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CALCULATION OF THE STRENGTH OF CASING COLUMNS SURROUNDED BY A VISCOUS-ELASTIC MEDIUM

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Abstract. For strengthening the walls of the well with the casing its mechanical properties and rheological parameters of the rocks should be considered. Radius of excited, viscous-elastic rocks and influence of internal friction angle on the strength of the casing have been analyzed in the article. Considering rheological properties of rocks expressions of normal and tangential stresses influencing lateral surface of casing string have been obtained. It has been determined that by increase of the radius of the excited zone of rocks and internal friction angle the flowing limit of the material of casing string increases too. As a result of carried out calculations the table has been compiled and corresponding graphics have been constructed.

Keywords: stress, rocks pressure, rocks, casing string, strength condition.
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1 Introduction

Securing wells with durable casing pipes is one of the important tasks of successful field development. Clarification of the calculated loads acting on the casing is the basis for saving metals in the manufacture of pipes (Feodosev, 1999, Myasnikov & Shirinzade, 1971).

Modern problems of securing oil and gas wells, especially in salt-bearing plastic and sandy-plastic clayey deposits, can be solved using a new direction - the transition from deterministic models to adaptive ones, suitable for various options for evaluating the strength and durability of casing strings, taking into account rheological effects (Amenzade, 1976; Feodosev, 1999) .

Exploitation of oil and gas wells begins after lining the walls of the well by the casing string. As a rule lining of the walls of the well is calculated due to the influencing lateral rock pressure and internal hydrostatic pressure. Lateral pressure is accepted as a part of rock pressure. After running the casing and cementing it one of the main loadings influencing the casing is lateral pressure. When calculating lateral pressure in most cases wells of the well even in the environment with rheological complex property are considered elastic, and in complex geological conditions lateral pressure are equalized to rock pressure (Gentsev & Estrin, 1972; Timoshenko & Goodver, 1975).

Walls of the deep: drilled wells contain rocks with various properties and consisting of clay, sand, clay-sand mixture. They act as rheological mediums having various properties. For this purpose it is expedient to use Maxwell model for viscous-granular mediums (Myasnikov & Shirinzade, 1971).

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2 Main part

Considering rheological properties of the environment calculation of the strength of the casing is of great significance in obtaining of real results. That's why considering rheological properties of the environment the problem of determination of rocks pressure transferred to lateral surface of the casing string. At this moment casing string is in entire contact.

Stress position of the pipe with cross-section in the form consentric circle is determined by Lame equations (Amenzade, 1976).

We write boundary condition for casing string:

$$\sigma_r|_{r=a} = -\gamma_m \cdot H; \qquad \sigma_r|_{r=b} = -P_y$$

Then normal and tangential equations are as follows:

$$\begin{aligned} \sigma_r &= \tfrac{b^2}{r^2}\left(\tfrac{r^2-a^2}{b^2-a^2}\right)(\gamma_m \cdot H - P_y) - \gamma_m \cdot H \\ \sigma_t &= \tfrac{b^2}{r^2}\left(\tfrac{r^2+a^2}{b^2-a^2}\right)(\gamma_m \cdot H - P_y) - \gamma_m \cdot H \end{aligned} \tag{1}$$

Here a and b are correspondingly internal and external radius of the casing string, r is polar coordinate of the point in the pipe trunk, H is the running depth of the casing, P_y is the rock pressure transferred to the lateral surface of the casing string.

Let's write the condition of equilibrium limit in the common form (Feodosev, 1999).

$$\sigma_r - \sigma_t = \sin\varphi\,(\sigma_r + \sigma_t) + 4\gamma v_0 \frac{a}{r^2} \tag{2}$$

Here φ is internal friction angle, γ is viscosity coefficient.

