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Research on the causes and consequences of uneven loads on the production casing

Badanie przyczyn i skutków oddziaływania nierównomiernych obciążeń na eksploatacyjną kolumnę rur okładzinowych

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ABSTRACT: An analysis of industrial materials from oil and gas fields of the Carpathian region has shown that casing collapse is most often recorded after a long period of well operation in intervals of dutile (plastic) rocks (salts, clays), in cases of concentric installation of casing strings (intermediate and production) when cement between them is absent or of low quality. We analytically solved the problem of determining the magnitude of the contact pressure acting on the production casing from the collapsed intermediate casing due to rock pressure. The calculations were based on Timoshenko-type shell theory and the inverse symmetric problem of two-shell interaction. A model of shell interaction was chosen that best represents edge displacements during dent deformation. The dependencies obtained for determining the contact pressure on the production casing from the side of the crushed intermediate casing show that the maximum contact pressures occur at the edges of the contact area, and their value significantly exceeds the pressures that occur under a uniform loading scheme. The resistance of a system consisting of two concentric casing strings to external pressure from ductile rocks in the absence of or low-quality cementing material between them should be assessed by the crushing pressure of the outer string pipes. Therefore, preventing the intermediate casing from being crushed is a priority in maintaining the integrity of the well casing as a whole. Measures have been proposed to improve the reliability of well cementing in ductile rocks, which include calculating the crushing strength of casing strings, taking into account the effect of rock pressure in ductile rocks, reducing the cavernosity of the wellbore, forming a high-quality cement ring, preventing corrosion and wear of casing pipes, and taking into account the reduction in pipe strength characteristics during long-term well operation when calculating the strength of the intermediate column, etc.

Keywords: well, casing string, collapse, ductile rocks, contact pressure.

STRESZCZENIE: Analiza materiałów przemysłowych ze złóż ropy naftowej i gazu ziemnego w rejonie Karpat wykazała, że zgniecenia kolumn rur okładzinowych są rejestrowane głównie po długim okresie eksploatacji odwiertów w interwałach występowania skał plastycznych (podatnych na odkształcenie plastyczne) (sole, iły). Dotyczy to przypadków koncentrycznie umieszczonych kolumn rur okładzinowych (pośredniej i eksploatacyjnej) przy braku stwardniałego zaczynu cementowego między nimi lub jego niskiej jakości. Analitycznie rozwiązano zadanie wyznaczenia wielkości ciśnienia kontaktowego, działającego na kolumnę eksploatacyjną ze strony kolumny pośredniej, zgniecionej ciśnieniem górotworu. Podstawę obliczeń stanowiły równania teorii powłok typu Timoshenki oraz rozpatrzono zagadnienie obrotowo-symetryczne wzajemnego oddziaływania dwóch powłok. Wybrano schemat obliczeniowy wzajemnego oddziaływania dwóch powłok, który w największym stopniu modeluje przemieszczenie krawędzi podczas powstawania wgniecenia. Otrzymane zależności do wyznaczania wielkości ciśnienia kontaktowego na kolumnę eksploatacyjną ze strony wgniecionej kolumny pośredniej wskazują, że maksymalne ciśnienia kontaktowe występują na krawędziach obszaru kontaktu, a ich wielkość znacznie przewyższa wartości ciśnień występujących przy równomiernym schemacie obciążenia. Odporność układu dwóch koncentrycznych kolumn rur okładzinowych na działanie ciśnienia zewnętrznego ze strony skał plastycznych, w przypadku braku lub niskiej jakości stwardniałego zaczynu cementowego między nimi, należy oceniać wielkością ciśnienia zgniecenia rur kolumny zewnętrznej. Dlatego priorytetowe znaczenie dla zachowania integralności orurowania odwiertu ogółem ma zapobieganie zgnieceniu kolumny pośredniej. Zaproponowano metody mające na celu zwiększenie niezawodności cementowania odwiertów w skałach plastycznych, które przewidują wykonanie obliczeń odporności kolumn okładzinowych na zgniecenie z uwzględnieniem oddziaływania ciśnienia górotworu, zmniejszenie kawernistości otworu wiertniczego, uzyskanie wysokiej jakości płaszcza cementowego, zapobieganie korozji i zużyciu rur okładzinowych oraz uwzględnienie obniżenia parametrów wytrzymałościowych rur podczas długotrwałej eksploatacji odwiertu podczas obliczeń wytrzymałościowych kolumny pośredniej itd.

