A QUANTITATIVE EVALUATION METHOD FOR THE STABILITY AND SEALING CAPACITY OF CAP ROCK IN CO2 STORAGE SITE

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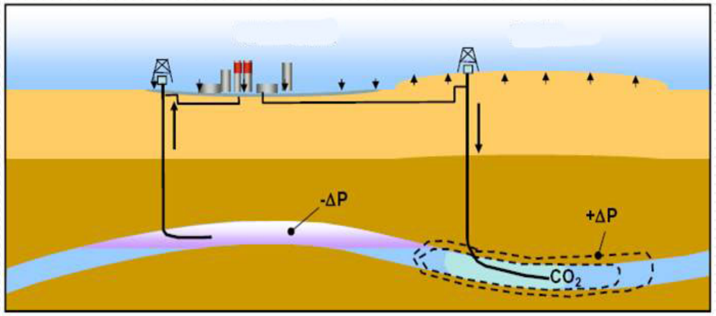
OUTLINES

- Geomechanical View of CCS safety
- Rock fracure evaluation of cap rock stability & sealing capacity
- A evaluation of CO2-EOR project site with penny-shaped crack model
- Conclusion and suggestion

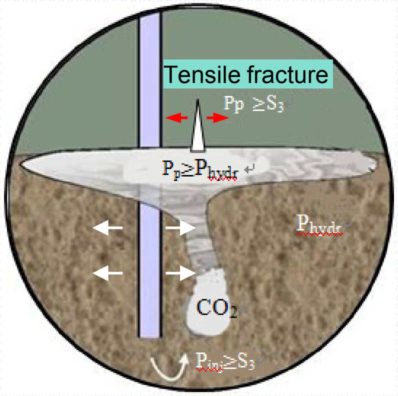
Geomechanical View of CCS safety

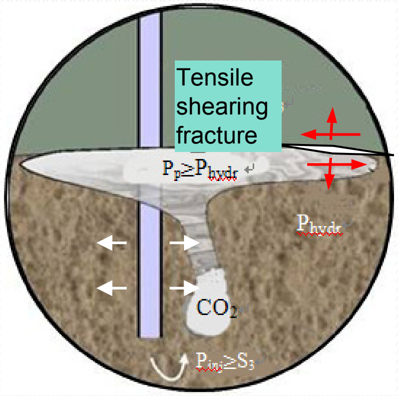
Geomechanical impacts of CO2 injection on cap rock safety & stability

- Strength failure and crack propagationI
- increasing pore pressure and reducing effective stress
- Buoyancy and capillary displacement pressure
- Thermodynamic and chemical process
- Fault activation

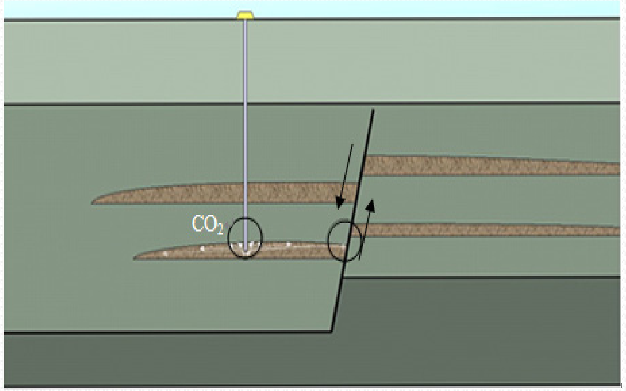


Differential ground deformation in Insala Krechba gas field (Jonny Rutqvist, 2008)