If to consider (1) in (2):

$$\begin{aligned} &\left[\tfrac{a^2}{r^2}\left(\tfrac{r^2-b^2}{a^2-b^2}\right)(\gamma_m H - P_y) - \gamma_m H\right] - \left[\tfrac{a^2}{r^2}\left(\tfrac{r^2+b^2}{a^2-b^2}\right)(\gamma_m H - P_y) - \gamma_m H\right] = \\ &= \left\{\left[\tfrac{a^2}{r^2}\left(\tfrac{r^2-b^2}{a^2-b^2}\right)(\gamma_m H - P_y) - \gamma_m H\right] + \left[\tfrac{a^2}{r^2}\left(\tfrac{r^2+b^2}{a^2-b^2}\right)(\gamma_m H - P_y) - \gamma_m H\right]\right\}\sin\varphi + \\ &+ 4\gamma v_0 \tfrac{a}{r^2} \end{aligned} \tag{3}$$

From here we get

$$-\frac{b^2}{r^2}(\gamma_m H - P_y)\left(\frac{2a^2}{b^2-a^2}\right) = \sin\varphi\left[\frac{b^2}{r^2}(\gamma_m H - P_y)\left(\frac{2r^2}{b^2-a^2}\right) - 2\gamma_m H\right] + 4\gamma v_0 \frac{a}{r^2} \tag{4}$$

If to consider that the rate of the displacement with regard to well axis in the contact zone, between the casing string and viscous-elastic environment is equal to zero (v=0), then we'll get the following expression for lateral pressure

$$P_y = \frac{\mu\gamma_d \cdot H}{(1-\mu)\left(\frac{a}{R}\right)^{f(\varphi)}}. \tag{5}$$

Here $\mu$is Puasson coefficient for rock, $\gamma_d \cdot H$ is average value for rock pressure, R is the external radius considered for the excited zone of viscous-elastic enfironment.

Internal friction angle is determined as

$$f(\varphi) = \frac{2\sin\varphi}{1+\sin\varphi}$$

Considering (5) in (1), let's determine normal and tangential items (for $r = 8case$) of the stress in lateral surface of casing string

$$\begin{aligned} \sigma_r &= -\tfrac{\mu\gamma_d H}{(1-\mu)\left(\frac{a}{R}\right)^{f(\varphi)}} \\ \sigma_t &= \tfrac{a^2+b^2}{b^2-a^2}\left[\gamma_m H - \tfrac{\mu\gamma_d H}{(1-\mu)\left(\frac{a}{R}\right)^{f(\varphi)}}\right] - \gamma_m H \end{aligned} \tag{6}$$

From expression (6) it becomes evident that the pressure transferred to the lateral surface of the casing string depends directly on φ and P parameters of viscous-elastic medium. Let's use the following data for calculation: casing string with the diameter $d-168$ mm; internal radius $a = 7,4sm$; external radius $b = 8,4sm$ and thickness of the wall $\delta = 10mm$; $\gamma_m = 18kN/m^3$, H=3000m, $\mu = 0,2; \mu_1 = 0,36$, $\gamma_d = 24\ kN/m^3$.

The obtained results are given in Table 1.

Table 1: Dependence of the stresses on the radius of the excited zone and internal friction angle