Słowa kluczowe: otwór wiertniczy, kolumna rur okładzinowych, zgniecenie, skały plastyczne, ciśnienie kontaktowe.

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Introduction

In recent years, there has been a significant increase in the volume of oil and gas drilling operations in fields with unstable flow (plastic) rocks in their geological structure (Chudyk et al., 2023; Paliichuk et al., 2022). Despite the fact that many theoretical and experimental studies have been devoted to the stability of well walls and casing strings in flow rocks, there is currently no clear, scientifically based understanding of the nature of the loads that cause damage to casing strings.

An analysis of industrial materials on well cementing in Ukrainian fields has revealed a significant number of wells that have been classified as inactive due to casing collapse (Kotskulych et al., 2012; Femiak et al., 2022). Therefore, the problem of increasing the reliability of well cementing in complex mining and geological conditions is relevant and requires further development.

The least studied and quite relevant problem is the crushing of casing strings during well operation in conditions where complications associated with the flow of plastic rocks rarely occur during drilling. In such cases, no special preventive measures were provided, which is typical for some deposits in Ukraine. Therefore, a comprehensive approach to this problem is needed, based on a comprehensive study and indepth analysis of the influence of many factors, which will make it possible to develop more effective technical and technological means and methods to prevent damage to casing strings.

Theoretical analysis

Among the causes of casing collapse, special attention should be paid to the study of the impact of uneven loading that occurs in intervals of flow rocks. The following conditions are necessary for its manifestation (Kovbasiuk et al., 2020; Beizyk et al., 2022):

- the presence of large cavities in the well and poor cementing quality or the absence of a cement ring behind the casing string;
- concentrated action from the crumpled intermediate column on the production column.

For the conditions of the first case, researchers (Yeremeev et al., 1974; Kovbasiuk et al., 2021) have theoretically and experimentally shown that under uneven external loading of the column by flowing rocks, its resistance to crushing is significantly reduced. The occurrence of a scenario in which the casing is subjected to an uneven external load from plastic rocks is very likely when they flow into the well. However, an analysis of industrial data on casing damage in oil fields in the Carpathian region showed that cases of casing crushing during well drilling and at the initial stage of their operation are quite rare. The vast majority of casing pipes, which had a safety factor of less than one for uniform rock pressure loading, withstood the uneven loading pattern of flowing rocks. This can be explained as follows:

- during the drilling process, the near-wellbore massif of plastic rocks is unconsolidated;
- the pressure of unconsolidated rocks on the casing string is significantly lower than the total rock pressure;
- during the process of covering the cement stone or casing string with plastic rocks, the latter are compacted, while the pressure of the rock on the string increases with a simultaneous decrease in the unevenness of the external load;
- the resistance of the casing string to crushing and the effect of the unevenness of the external load from flowing rocks on it depend on the configuration of the cavity and the location of the string in it, the radius of unconsolidation near the wellbore, and the physical and mechanical properties of the flowing rocks;
- as the unconsolidation radius of the near-wellbore formation increases, the unevenness of the external load from the flowing rock on the column will decrease;
- when plastic rocks cover the cement stone or casing, depending on the unevenness of the load, the pressure of the unconsolidated rocks, and the strength of the pipes, there are three possible options for the deformed state of the casing pipes:
  - no deformation,
  - slight deformation (increased ovality),
  - significant deformation (crushing);
- after the process of covering the cement stone or casing pipe with flow rocks is complete, the column will be subjected to uniform pressure, which may be equal to the total rock pressure after the initial density of the flow rocks is reached (before they are opened);
- in a viscoelastic medium (plastic rocks, cement stone) under the action of a uniform external load, pipes have greater resistance to crushing than under a hydraulic load scheme (Mochernyuk, 1966); therefore, casing pipes do not collapse even when the safety factor for rock pressure is less than one, since they were calculated according to the hydraulic load scheme.