Slipping or tensile failure in the interface of the reservoir and cap rock



Fault reactivation

Key Points for cap rock safety & stability

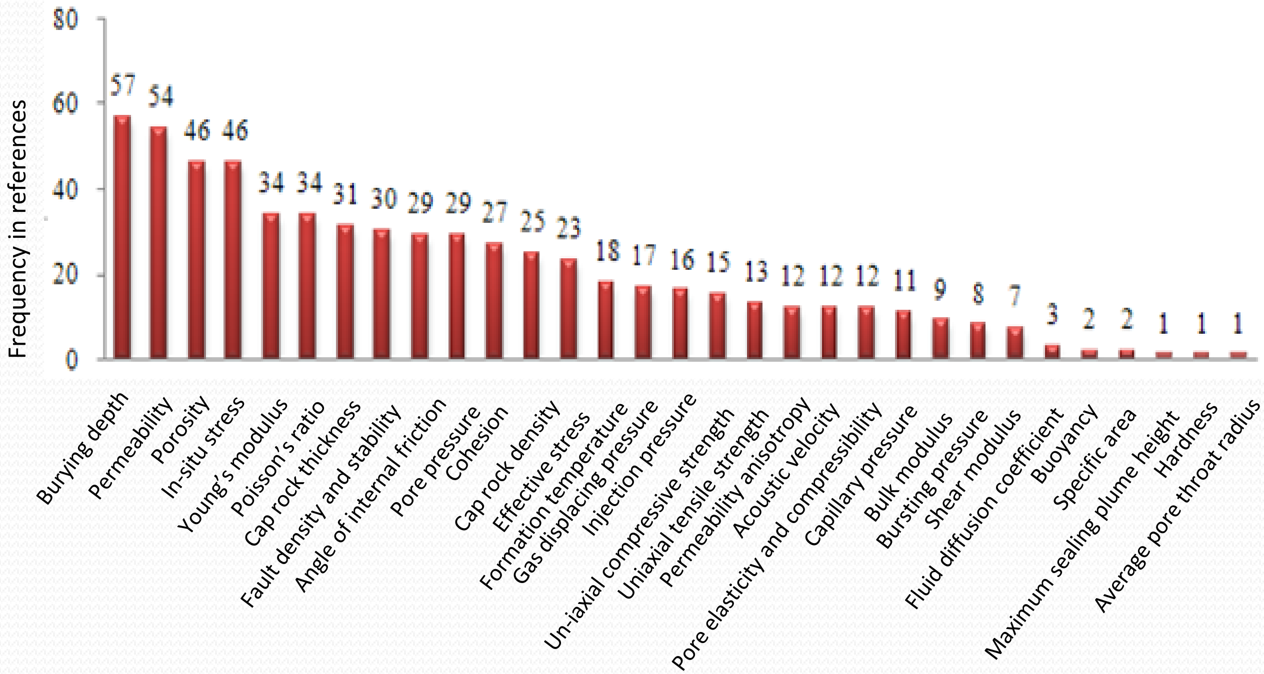
1、The maximum pore pressure or fracture pressure in cap rock

2、Physico-mechanical reduction or failure for cap rock under T-H-M-C coupled conditions

