ASPECTS REGARDING ROCK FRACTURING

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Abstract
The paper presents aspects regarding the breaking rocks criteria in Mohr's assumptions. During layers crossing by drilling, in rocks around the wellbore stress arise a complex state arises that can be translated in plane by Mohr's circles. Thus exceeding the limit values lead to breaking rocks. We analyzed two types of rocks from two different wells and we set triaxial state of compression
Keywords: rock fracturing, triaxial state of compression, Mohr's circle

1. Introduction

Rocks are characterized by composition, structure, and texture – depending on their genesis, as well as by their anisotropy, cracking and moisture. Under the pressure of external loads, rocks may get deformed, which usually leads to landslides and loss of stability.

Sliding takes place in preferential planes, and loss of stability is due to compression load, which can lead to the fracturing of the rocks via avulsion, shearing or the natural collapsing of the rocks.

Rock fracturing is preceded by plastic deformation; it can be ductile – caused by shearing and fragile (breakable) – determined by avulsion (cleavage).

The manner in which the rocks actually fracture is mainly dependent on the tension of the rocks.

2. Rock fracturing hypotheses

Rock fracturing theories are hypotheses that define the conditions under which deformation or resistance limits are reached at a certain point of a rock where a specific triaxial state of tension manifests. The resistance limit state is the state in which the rock loses its ability to resist; for ductile rocks maximum flow limit is taken into consideration, while in the case of fragile (breakable) rocks, the fracturing limit upon traction and, respectively, compression is taken into consideration.

In conclusion, rock fracturing represents the situation under which the rock becomes fragmented.

Tension states can be represented as surfaces on a three-dimensional plane, and in the form of intrinsic or curved lines, on a two-dimensional plane.

The mathematical equations for the surface, and the intrinsic line or curve specific to the fracturing limit of a rock are called fracturing criteria.

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The parameters of the tension states function as variables in the equations; the following constants also act as a series of coefficients, namely: cohesion, the angle of inner friction, fracturing resistance via simple traction and fracturing resistance via compression.

The general fracturing equation is a function that depends on the following tensions σ_1, σ_2, σ_3 and on the fracturing resistance tension [3].

$$f(\sigma_1, \sigma_2, \sigma_3, \sigma_{rez})>0 \qquad (1)$$

Resistance tension may be specific to traction or compression, and is calculated using the following formulas:

$$\sigma_{rt} = \frac{2c \times \cos\phi}{1+\sin\phi} \qquad (2)$$

$$\sigma_{rc} = \frac{2c \times \cos\phi}{1-\sin\phi} \qquad (3)$$

where c represents rock cohesion;
φ – angle of inner friction.

3. Mohr's fracturing criterion

Hypotheses with regard to solid fracturing have been issued by several researchers, such as: Galileo Galilei, Coulomb, Navier, Griffith, Mohr etc. [4]

The present paper further describes aspects regarding solid fracturing also taking into consideration Mohr's interpretation, which is the most adequate in the case of rock fracturing.

Mohr perfected the classic resistance theories and formulated the hypothesis that rocks unlimitedly fracture or get deformed upon tangential tension, τ, from the same plane and when the normal minimum traction tension reaches a limit value of σ_{rt}:

$$|\tau| = f(\sigma) \qquad (4)$$

or

$$|\tau| = \sigma tg\phi + c \qquad \text{şi} \quad \sigma_2 = -\sigma_{rt} \qquad (5)$$

In a two-dimensional plane, determining Mohr's circle radius, R, and the distance from the origin of the coordinate axes, and Mohr's center of the circle, C:

$$R = \frac{\sigma_1 - \sigma_2}{2} \quad (6)$$

$$C = \frac{\sigma_1 + \sigma_2}{2} \quad (7)$$

where σ_1 represents maximum main tension or axial tension;

$\sigma_2 = \sigma_3$ - main minimum tensions or lateral tensions.

Mohr's circle can be drawn (fig. 1).

Mohr circle characterizes the fracturing tension, tangential being the intrinsic line of the rock sample, the cut of the straight line on the ordinate; cohesion can be found at the unit tension scale, and the horizontal inclination is the inner friction angle.

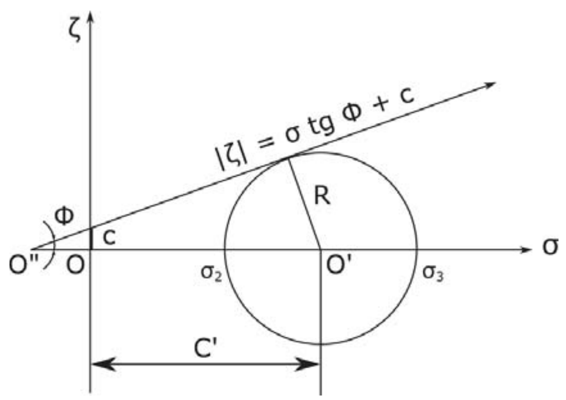

Fig. 1. **Mohr's circle**

As a result of triaxial compression tests, measurements can be made with respect to the main axial and lateral tensions of the rock samples taken from wells at certain depths.