After prolonged operation of wells, casing pipes in plastic rocks can only be crushed by uniform rock pressure due to local loss of stability of their shape, which is caused primarily by the harmful effects of corrosion and wear of the pipes (for example, the mineralization of water in the chemogenic Vorotyshchensky deposits of the Borislav-Pokutsky zone is within the range of 114–237 g/l). In this case, the probable scheme of uneven loading is the concentrated action on the pipes of the production column of the crumpled pipes of the intermediate column, if there is no plugging stone between them or its quality is low. For example, at the Oriv-Ulichnyansky field (Borislav oil-producing region), 75% of all cases of casing crushing occurred in the intervals of concentrically placed columns (intermediate and production) in the absence of plugging material between them after 7÷15 years of well operation (Kovbasiuk et al., 2020). The results of experimental studies (Gaivoronskii and Tsibin, 1981) are interesting in this regard. To determine the external pressures at which systems consisting of two pipes without a cement ring between them collapse, studies were conducted with pipes with a diameter of 32 mm and a wall thickness of 1.0 to 1.5 mm and pipes with a diameter of 22 mm and a wall thickness of 1.0 to 1.5 mm and a length of 400 mm, which simulate casing pipes with a diameter of 219 mm with wall thicknesses of 7÷10 mm and a diameter of 146 mm with wall thicknesses of 7÷10 mm made of steel of strength group D.

A smaller pipe was inserted into a larger pipe, leaving the annular space between them empty. External pressure was applied to the first pipe until it collapsed. With different ratios of pipes with outer diameters and wall thicknesses of 32 × 1.0 mm / 22 × 1.0 mm; 32 × 1.0 mm / 22 × 1.5 mm; 32 × 1.5 mm / 22 × 1.0 mm; 32 × 1.5 mm / 22 × 1.5 mm – after the outer pipes were crushed under pressures of 14 MPa or 26 MPa, the inner pipes were immediately crushed, which, under hydrostatic pressure, were crushed at significantly higher pressures (25 or 44 MPa, respectively).

This confirmed that production columns can be crushed by contact pressure at pressures significantly lower than the critical pressure.

During the above-mentioned experimental studies, hydrostatic pressure was applied to the outer pipe. However, the crushing of casing strings in flowing rocks occurs due to rock pressure, under which the dynamics of deformation of the outer column pipes are different.

We analytically solved the problem of determining the magnitude of contact pressure that arises in the specified scheme of interaction between the columns. It is based on the inverse symmetric problem of interaction between two shells, which is based on the Timoshenko shell theory (Pelekh and Sukhorolskii, 1980).

Selection of the calculation scheme

To solve this problem, it is essential to choose a suitable scheme for the interaction between the columns when the intermediate column is crushed, which would best correspond to the actual conditions.

As noted above, almost all cases of casing collapse in the Carpathian fields have been recorded after prolonged operation of wells in flow rock intervals. During long-term operation of wells, flow rocks (salts, clays) cover the intermediate column (in the absence of cement stone behind it) or cement stone, creating pressure on the column p_2, which under certain conditions can be equal to rock pressure (Kovbasiuk et al., 2021; Grydzhuk et al., 2022). Failure to take rock pressure into account when designing the intermediate column, manufacturing defects, wear and corrosion of casing pipes, etc., can cause it to collapse. Free deformation of the pipe in the radial direction (growth of the larger axis of an oval pipe) is prevented by the cement shell or rock, so the crushing takes the form of a dent.

Pipe buckling in the form of a one-sided dent in the presence of cement stone or rock behind the casing pipe has been proven experimentally by researchers (Yeremeev et al., 1974; Kovbasiuk et al., 2020).

The load and interaction diagram between the columns in the case of external (intermediate) crushing is shown in Figure 1. Let us assume that the space between the columns is filled with a liquid with a pressure of p_1, and the pressure in the producing column is p_0.