3、 Physical and mechanical Sealing ability of cap rock under buoyancy force

4、Fault stability evaluation and activation prediction

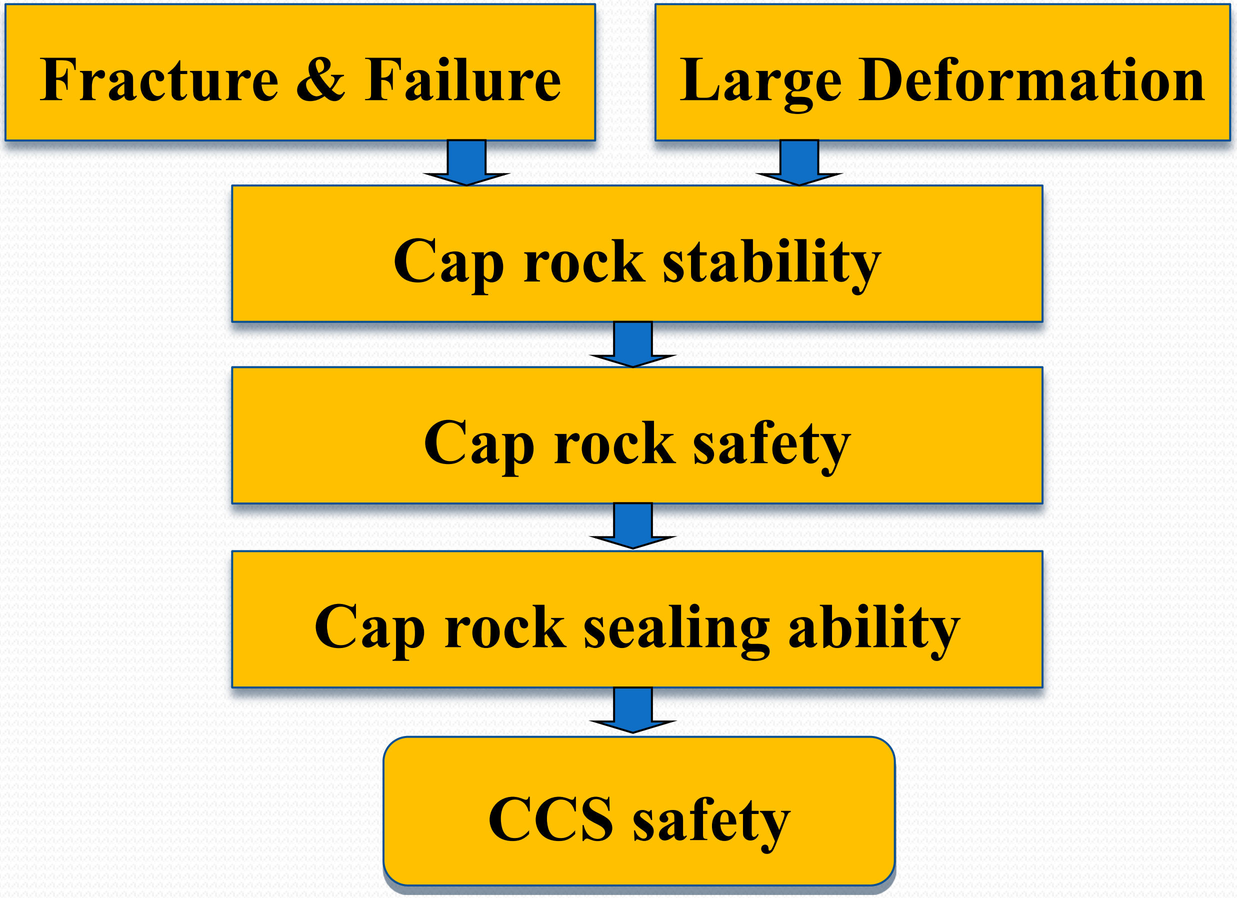
Evaluation indexes



Relative importance based on usage frequency of different indexes for cap rock stability evaluation

➢The most frequently used indexes for evaluating cap rock stability are buried depth, permeability, porosity, in-situ stresses

Critical role of cap rock fracture & failure



Rock fracture evaluation of cap rock stability and sealing capacity

Why Fracture Mechanics Approach to Cap Rock Stability

- Flaws and cracks determine rock strength
- Fractures and cracks produce large deformation
- Crack formation degrades sealing capacity
- Crack propagation produce leaking path

Main steps of cap rock stability evaluation by rock fracture mechanics

- Set up fracture or crack model from geological model
- Set up fractures criterion for this model
- Determine stress intensity factors of the cracks
- Determine fracture toughness of the cap rocks
- Apply the criterion to determine the critical pressure
- Check the sealing capacity under this critical pressure

Review of Some fundmentals of rock fracture mechanics

Stress intensity factors:

K_I、 K_{II} 、 K_{III}

Fracture toughness ：

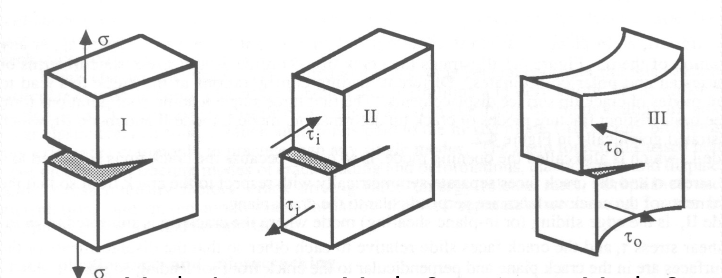
K_{IC}、 K_{IIC} 、 K_{IIIC}

Fracture criterion ：

$K_I = K_{IC}$ 、 $K_{II} = K_{IIC}$ 、 $K_{III} = K_{IIIC}$

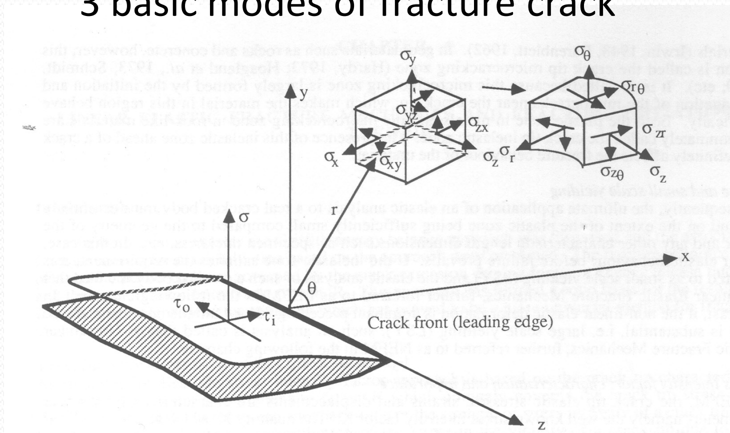
Mixed mode fracture criterion ：

$K_I/K_{IC} + \lambda K_{II}/K_{IIC} + \gamma K_{III}/K_{IIIC} = K_C$



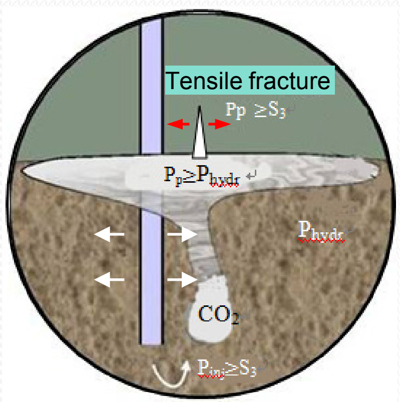
Mode 1 Mode 2 Mode 3

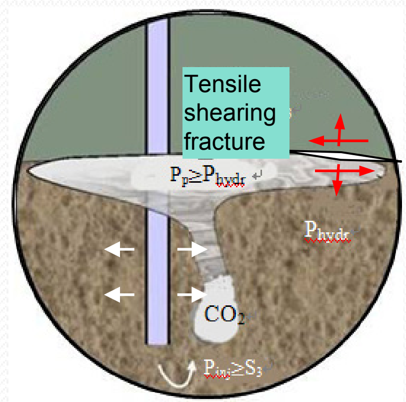
3 basic modes of fracture crack

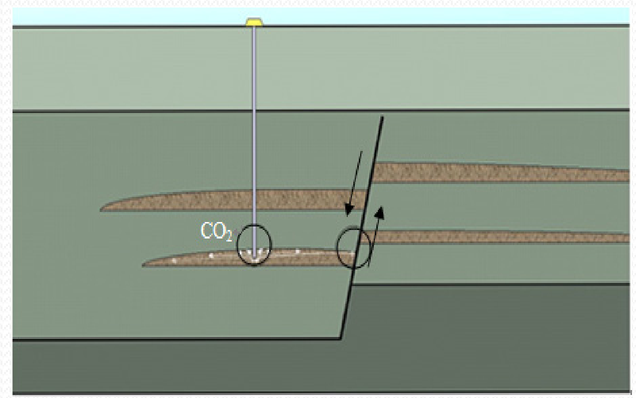


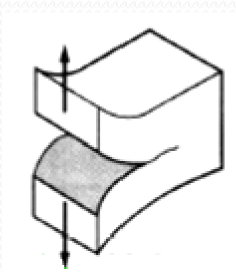
Stress state near the crack tip

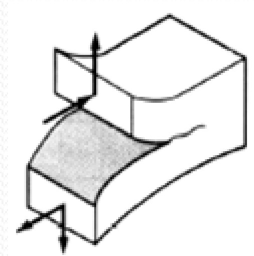
Typical fracture modes of the cap rock and their fracture criterion

