Research of long-term stability of the near-wellbore zone

M M Aliev, M M Baiburova and Z F Ismagilova

Almetyevsk State Oil Institute, 2, Lenin Str., Almetyevsk, 423250, Russia

E-mail: bayburovam@gmail.com

Abstract. The authors used the criterion of short-term rock strength, transformed for the case of long-term strength in order to assess the long-term stability of the borehole wall and determine the permissible pressure in the wellbore. The long-term strength criterion is written according to the method of P.P. Balandina. As a result of the study, it was proved that the determination of the long-term strength of a rock is reduced to a decrease in the values of the short-term strength limits. A curve of the long-term strength of an inclined well is constructed according to a generalized dependence. The expression is obtained that allows determining the time of long-term strength.

1. Introduction

Prognostication of well wall stability is a prerequisite for achieving a reduction in drilling complications. The rocks that compose the walls of the wells are in a difficult state. During the process in the well, the pressure is constantly changing, the number of hydraulic pulses is increasing [1,2]. The cyclic loading resulting from these operations leads to loss of rock stability due to fatigue failure. Practice has established that even if the pressure of the liquid column in the wellbore is lower than the tensile strength of the rocks surrounding the wellbore, after some time the walls of the wells collapse.

The condition for the transition of a loaded solid to a state of destruction when its bearing capacity is exhausted is called the strength criterion. In a complex stress state, the equation of limit equilibrium should contain invariants characterizing its stress state. In the general case, the strength criterion is determined by some ultimate surface.

Today, many different particular criteria for strength under difficult stress conditions have been proposed. [3,4,5]. In engineering calculations, strength hypotheses are used, based on the assertion that the destruction process depends on a change in the shape of the body. When the potential energy of body shaping reaches its ultimate state, its destruction or transition to plastic deformation occurs.

2. Materials and methods

To construct the criterion of long-term strength, the criterion of short-term strength K.V. Zakharova is used in the form

\[
a_1\sigma_x^2 + a_2\sigma_y^2 + a_3\sigma_z^2 + a_4\sigma_x\sigma_y + a_5\sigma_x\sigma_z + a_6\sigma_y\sigma_z + a_7\sigma_x + \\
+ a_8\sigma_y + a_9\sigma_z + a_{10}\tau_{xy}^2 + a_{11}\tau_{xz}^2 + a_{12}\tau_{yz}^2 + a_{13} = 0.
\]

(1)

Consider a rock for which the criterion K.V. Zakharova turns into the criterion of P.P. Balandina [6] and is written as
\[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1 \sigma_2 - \sigma_1 \sigma_3 - \sigma_2 \sigma_3 + (\sigma_c - \sigma_p) x \times (\sigma_1 + \sigma_2 + \sigma_3) = \sigma_c \sigma_p. \] (2)

We will carry out the long-term strength criterion according to the technique proposed in [6]. From this technique, it follows that in the case of constantly acting stresses, one can obtain such a record of the strength criterion for which the expression of the short-term strength criterion remains on the left side, and some damped time function remains on the right side.

Using the methodology described above, is written down the criterion of long-term strength for materials that obey criterion (2). The damping function of time will enter both the left and the right side.

\[\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1 \sigma_2 - \sigma_1 \sigma_3 - \sigma_2 \sigma_3 + [\sigma_c(t) - \sigma_p(t)] x \times (\sigma_1 + \sigma_2 + \sigma_3) = \sigma_c(t) \sigma_p(t). \] (3)

Thus, the determination of the long-term strength of the rock is reduced to a decrease in the values of short-term strength.

To determine the strength characteristics, it is necessary to conduct a series of experiments that should be planned so that as a result it was possible to record the dependence. It is proposed to approximate the long-term strength curve in the form

\[\sigma_c(t) = \sigma_{c\infty} + (\sigma_c - \sigma_{c\infty})e^{-a_0t}, \] (4)

where \(a_0\) — approximation parameter,

\(\sigma_c\) — compressive strength with short-term compressive load,

\(\sigma_{c\infty}\) — compressive strength if \(t \to \infty\).