Let us model a dent in the form of a cylindrical panel (let us call it the second shell) with a radius ρ_2 and an angle ω_2, which can slide in the radial direction (hinged edges). The choice of this dent model is due to the fact that its shape is similar to a cylindrical panel. Since the deformation of the dent

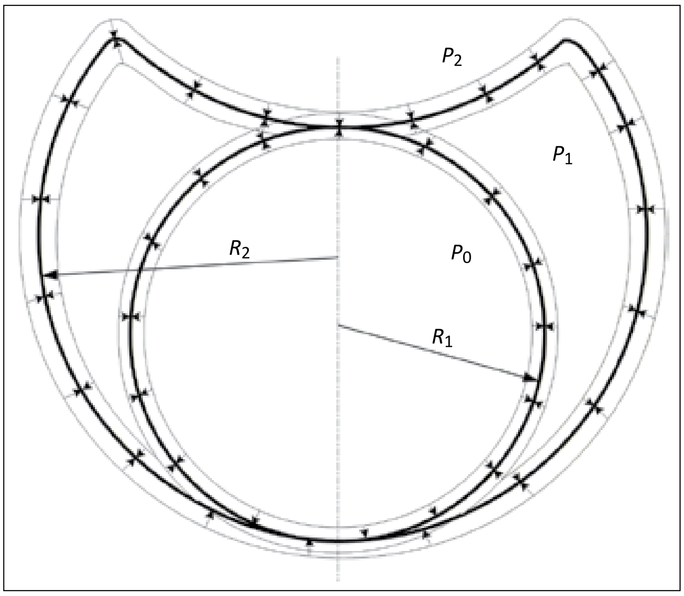

Figure 1. Loading diagram for casing strings after crushing the outer one: p_2 – pressure of flow-ing rocks; p_1 – pressure of fluid between strings; p_0 – pressure of fluid in the production string; R_1 – radius of casing pipes of the production string; R_2 – radius of casing pipes of the intermediate string

over time leads to the displacement of its edges in the radial direction, we have chosen a scheme in which the edges are hinged. This scheme best simulates the movement of the dent edges during their deformation. Since the producing column (first shell) is under the action of a symmetrical load, we will consider only its upper part, replacing the lower part with forces and moments.

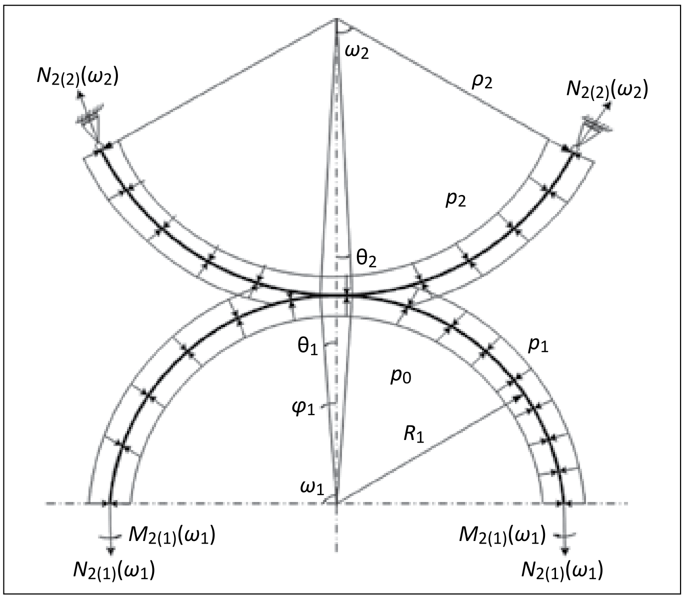

Figure 2. Calculation scheme for determining contact pressure during interaction between two shells: p_2 – pressure of flowing rocks; p_1 – pressure of fluid between strings; p_0 –pressure of fluid in the production string; R_1 – radius of casing pipes of the production string; R_2 – radius of casing pipes of the intermediate string; N and M – are forces and moments acting in the corresponding shell 1 or 2 in sections perpendicular to the coordinate axes; φ – central angle of the guide arc; θ – central angles that determine the size of the contact area; ω – central angles that determine the size of arches 1 and 2 and the position of their hinged supports relative to the symmetry axis of the calculation scheme.

This resulted in a calculation scheme for the interaction of two shells, which is shown in Figure 2. This interaction is characterized by the pressure p_1 or p_2 between the two shells at the contact area. Its size is determined by the central angles θ_1 or θ_2, which are related by the ratio $\rho_2\theta_2 = R_1\theta_1$.