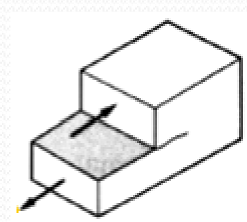


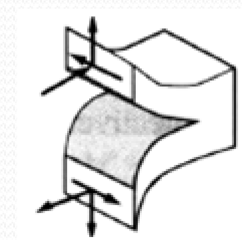












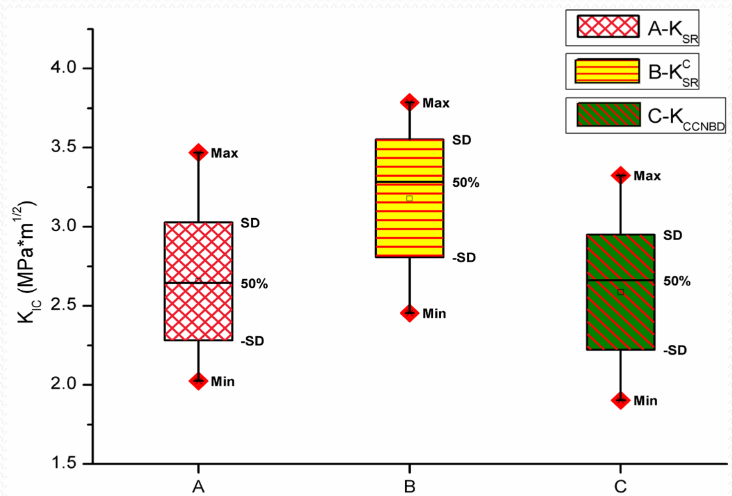
$K_I=K_{IC}$ $K_I/K_{IC}+\lambda K_{II}/K_{IIC}=K_C$ $K_{II}=K_{IIC}$ $K_I/K_{IC}+\lambda K_{II}/K_{IIC}+\gamma K_{III}/K_{IIIC}=K_C$

Mode 1 crack Model 1+2 Mixed Mode or mode 2 crack Mode 2 or 1+2+3 Mixed mode crack

KIC testing methods comparison

Specimen diameters D [mm]	Values of K_{IC} obtained from ISRM suggested chevron specimens				
	SR specimen			CCNBD specimen	
	P_{max} [kN]	K_{SR} [MPa·m$^{1/2}$]	K_{SR}^{C} [MPa·m$^{1/2}$]	P_{max} [kN]	K_{CCNBD} [MPa·m$^{1/2}$]
50	$1.24_6 \pm 0.167$	$2.59_6 \pm 0.328$	$2.97_6 \pm 0.309$	$1.71_3 \pm 0.159$	$0.55_3 \pm 0.051$
55	$1.52_5 \pm 0.404$	$2.41_5 \pm 0.33$	$3.08_5 \pm 0.41$	$3.87_5 \pm 0.408$	$0.89_5 \pm 0.094$
68	$1.99_5 \pm 0.251$	$2.57_5 \pm 0.177$	$3.2_5 \pm 0.293$	$9.31_6 \pm 1.102$	$2.35_6 \pm 0.278$
74	$2.83_5 \pm 0.364$	$3.07_5 \pm 0.345$	$3.5_5 \pm 0.34$	$13.27_8 \pm 1.89$	$2.67_8 \pm 0.379$
80	—	—	—	$19.4_3 \pm 1.849$	$2.84_3 \pm 0.271$