Next, getting \(\kappa = \sigma_{c\infty} / \sigma_c\) equation (4) can be reduced to

\[\sigma_c(t) = \sigma_c(\kappa + (1 - \kappa)e^{-a_0t}). \] (5)

Parameter \(\kappa = \sigma_{c\infty} / \sigma_c < 1\) can vary over a wide range. The reason for the change in this parameter will be an increase in rock damage over time, as well as a weakening of structural intermolecular bonds. The considered parameter \(\kappa\) is usually determined by conducting a long-term test of rock samples under various deformation conditions.

The parameter \(a_0\) included in (5) determines the shape of the long-term strength curve

\[y = \sigma_c(\kappa + (1 - \kappa)e^{-a_0t}) = f(t). \]

We construct a curve of long-term strength according to the obtained dependence. To do this, we assume that \(\kappa = 0.5\). By changing the parameter \(a_0\) we build lines \(y = f(t)\).

Analyzing the obtained graphs, we observe the influence of the approximation parameter on the limiting value of the compression stress.

To derive the equation for finding the time of long-term strength, we use the strength criterion given by N. Rabinovich [7].
Figure 1. Graph of compression stress $\sigma_c$ versus time $t$ for various parameters $a_0$.

Consider the long-term strength of an inclined well wall filled with fluid. In the polar coordinate system, the stress intensity

$$\sigma_u = \frac{\sqrt{2}}{2} \left[ \left( \sigma_r - \sigma_\theta \right)^2 + \left( \sigma_r - \sigma_z \right)^2 + \left( \sigma_\theta - \sigma_z \right)^2 + 6 \left( r_z^2 + r_\theta^2 + r_z^2 \right) \right]^{\frac{1}{2}}.$$  

(6)

takes maximum value at angle $\theta = \pi/2$.

The voltage components according to [7] are defined as

$$\sigma_r = -q, \quad \sigma_\theta = q - 2a - 4b, \quad \sigma_z = -c - 4b,$$

$$r_\theta = r_z = 0, \quad r_\theta = d, \quad q = \frac{p_c - p_n}{p_z - p_n},$$

where $p_c$ - retaining fluid pressure,
$p_z$ - overlying rock pressure,
$p_n$ - reservoir (pore) pressure.
$q$ - reduced well pressure.

Hence we find that

$$\left( \sigma_r - \sigma_\theta \right)^2 = \left[ 2(q - a) - 4b \right]^2 = 4(q - a)^2 - 16(q - a)b + 16b^2;$$

$$\left( \sigma_r - \sigma_z \right)^2 = \left[ (q - a) + K \right]^2 = (q - a)^2 + 2K(q - a) + K^2;$$

$$\left( \sigma_\theta - \sigma_z \right)^2 = \left[ (q - a) - K - 4b \right]^2 = (q - a)^2 + 8Kb + K^2 +$$

$$+ 16b^2 - 8b(q - a) - 2K(q - a);$$

$$6r_\theta^2 = 6d^2;$$
where $K = a - c - 4vb$;

\[
a = \frac{1 + 2v - (1 - 2v) \cos 2a_0}{4(1 - v)} \cos a_0;
\]
\[
b = \frac{1 - 2v}{4(1 - v)} \sin a_0 \sin 2a_0;
\]
\[
c = \frac{1 + (1 - 2v) \cos 2a_0}{2(1 - v)} \cos a_0;
\]
\[
d = \frac{1 - 2v}{2(1 - v)} \sin 2a_0.
\]

where \(v\) - rock Poisson's ratio.

