Calculation the Margin of Safety and Durability According to Change Thickness the Pipeline

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Abstract. In the article the analysis and to mathematically calculated the margin of safety and durability according to change thickness of pipeline. The proposed conditions on the application of the obtained results.

1. Introduction
The security level of the technological line section of the main pipeline (MP) directly depends on the following parameters: level and character of the intense deformed state, pipeline geometry, chemical and structural composition [1].

In the conditions of a large number of short-term changes of pressure in MP is observed increase level of intensity in a pipeline wall that it leads to reduction of an operational resource.

In the course of product transport at the stationary mode on MP with the internal pressure $P_1$ in the wall of MP appears circumferential stresses, which lead to changes of internal geometry of the pipeline.

At emergence of the non-stationary mode, which is characterized by increase of pressure from $P_1$ to $P_2$, appear ring tensions leading to reduction in reserve of strength and durability. By the achievement of considerable indicators of tension in a wall of MP appears a bend, which is followed by the displacement of the axis of the pipeline and the soil massif, loss of stability. As a result appears an emergency situation in the form of break (Figure 1) [2].

![Appearance of bending moments.](image)

Figure 1. Appearance of bending moments.

The research objective is to mathematically calculate the margin of safety and durability according to change thickness the pipeline.

2. Research
We will apply the differential equation of a curved surface:

$$
\frac{\partial^4 w}{\partial x^4} + \frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial x^4} = \frac{q}{D},
$$

(1)
where q – the loading distributed on an inner surface of a wall of the pipeline
w – the deflection of the pipeline wall
D – flexural rigidity

We will apply the membrane theory of thin-walled casings and we will write down the differential
equation of a bend of a pipeline wall with a cylindrical casing (form) [3]:

\[
\frac{\partial^4 w}{\partial x^4} + 4 \beta w = \frac{q}{D},
\]

where \(\beta\) – mechanical-geometrical coefficient

We will transform the differential equation of a bend of a wall and we will write down a final form
of the common decision of a bend:

\[
w = e^{\beta x} (C_1 \sin \beta x + C_2 \sin \beta x) + e^{-\beta x} (C_3 \sin \beta x + C_4 \sin \beta x) + f(x),
\]

a fast-rising function

a fast damped function

In the conditions of the solving of a task on a bend of the pipeline long the L is important a fast
damped function characterizing a small section on length of L with the operating maximum bend. We
will consider appearance of the maximum deflection of a pipeline wall at the non-stationary mode at
figures 2 and 3.

\[w_{\text{max}} = \frac{P_2 \cdot R^2}{\delta \cdot E},\]

where \(f(x) = \frac{\Delta P \cdot R^2}{\delta \cdot E}\)

by \(C_3, C_4, X = 0 \rightarrow \frac{\Delta P \cdot R^2}{\delta \cdot E}\) where \(\Delta P = P_2 - P_1\)

Calculated the bending moment of a MT:

\[M_x = -D \frac{d^2 w}{dx^2},\]
Figure 3. Appearance of the bending moment of a pipeline.

\[ \sigma_{\text{max}} = \pm \frac{6(P_2 - P_1) \cdot R^2}{\delta^3 \cdot E} \cdot 2 \left( \sqrt{\frac{3(1 - \nu^2)}{(R\delta)^2}} \right)^2, \quad \frac{\delta^3 \cdot E}{12(1 - \nu^2)} = \pm \frac{(P_2 - P_1) \cdot R}{\delta} \cdot \sqrt{\frac{3}{1 - \nu^2}}, \]  \tag{6}

Taking into account action of internal pressure and a bend will applicable the fourth (power) theory of durability, which is often used in practice and coincides with experiences for plastic materials, for the purpose of determination of equivalent tension \[4\].

\[ \sigma_{\text{com}, \text{max}} = \sigma_{\text{max}} \cdot \sqrt{1 + 4.9 \cdot \frac{P_2 - P_1}{P_1} \left( \frac{1 + 1.73 \cdot \frac{P_2 - P_1}{P_1}}{} \right)} = \sigma_{\text{max}} \cdot K, \]  \tag{7}

For definition of durability of \( N_{\text{dur}} \) by changing of pressure from \( P_1 \) to \( P_2 \) we will use Manson's formula for low-cyclic destruction.

\[ E_a = \frac{1}{2} \left( \ln \frac{1}{1 - \Psi} \right)^{0.6} \cdot n_g^{-0.6} + 0.75 \cdot \frac{\sigma_b - \sigma_m}{E} \cdot n_g^{-0.12}, \]  \tag{8}

where \( \varepsilon_a \) - amplitude of variable deformations; \( \Psi \) - transverse contraction of the material; \( \sigma_b \) – limit of strength of metal; \( \sigma_m \) – the average tension of a cycle; \( N_{\text{dur}} \) – the number of cycles before destruction.

\[ n_g = \left[ \frac{3.5 \cdot \left[ n_b - 0.5 \left( 1 + \frac{1}{K} \right) \right]}{1 - \frac{1}{K}} \right]^{8.33}, \]  \tag{9}

Will hold the count key indicators by the initial conditions: \( P_1 = 4 \text{ MPa}, D = 700 \text{ mm}, \sigma_b = 520 \text{ MPa}, n_g = 30 000, \text{ Steel - 17G1C at tablet 1 and figures 3-5.} \)

**Table 1.** Key indicators MT.

| \( \frac{P_2 - P_1}{P_1} \) | \( \delta \) | \( n_b \) | \( n_g \) |
|---|---|---|---|
| 0.1 | 7 | 2.114 | 3.4E+06 |
| 0.1 | 8 | 2.423 | 2.2E+07 |
| 0.1 | 9 | 2.734 | 1.0E+08 |
| 0.1 | 10 | 3.046 | 3.9E+08 |
| 0.1 | 11 | 3.361 | 1.2E+09 |
| 0.1 | 12 | 3.677 | 3.3E+09 |
Figure 4. The dependence of the margin of safety from the thickness of MP.

Figure 5. The dependence of the margin of safety and margin of durability from the pressure change.
Figure 6. The dependence of the margin of safety from the thickness of MP and pressure change.

4. Conclusion
It is shown that increasing in thickness of the pipeline wall at 1 mm on average increases margin of safety from 6 to 18%, and the durability from 3 to 10 times, and these indicators decrease with increase $P_2$. Thus it is mathematically proved that increase of the thickness of MP wall increases durability and increases margin of safety of MP. Design institutes and the construction organizations for increase of safety at operation of MP, the transporting wide fractions of hydrocarbons, can use the obtained data.

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