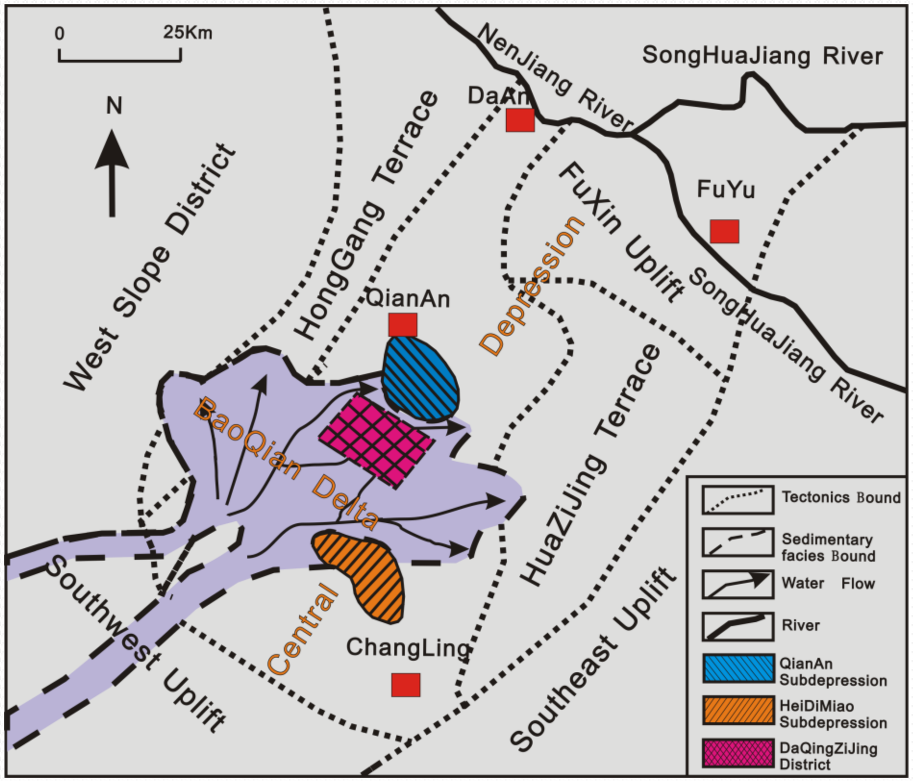
Summary of Mode-I fracture toughness values tested from SR and CCNBD specimens



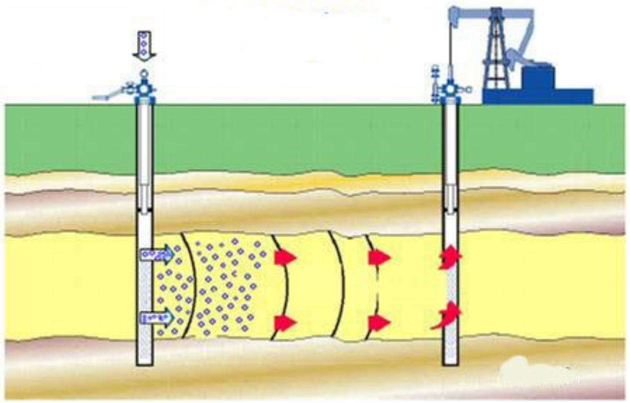
Box-Whisker plots of CCNBD and SR values

A evaluation of CO2-EOR project site with penny-shaped crack model

Project background



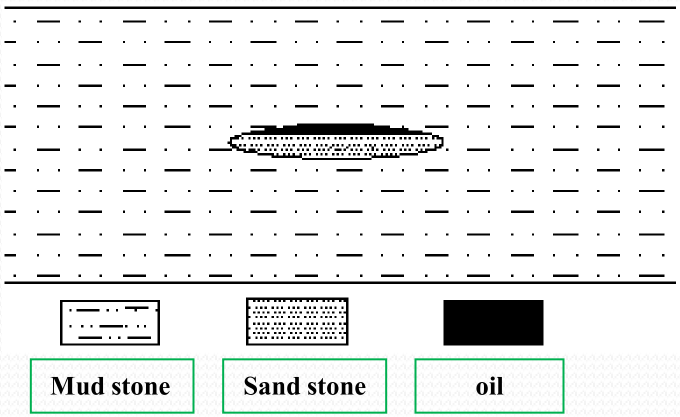
Tectonic position and sedimentary facies in DaQingZiJing oil field
Revised from Chen Mian, (2008)