If the representation of Mohr's circle is rendered on scale, the inner friction angle, φ, and the rock cohesion, c, can be determined via measuring.

If the fraction resistances via traction and compression are known, the following can be determined analytically:

$$\phi = arctg \frac{\sigma_{rc} - \sigma_{rt}}{2\sqrt{\sigma_{rc} \times \sigma_{rt}}} \quad (8)$$

$$c = \frac{1}{2}\sqrt{\sigma_{rc} \times \sigma_{rt}} \quad (9)$$

The main maximum tension, σ_1 is:

$$\sigma_1 = \frac{2c \times \cos\phi}{1 - \sin\phi} + \sigma_2 \frac{1 + \sin\phi}{1 - \sin\phi} \quad (10)$$

or taking into account the following formulas (2) and (3) it can be determined as:

$$\sigma_1 = \sigma_{rc} + \sigma_2 \frac{\sigma_{rc}}{\sigma_{rt}} \quad (11)$$

Tensions on the fracturing plane are [1]:

$$\sigma_\alpha = \frac{\sigma_1 + \sigma_2}{2} + \frac{\sigma_1 - \sigma_2}{2}\cos 2\alpha \quad (12)$$

$$\tau_\sigma = \frac{\sigma_1 - \sigma_2}{2}\sin 2\alpha \quad (13)$$

The direction of the fracturing plane with the horizontal (the plane of maximum main tension) is:

$$\alpha = 45^0 + \frac{\phi}{2} \quad (14)$$

Total tension on the fracturing plane is:

$$p_\alpha = \sqrt{\sigma_\alpha^2 + \tau_\alpha^2} \quad (15)$$

Tilting towards the normal to the fracturing surface is:

$$tg\delta = \frac{\tau_\alpha}{\sigma_\alpha} \quad \text{or} \quad \delta = arctg\frac{\tau_\alpha}{\sigma_\alpha} \quad (16)$$

4. Experimental results

Several experiments were conducted on two types of rock, i.e., marl and clay, making use of the installation for the determination of the triaxial tension state owned by the faculty of IPG.

The measured and calculated data are presented in tables 1 and 2 for wells A and B, respectively[2]. Tensions were measured, center and radius of the Mohr's circle were calculated and cohesion and inner friction angle were graphical determined.

Well A

Depth	H=1010 m
Rock type	Marl
Sample diameter	54 mm
Sample height	108 mm

*Table 1***Measured and calculated data for well A**

No.	Lateral tension $\sigma_2 \times 10^5 N/m^2$	Maximum principal tension $\sigma_1 \times 10^5 N/m^2$	Center of Mohr's circle $C \times 10^5 N/m^2$	Radius of Mohr's circle $R \times 10^5 N/m^2$	Cohesion $c \times 10^5 N/m^2$	Inner friction angle Φ, degrees
1	0	90	45	45	10	50
2	61	480	270,5	209,5	30	45
3	132	648	390	258	140	20

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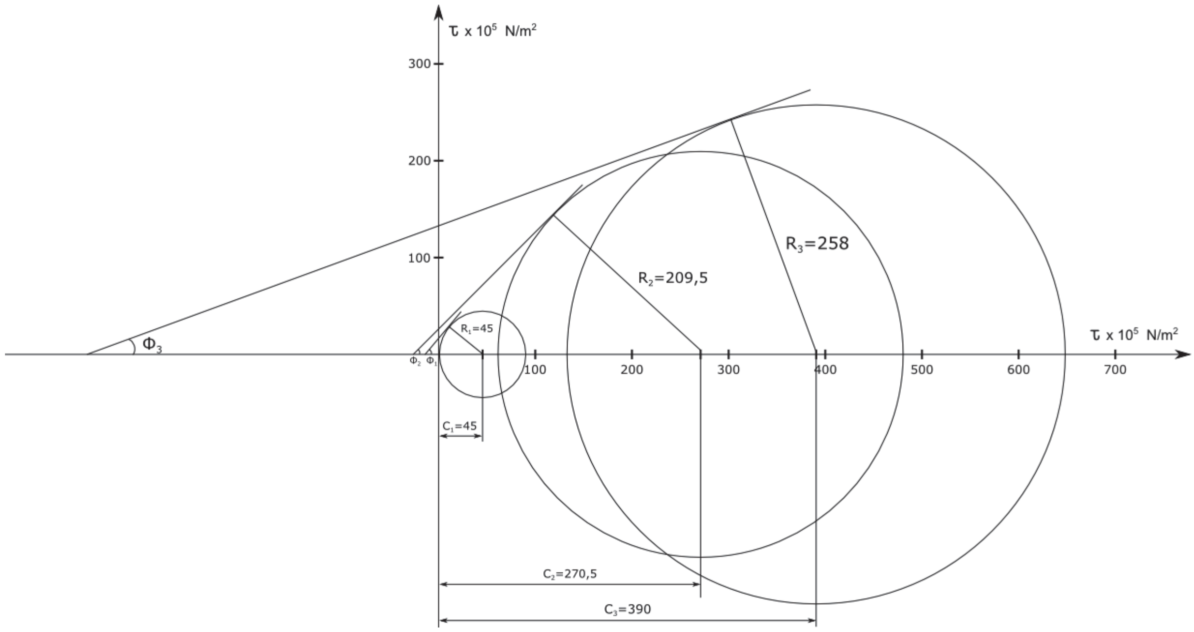