Substituting the obtained values in (6), we write

\[
\bar{\sigma}_u = \frac{\sqrt{2}}{2} [6(q-a)^2 + 8(q-a)b + 2K^2 + 32b^2 + \\
\frac{1}{2} + 8Kb + 6d^2]^2 = [3(q-a)^2 + (c-a + 4vb)^2 + 3d^2 - \\
-4(q-a)b + 16b^2 + 4Kb]^2.
\] (7)

With these components, the average pressure is

\[
\bar{\sigma} = \frac{1}{3} (\sigma_r + \sigma_c \sigma_\theta) = \frac{1}{3} (-q - c - 4vb + q - 2a - 4b) = \\
= -\frac{1}{3} (c + 2a + 4vb + 4b).
\] (8)

We write criterion (3) in the form:

\[
\bar{\sigma}^2 + 3(\sigma_c(t)) \bar{\sigma} = \sigma_c(t) \sigma_p(t),
\] (9)

where

\[
\sigma_c = a \sigma_p; \quad \sigma_c(t) = a \sigma_p(t); \quad \sigma_p(t) = \frac{\sigma_c(t)}{a};
\]

The stress intensity has the form

\[
\sigma_u = \left[3(q-\delta)^2 + (1-\delta)^2\right]^{1/2}.
\] (10)

Criterion (9) can be written as follows

\[
\sigma_u^2 - 3\bar{\sigma} \sigma_c(t) (\frac{1 - \alpha}{\alpha}) = \frac{\sigma_c^2(t)}{\alpha}.
\] (11)

From here we define
Denote $\sigma_c(t) = A$, then (12) we write in the form

$$A = -1.5\sigma (1-\alpha) + \sqrt{2.25\sigma^2 (1-\alpha)^2 + \sigma_u^2}.$$  \hspace{1cm} (12)

Moreover, according to (5), the time of long-term resistance is determined as

$$t = -e^{\theta} / a_0,$$  \hspace{1cm} \text{where} \hspace{1cm} \theta = \frac{1}{1-\kappa} \left( \frac{A}{\sigma_c} - \kappa \right).$$

Given that the value of the compressive strength is denoted by $A$, we write equation (4)

$$A = \sigma_c (\kappa + (1-\kappa)e^{-a_0 t}).$$

From here

$$e^{-a_0 t} = \frac{1}{1-\kappa} \left( \frac{A}{\sigma_c} - \kappa \right).$$

Logarithm, we find the time of long-term strength

$$t = -\frac{1}{a_0} \ln \left[ \frac{A}{\sigma_c} - \kappa \right] / (1-\kappa).$$

This formula makes it possible to find the desired value.

3. Results and discussion

Thus, it is proved that the determination of long-term strength reduces to a decrease in the values of short-term strength. An expression is obtained that allows determining the time of long-term rock strength surrounding the well wall. The curves constructed on the basis of the obtained data allow estimating the dependence of the compression stress on time.

4. Conclusion

The study of the stress-strain state of the near-wellbore zone of the well, the results expand the possibilities of applying the criteria for fatigue failure of the walls of the wells from cyclic hydrodynamic loads, allows reasonable choice of the methods of drilling wells, methods, mode of tripping operations, increase the stability of the walls of the wells.

References

[1] Aliev M M, Baiburova M M, Ibragimov I I, Ismagilova Z F and Lutfullin A A 2017 Investigation of relationships of geomechanic properties of layered rocks depending on hydrostatical pressure. Society of Petroleum Engineers – SPE Russian Petroleum Technology Conference 16-18 October Moscow

[2] Aliev M M, Ismagilova Z F and Baiburova M M 2017 Determination of elastic characteristics of anisotropic rocks under volumetric compression Scientific notes of Almetyevsk State Oil Institute 16 6-10

[3] Zaharov K V 1961 Strength criterion of laminated plastics Plast. Massy 8 61-67

[4] Goldenblat I I, Kopnov V A 1965 Strength criterion of anisotropic materials Izv. AN SSSR Mekhanika 6 77-83

[5] Nasseri M H B et al. 2003 Anisotropic strength and deformational behavior of Himalayan schists International Journal of Rock Mechanics & Mining Sciences 40 3-23
[6] Balandin P P 1937 On the question of strength hypotheses *Bulletin of engineers and technicians* 1 19-24

[7] Rabinovich N R 1989 *Engineering problems of continuum mechanics of drilling* (Moscow: Nedra)