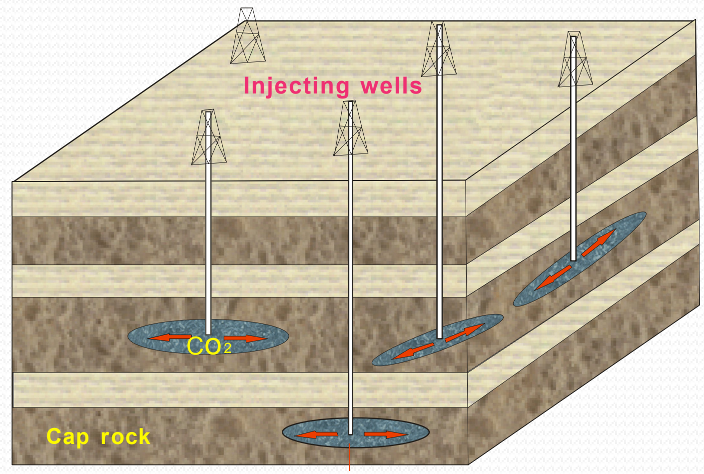


CO_2-EOR (IEA,2000)

- DaQingZiJing oil field is located in a tectonic depression surrounded by the southeast uplift, southwest uplift and west slope district;
- Its principal sedimentary facies include delta facies, semi-deep — deep lake facies;
- It has a lot of sand lens oil reservoir.

Penny-shaped model for sand lens reservoir

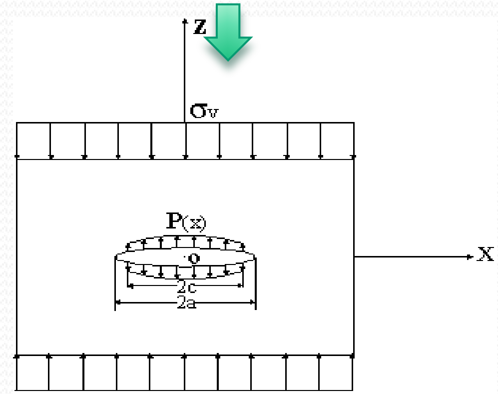


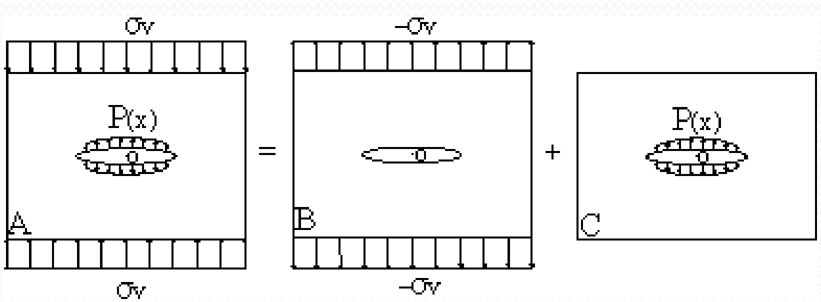


Sand lens reservoir

$$K_{\mathrm{I}} = K_{\mathrm{A}} = K_{\mathrm{B}} + K_{\mathrm{C}}$$

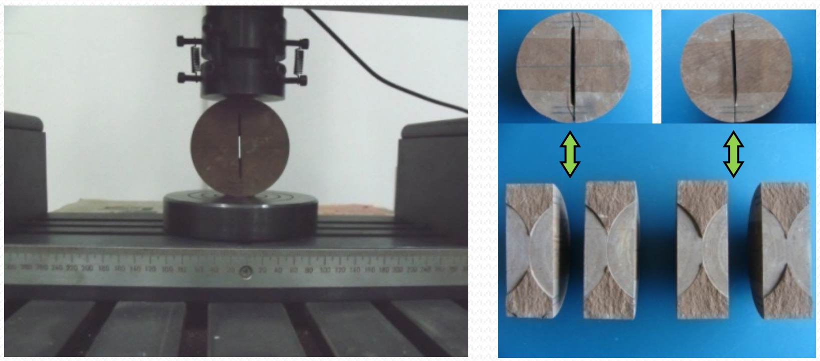
$$K_{\mathrm{I}} = \int_{-c}^{c} \sqrt{\frac{a}{\pi(a^2 - x^2)}}\, P(x)dx - \sigma_{\mathrm{h}}\sqrt{\pi a}$$