R(mm)	$\varphi = 10^0; f(\varphi) = 0,296$				$\varphi = 20^0; f(\varphi) = 0,507$			
	P_y	σ_r	σ_t	σ_a	P_y	σ_r	σ_t	σ_a
	MPa				MPa			
100	16,4	-16,4	181,9	187,9	17,5	-17,5	114,7	121,6
150	18,5	-18,5	165,3	172,3	21,5	-21,5	141,7	150,1
200	20,1	-20,1	152,3	160,1	24,8	-24,8	115,0	125,4
250	21,5	-21,5	141,4	149,9	27,8	-27,8	91,4	103,9
300	22,7	-22,7	132,0	141,1	30,5	-30,5	70,0	85,1
350	23,7	-23,7	123,6	133,3	33,0	-33,0	50,3	68,7
400	24,7	-24,7	116,0	126,3	35,3	-35,3	32,0	54,9
450	25,6	-25,6	109,0	119,9	37,5	-37,5	14,8	44,6
500	26,4	-26,4	102,6	114,1	39,5	-39,5	-1,5	39,0
550	27,1	-27,1	96,6	108,6	41,5	-41,5	-17,0	39,3
600	27,9	-27,9	91,0	103,6	43,3	-43,3	-31,9	44,5
650	28,5	-28,5	85,7	98,9	45,1	-45,1	-46,1	52,8
700	29,2	-29,2	80,7	94,4	46,9	-46,9	-59,8	62,7
750	29,8	-29,8	75,9	90,2	48,5	-48,5	-73,1	73,2
800	30,3	-30,3	71,4	86,3	50,2	-50,2	-85,9	84,0
850	30,9	-30,9	67,1	82,6	51,7	-51,7	-98,3	94,8
900	31,4	-31,4	62,9	79,0	53,2	-53,2	-110,4	105,5
R(mm)	$\varphi = 10^0; f(\varphi) = 0,296$				$\varphi = 20^0; f(\varphi) = 0,507$			
	P_y	σ_r	σ_t	σ_a	P_y	σ_r	σ_t	σ_a
	MPa				MPa			
950	31,9	-31,9	58,9	75,6	54,7	-54,7	-122,1	116,2
1000	32,4	-32,4	55,0	72,5	56,2	-56,2	-133,5	126,6
1050	32,9	-32,9	51,3	69,4	57,6	-57,6	-144,7	136,9
1100	33,3	-33,3	47,7	66,5	58,9	-58,9	-155,6	147,1
1150	33,8	-33,8	44,2	63,8	60,3	-60,3	-166,2	157,0
1200	34,2	-34,2	40,8	61,2	61,6	-61,6	-176,7	166,8
1250	34,6	-34,6	37,5	58,8	62,9	-62,9	-186,9	176,4
1300	35,0	-35,0	34,3	56,5	64,2	-64,2	-196,9	185,9
1350	35,4	-35,4	31,2	54,3	65,4	-65,4	-206,7	195,2
1400	35,8	-35,8	28,1	52,3	66,6	-66,6	-216,4	204,3
1450	36,2	-36,2	25,2	50,4	67,8	-67,8	-225,9	213,3
1500	36,5	-36,5	22,3	48,6	69,0	-69,0	-235,2	222,2
1550	36,9	-36,9	19,4	47,0	70,1	-70,1	-244,4	230,9
1600	37,2	-37,2	16,7	45,5	71,3	-71,3	-253,4	239,5
1650	37,6	-37,6	14,0	44,2	72,4	-72,4	-262,3	248,0
1700	37,9	-37,9	11,4	43,0	73,5	-73,5	-271,1	256,4
1750	38,2	-38,2	8,8	41,9	74,6	-74,6	-279,7	264,6
1800	38,5	-38,5	6,2	41,0	75,7	-75,7	-288,2	272,8
1850	38,9	-38,9	3,7	40,2	76,7	-76,7	-296,6	280,8