Solution of the problem

The task is to determine the contact pressure $p_1(\theta_1) = p_2(\theta_2)$ and the size of the contact area, which is characterized by the central angles θ_1 and θ_2, where $\theta_2 = \theta_1 R_1/\rho_2$. For this, methods for solving contact problems of the theory of elastic anisotropic shells were used (Pelekh and Sukhorolskii, 1980). According to this, in the absence of surface tangential stresses, the initial system of equations has the following form:

$$
\begin{aligned}
&\frac{d^2F}{d\phi^2} + F = \sigma \cdot \frac{R^2}{A} \\
&\frac{d^2\gamma}{d\phi^2} + \frac{(t^2-1)}{R} \cdot \frac{dF}{d\phi} = 0 \\
&\frac{d^2w}{d\phi^2} + w = F \cdot (1+s^2) - R \cdot \frac{d\gamma}{d\phi} - \sigma \cdot \frac{s^2 \cdot R^2}{A}
\end{aligned} \qquad (1)
$$

where:

A – the reduced tensile stiffness of the shell:

$$A = \frac{E \cdot \delta}{(1-\nu^2)} \qquad (2)$$

t^2, s^2 – dimensionless parameters characterizing the cylindrical shell:

$$t^2 = \frac{R^2 \cdot 12}{\delta^2} + 1 \qquad s^2 = \frac{12}{5 \cdot (1-\nu)} \qquad (3)$$

R – shell radius [m],
σ – surface stress [Pa],
φ – central angle of the guide arc [rad],
δ – shell thickness [m],
E – elastic modulus (Young's modulus) [Pa],
ν – Poisson's ratio.

The quantities u, v, w, and γ characterize the displacement (axial, tangential, radial, respectively) and the angle of rotation of the middle surface of the shell.

N_1, N_2, N_{12}, Q_1, Q_2, and M_1, M_2, M_{12} – are forces and moments acting on areas normal to the coordinate axes.

The relations that establish the dependence of forces on generalized displacements are as follows:

$$
\begin{aligned}
&N_2 = \frac{A}{R} \cdot F \quad N_1 = \frac{\nu \cdot A}{R} \cdot F \quad Q_2 = -\frac{A}{R}\frac{dF}{d\phi} \\
&M_2 = \frac{\delta \cdot B}{2R} \cdot \frac{d\gamma}{d\phi} \quad M_1 = \frac{B \cdot \nu \cdot \delta}{2R} \cdot \frac{d\gamma}{d\phi}
\end{aligned} \qquad (4)
$$

where:

B – reduced bending stiffness of the shell [N]:

$$B = \frac{\delta^2 \cdot E}{(1-\nu^2) \cdot 6} \qquad (5)$$

The first contact condition is obtained based on the relations for the change in the curvature of the shells in the contact area:

$$\chi_1 = \frac{1}{R_1'} - \frac{1}{R_1} \qquad \chi_2 = \frac{1}{\rho_2'} - \frac{1}{\rho_2} \qquad (6)$$

where:

R_1', ρ_2' – radii of curvature of the shells after their deformation [m].

Considering that $R_1' = -\rho_2'$ at the external contact of the shells, from (6) we find:

$$\chi_1 + \chi_2 = -\left(\frac{1}{R_1} + \frac{1}{\rho_2}\right) \quad (7)$$

The second condition of contact is the continuity of radial deformations of shells in the contact area.

Considering radial deformations of shells at points $\varphi_1 = 0$, $\varphi_2 = 0$, the condition of continuity of deformations can be written as follows:

$$w_1(0) + w_2(0) = 0 \quad (8)$$

Boundary conditions:

- for the first shell:

$$Q_{2(1)}(\omega_1) = 0, \quad \gamma_1(\omega_1) = 0, \quad v_1(\omega_1) = 0 \quad (9)$$

- for the second shell:

$$Q_{2(2)}(\omega_2) = 0, \quad M_{2(2)}(\omega_2) = 0, \quad v_2(\omega_2) = 0 \quad (10)$$

Surface stresses:

- for the first shell:

$$\sigma_1(\phi_1) = \begin{cases} p_0 + q_1(\phi_1) & \text{for } 0 \le \phi_1 \le \theta_1 \\ p_0 - p_1 & \text{for } \theta_1 < \phi_1 \le \omega_1; \quad \omega_1 = \dfrac{\pi}{2} \end{cases} \quad (11)$$

- for the second shell:

$$\sigma_2(\phi_2) = \begin{cases} p_2 + q_2(\phi_2) & \text{for } 0 \le \phi_2 \le \theta_2 \\ p_2 - p_1 & \text{for } \theta_2 < \phi_2 \le \omega_2 \end{cases} \quad (12)$$

The solution of the differential equations system (1) under the conditions of deformation compatibility (6)÷(8) and boundary conditions (7)÷(14) is carried out using the operational method in the dissertation (Kovbasiuk, 1998). In the process, system (1) was solved with respect to the stresses σ on the shell surfaces.