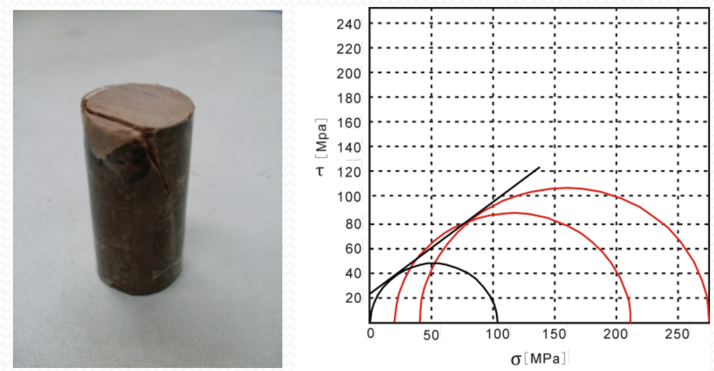


Penny-shaped model

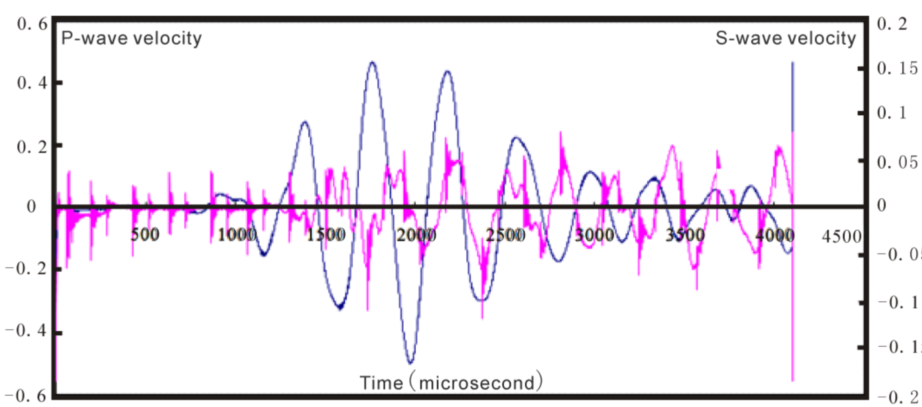
Parameter testing



Fracture toughness (KIC) testing using CCNBD specimen



Tri-axial compressive strength testing



Dynamic elastic parameters testing

The maximum injection pressure and sealing height of CO2 plume

Fracture criterion with Insitu fracture toughness correction (revised from Chen Mian, 2008)

$$\begin{cases} K_I' = K_{IC}^C \\ K_I' = \omega K_I = \left[\frac{W}{\pi a}\tan\frac{\pi a}{W}\right]^{1/2} K_I \\ K_{IC}^C = \delta K_{IC} = \frac{1}{\sqrt{1-\frac{1}{2}(1-2\xi\,\nu_d)^2\left(\frac{P-\sigma_p}{R_c}\right)^2}} K_{IC} \end{cases} \qquad \xi = \frac{1+\sin\varphi}{1-\sin\varphi}$$

Evaluation results:

The maximum injection pressure of cap rock at the nip of sand lens reservoir———20MPa

The maximum injection pressure of cap rock at the bottom of injection well———32MPa

The maximum sealing height of CO2 plume for well H77 cap rock ———380m

Conclusions and suggestion

Conclusions and suggestion

① A quantitative evaluation method for cap rock stability based on geomechanics and rock fracture mechanics is proposed.

② The designed maximum injection pressure and tested safe pressure has a good agreement with our evalulation, which indicates the efficiency of our calculation model and method.

③ The maximum sealing CO_2 plume height of the cap mudstone indicates that the example oil field can use the max injection pressure in full scale.

④ Systematic methods for CCS safety evaluation should be developed with effective and quantitative analysis of cap rock fracture stability.

Thanks for your attention