R(mm)	$\varphi = 30^0; f(\varphi) = 0,656$				$\varphi = 40^0; f(\varphi) = 0,757$			
	P_y	σ_r	σ_t	σ_a	P_y	σ_r	σ_t	σ_a
	MPa				MPa			
100,0	18,3	-18,3	167,0	173,8	18,8	-18,8	162,5	169,6
150,0	23,9	-23,9	122,8	132,5	25,6	-25,6	108,8	119,7
200,0	28,8	-28,8	83,4	96,8	31,8	-31,8	59,4	76,1
250,0	33,4	-33,4	47,4	66,3	37,7	-37,7	12,9	43,7
300,0	37,6	-37,6	13,8	44,1	43,3	-43,3	-31,4	44,3
350,0	41,6	-41,6	-18,0	39,5	48,6	-48,6	-73,9	73,8
400,0	45,4	-45,4	-48,2	54,2	53,8	-53,8	-114,9	109,6
450,0	49,1	-49,1	-77,1	76,5	58,8	-58,8	-154,7	146,2
500,0	52,6	-52,6	-105,0	100,7	63,7	-63,7	-193,4	182,6
550,0	56,0	-56,0	-131,9	125,1	68,5	-68,5	-231,3	218,4
600,0	59,2	-59,2	-158,0	149,3	73,1	-73,1	-268,2	253,7
650,0	62,4	-62,4	-183,3	173,1	77,7	-77,7	-304,5	288,3
700,0	65,6	-65,6	-208,0	196,4	82,2	-82,2	-340,1	322,4
750,0	68,6	-68,6	-232,1	219,2	86,6	-86,6	-375,0	356,0
800,0	71,6	-71,6	-255,6	241,7	90,9	-90,9	-409,4	389,0
850,0	74,5	-74,5	-278,7	263,7	95,2	-95,2	-443,3	421,6
900,0	77,3	-77,3	-301,3	285,2	99,4	-99,4	-476,7	453,7

R(mm)	$\varphi = 30^0; f(\varphi) = 0,656$				$\varphi = 40^0; f(\varphi) = 0,757$			
	P_y	σ_r	σ_t	σ_a	P_y	σ_r	σ_t	σ_a
	MPa				MPa			
950,0	80,1	-80,1	-323,4	306,5	103,6	-103,6	-509,6	485,4
1000,0	82,8	-82,8	-345,2	327,3	107,7	-107,7	-542,2	516,7
1050,0	85,5	-85,5	-366,5	347,8	111,7	-111,7	-574,3	547,7
1100,0	88,2	-88,2	-387,6	368,0	115,7	-115,7	-606,1	578,3
1150,0	90,8	-90,8	-408,3	387,9	119,7	-119,7	-637,5	608,6
1200,0	93,4	-93,4	-428,7	407,5	123,6	-123,6	-668,6	638,5
1250,0	95,9	-95,9	-448,8	426,9	127,5	-127,5	-699,4	668,2
1300,0	98,4	-98,4	-468,6	445,9	131,3	-131,3	-729,8	697,6
1350,0	100,9	-100,9	-488,2	464,8	135,1	-135,1	-760,0	726,7
1400,0	103,3	-103,3	-507,5	483,4	138,9	-138,9	-790,0	755,6
1450,0	105,7	-105,7	-526,6	501,8	142,7	-142,7	-819,6	784,2
1500,0	108,1	-108,1	-545,5	519,9	146,4	-146,4	-849,0	812,6
1550,0	110,5	-110,5	-564,2	537,9	150,0	-150,0	-878,2	840,7
1600,0	112,8	-112,8	-582,6	555,7	153,7	-153,7	-907,2	868,6
1650,0	115,1	-115,1	-600,9	573,3	157,3	-157,3	-935,9	896,4
1700,0	117,4	-117,4	-618,9	590,7	160,9	-160,9	-964,4	923,9
1750,0	119,6	-119,6	-636,8	607,9	164,5	-164,5	-992,7	951,2
1800,0	121,8	-121,8	-654,5	625,0	168,0	-168,0	-1020,9	978,4
1850,0	124,1	-124,1	-672,0	641,9	171,6	-171,6	-1048,8	1005,3

For providing the reliable work regime and durability of the casing string in the well one of the main problems is the precise calculation of the critic pressure considering flowing limit of the pipe material. Considering the value of the stresses influencing in the lateral surface of the casing string because of the viscous-elastic medium flowing limit of the stress has been determined applying the theory of energetic strength.

$$\sigma_a = \sqrt{\sigma_r^2 + \sigma_t^2 - 2\mu_1 \sigma_r \sigma_t} \tag{7}$$

here μ_1 is Poisson's coefficient for pipe material.