From here, a nonlinear equation was obtained for determining θ_1, applying conditions (11)–(12) and the contact pressure condition $p_1(\theta_1) = p_2(\theta_2)$, as well as the condition of a small contact area:

$$\frac{\dfrac{\rho_2^2}{A_2}\cdot p_1 - \dfrac{\rho_2^2}{A_2}\cdot p_2 - \dfrac{R_1^2}{A_1}\cdot p_0 + \dfrac{R_1^2}{A_1}\cdot p_1}{\left[a_1\cdot\dfrac{R_1^2}{A_1} + ma_2\dfrac{\rho_2^2}{A_2}\right]\cdot\dfrac{\sinh\theta_1}{b} - \left[s_1^2\dfrac{R_1^2}{A_1} + m^2 s_2^2\dfrac{\rho_2^2}{A_2}\right]\cdot\left[\dfrac{\theta_1\sinh\theta_1}{b} + \dfrac{1}{b^2} - \dfrac{\cosh\theta_1}{b^2}\right]} -$$

$$- \frac{-\chi_0 + P}{c^2\cdot\dfrac{\sinh\theta_1}{b} - b\theta_1\sinh\theta_1 + \cosh\theta_1} = 0 \quad (13)$$

where:

$$a_1 = \frac{\left(t_1^2 + s_1^2\right)\cdot\pi}{4} - \frac{\left(t_1^2 - 1\right)\cdot 2}{\pi}$$

$$m = \frac{R_1}{\rho_2}$$

$$a_2 = \frac{\left(t_2^2 - s_2^2\right)}{2}\cdot\operatorname{ctg}\omega_2 + \frac{\left(t_2^2 - 1\right)}{\sin\omega_2}\cdot\left[\frac{\omega_2}{\sin\omega_2} - 2\right] + \frac{\left(t_2^2 + s_2^2\right)\omega_2}{2}\cdot\left[1 + \operatorname{ctg}^2\omega_2\right]$$

$$b^2 = \left(\frac{\left(t_1^2 + s_1^2\right)}{A_1} + \frac{m^2\cdot\left(t_2^2 + s_2^2\right)}{A_2}\right)\cdot\left(\frac{s_2^2}{A_2} + \frac{s_1^2}{A_1}\right)^{-1}$$

$$c^2 = \left(\frac{\left(t_1^2 - 1\right)\cdot 2}{A_1\cdot\pi} + \frac{m\cdot\left(t_2^2 + s_2^2\right)}{A_2}\cdot\operatorname{ctg}\omega_2 + \frac{\left(t_2^2 - 1\right)\cdot m}{A_2\cdot\sin\omega_2}\right)\cdot\left(\frac{s_1^2}{A_1} + \frac{s_2^2}{A_2}\right)^{-1}$$

$$\chi_0 = \left(\frac{1}{\rho_2} + \frac{1}{R_1}\right)\cdot\left(\frac{s_1^2}{A_1} + \frac{s_2^2}{A_2}\right)^{-1}$$

$$P = \left(\frac{p_2}{A_2} + \frac{p_0}{A_1} - \frac{p_1}{A_2} - \frac{p_1}{A_1}\right)\cdot\left(\frac{s_1^2}{A_1} + \frac{s_2^2}{A_2}\right)^{-1}$$

The formula for determining the contact pressure at any point in the contact area was obtained in the form:

$$q_1(\phi_1) = \frac{\left(\frac{\rho_2^2}{A_2} p_1 - \frac{R_1^2}{A_1} p_0 - \frac{\rho_2^2}{A_2} p_2 + \frac{R_1^2}{A_1} p_1\right) \cdot \cosh\phi_1}{\left[a_1 \frac{R_1^2}{A_1} + m a_2 \frac{\rho_2^2}{A_2}\right] \cdot \frac{\sinh\theta_1}{b} - \left[s_1^2 \frac{R_1^2}{A_1} + m^2 s_2^2 \frac{\rho_2^2}{A_2}\right] \cdot \left[\frac{\theta_1 \sinh\theta_1}{b} + \frac{1}{b^2} - \frac{\cosh\theta_1}{b^2}\right]} \tag{14}$$

From (14), it can be seen that the law of distribution of contact pressures in the contact area is expressed explicitly through the hyperbolic cosine.