Fig. 2 **Mohr's circle for marl**

Well B

Depth	765 m
Rock type	Clay
Sample diameter	54 mm
Sample height	108 mm

Table 2 **Measured and calculated data for well B**

No.	Lateral tension $\sigma_2 \times 10^5 N/m^2$	Maximum principal tension $\sigma_1 \times 10^5 N/m^2$	Center of Mohr's circle $C \times 10^5 N/m^2$	Radius of Mohr's circle $R \times 10^5 N/m^2$	Cohesion $c \times 10^5 N/m^2$	Inner friction angle Φ, degrees
1	0	48	24	24	16	30
2	35	121	78	43	20	17
3	70	180	125	55	29	12

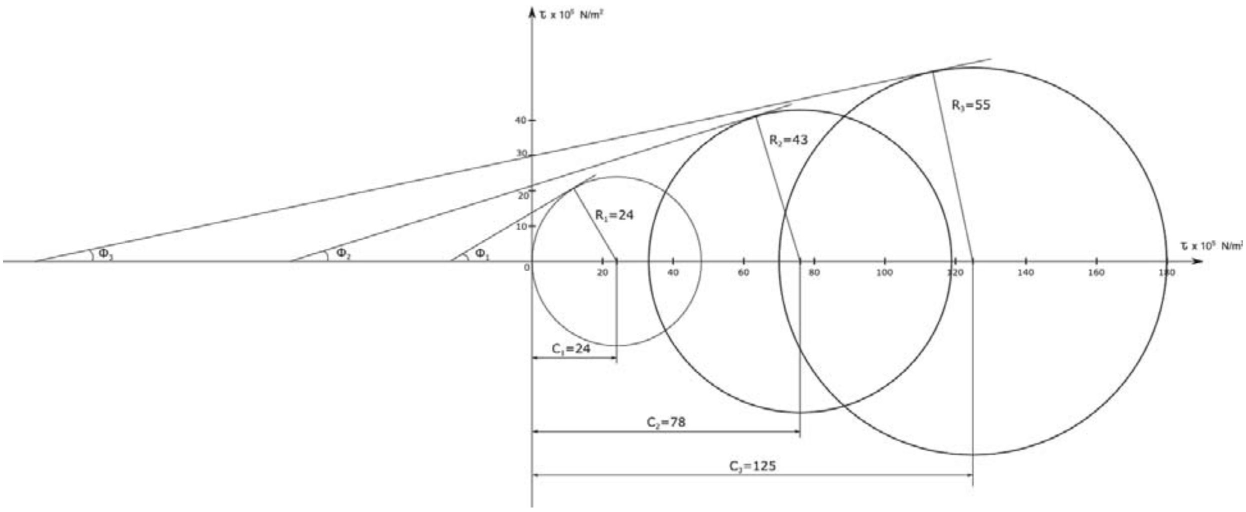

Fig. 3 **Mohr's circle for clay**

The direction of the fracturing plane with the horizontal (the plane of maximum main tension) is (14):

$$\alpha = 70^0$$

$$2\alpha = 140^0$$

Tensions on the fracturing plane are (12) and (13):

$$\sigma_\alpha = 10,52 \times 10^5 N/m^2$$

$$\tau_\alpha = 28,92 \times 10^5 N/m^2$$

Total tension on the fracturing plane is (15):

$$p_\alpha = 30,77 \times 10^5 N/m^2$$

Tilting towards the normal to the fracturing surface is (16):

$$\delta = 70,01^0$$

5. Conclusions

1. Rocks fragilely fracture upon single-direction (monoaxial) compression or traction loads and ductilely fracture upon triaxial compression loads.
2. The nature, structure, texture and the degree of fracturing of the rocks may facilitate fracturing via avulsion (fragile) or shearing (ductile).
3. Rock fracturing is dependent on the structure flaws of mineral crystals.
4. Temperature, humidity and other environmental factors affect the ductile behavior of rocks in the fracturing process.

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