By the help of the calculation results graphics corresponding to the flowing limit of the material and dependence of the normal stress on the radius of the excited zone have been constructed.

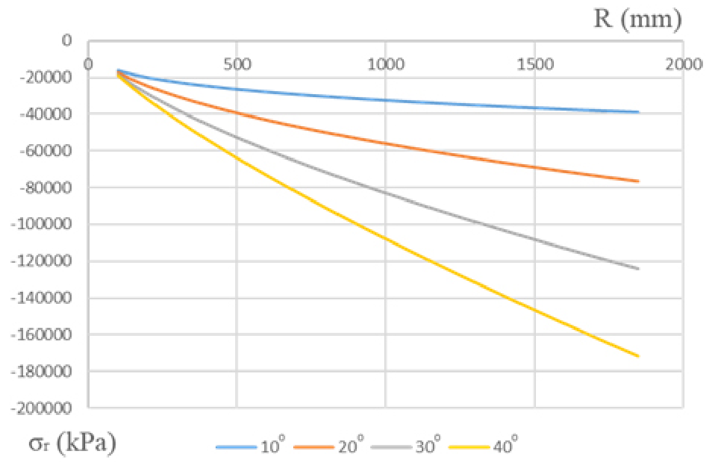

Figure 1: $1.\varphi_1 = 10°; 2.\varphi_2 = 20°; 3.\varphi_3 = 30°; 4.\varphi_4 = 40°$. Dependence graphics of σ_r on R and φ.

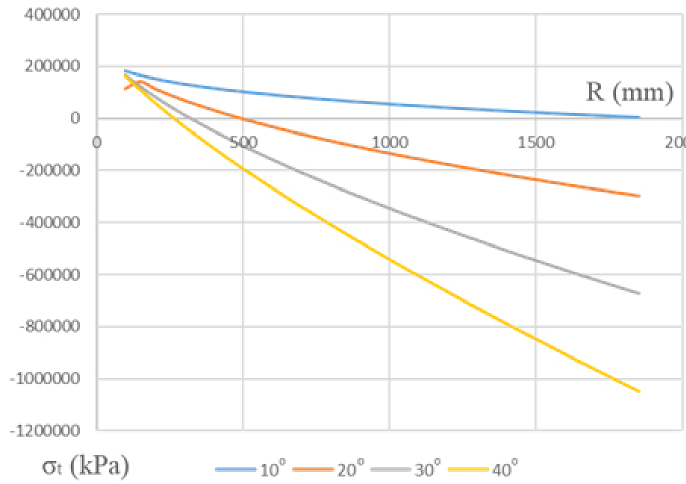

Figure 2: $1.\varphi_1 = 10°; 2.\varphi_2 = 20°; 3.\varphi_3 = 30°; 4.\varphi_4 = 40°$. Dependence graphics of σ_t on R and φ.

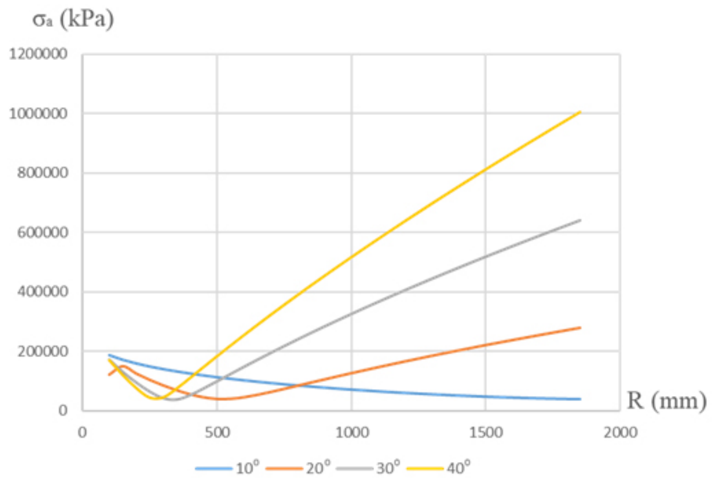

Figure 3: $1.\varphi_1 = 20°; 2.\varphi_2 = 30°; 3.\varphi_3 = 40°; 4.\varphi_4 = 40°$. Dependence graphics of σ_a on R and φ.