The maximum surface tension occurs at the edges of the contact area and is expressed by the dependence.

$$\sigma_{max} = \frac{\left(\frac{\rho_2^2}{A_2} p_1 - \frac{R_1^2}{A_1} p_0 - \frac{\rho_2^2}{A_2} p_2 + \frac{R_1^2}{A_1} p_1\right) \cdot \cosh\theta_1}{\left[a_1 \frac{R_1^2}{A_1} + m a_2 \frac{\rho_2^2}{A_2}\right] \cdot \frac{\sinh\theta_1}{b} - \left[s_1^2 \frac{R_1^2}{A_1} + m^2 s_2^2 \frac{\rho_2^2}{A_2}\right] \cdot \left[\frac{\theta_1 \sinh\theta_1}{b} + \frac{1}{b^2} - \frac{\cosh\theta_1}{b^2}\right]} + p_0 \tag{15}$$

Results and discussion

Since the cylindrical panel (dent) is in a deformed state, i.e., beyond the elastic limit, the Engesser modulus E^* (Timoshenko, 1971) is used instead of Young's modulus E when calculating the reduced stiffness of the cylindrical panel.

Let us calculate the contact angle and the maximum surface load acting on the production column from the side of the crushed intermediate column using the example of well 175-Oriv (Borislav oilfield).

Calculated values: $E = 2.1 \cdot 10^{11}$ Pa, $\nu = 0.3$, $R_1 = 73 \cdot 10^{-3}$ m, $\delta_1 = 11 \cdot 10^{-3}$ m, $R_2 = 122.2 \cdot 10^{-3}$ m, $\delta_2 = 8 \cdot 10^{-3}$ m, density of drilling mud between casing columns $\rho_{dm} = 1200$ kg/m^3, average rock density $\rho_r = 2300$ kg/m³, oil density in the production column $\rho_o = 800$ kg/m³, depth of the crushed intermediate column $h = 2319$ m. We assume that the external pressure on the intermediate column is equal to the rock pressure $p_2 = \rho_n \cdot g \cdot h$.

Table 1 shows the results of calculating the total contact angle $2\theta_1$, and the maximum surface tension for different values of the Engesser modulus for the dent.

Table 1. Calculation results

Ratio E^*/E	Total contact angle $2\theta_1$ [°]	Maximum surface tension, σ_{max} [MPa]
1.000	0.91	1162
0.891	1.08	993
0.681	1.22	764
0.493	1.72	591
0.262	3.01	382

Thus, as the ratio E^*/E decreases, the contact angle increases and the maximum surface tension decreases, but even at low values of E^*/E, the contact pressures significantly exceed the pressures that arise in a uniform load pattern of the production string.

Conclusions

In the event of crushing of the intermediate casing string, contact pressures significantly exceeding the strength of the production string will be transferred to the production column. The resistance to external pressure in flow rocks of a system with two concentric casing strings (production and intermediate) with low-quality cementing material between them or its absence should be assessed by the crushing pressure of the outer (intermediate) column pipes. Therefore, in order to increase the durability of the well casing, it is a priority to develop measures to prevent the crushing of the intermediate casing string. These main measures include:

- calculating the crushing strength of casing strings, taking into account the effect of rock pressure in flow rocks;
- using effective cementing solutions and drilling muds;
- reducing the cavernousness of the wellbore;
- selecting a rational well design;
- forming a high-quality cement ring;
- preventing corrosion and wear of casing pipes and taking into account the reduction in pipe strength characteristics during long-term well operation when calculating the strength of the intermediate column.

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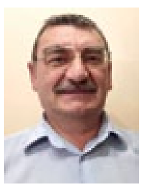

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