\can be developed;
- 3D geological\numerical modelling of geomechanics response of caprock during the CO_2 injection and after the injection should be carried out based on the experimental researches.
- Ideal cap rock stability accessment method could be established in the near future.

Thank you
for your attention!