As it is seen from the graphics by the increase of the radius of the excited zone and value of the internal friction angle the pressure transferred to the lateral surface also increases. It should be mentioned by the increase of rheological parameters of the rocks R and φ flowing limit of the stress increases rapidly.

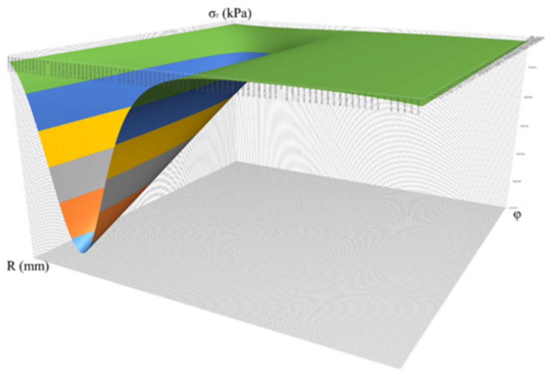

Figure 4: 3D graphs showing the dependence of σ_r on R and φ.

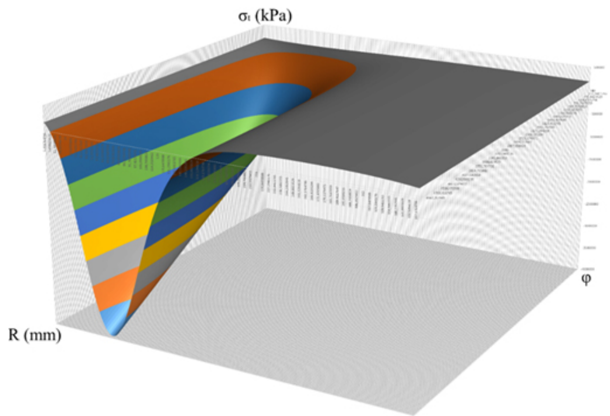

Figure 5: 3D graphs showing the dependence of σ_t on R and φ.

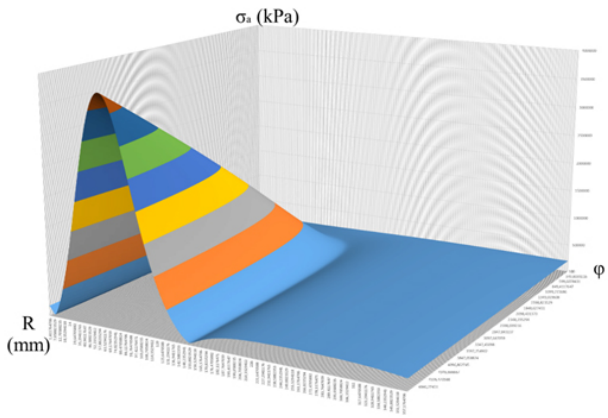

Figure 6: 3D graphs showing the dependence of σ_a on R and φ.

Three-dimensional graphs (Fig.4-6) characterizing the changes in σr, σt and σa, which affect the ground's surface in an elastic environment with a protective pipeline, depending on R and φ, have been constructed. These graphs clearly show how the stresses change with these parameters.

It is important to note that for large values ??of φ a very large value of σa is obtained, which cannot be achieved practically. From this we can conclude that the stability and reliability calculations of casing strings surrounded by viscous fluids require a completely new theoretical and practical approach.

3 Conclusion

As a result of calculations it was found that in those cases when there is a viscous-free-flowing medium behind the column, the load on the casing column increases significantly. Moreover, with an increase in the dimensional (in particular R) and rheological parameters of the viscous-free-flowing medium, the lateral pressure transmitted to the column increases.

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