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THE ESTIMATION OF TECHNICAL STATE OF MARINE PIPELINES

Procedures of calculation of stress-deformation state of the most hazardous submarine pipeline sections are considered, an example of the calculation is given.

In the oil fields under development in the shelf of Vietnam marine pipelines for offshore pumping of high-solidification oils, gas-liquid mixtures, gas and water to maintain formation pressure are in operation. The constructive design of pipelines is performed without sea bottom penetration. As is shown by the world practice, the main causes of failures of such pipelines in operation can be damage from ship anchors, internal and external corrosion of pipes, excessive bends in vertical and horizontal planes, wear of pipelines at the intersection points, damage resulting from metal fatigue caused by waves, currents, changes in pressure and temperature of a product being pumped, bottom deformation and sagging of pipelines, damage caused by construction work in the immediate proximity to pipelines.

To ensure reliable and trouble-free operation of marine pipelines and to make a timely decision regarding time and type of repair one should possess true information about technical condition of these pipelines.

In case of impossibility of using traditional methods of checking required parameters, applied for pipelines laid on the ground, it becomes necessary to develop and to update the procedures of obtaining such parameters by theoretical methods.

This work is carried out in several steps.

At first map-making of pipelines with the help of specially equipped vessels is performed, whereby their actual location is determined and displacements caused by underwater currents are registered.

Then the diving inspection to determine a pipeline disposition on the ground and to make a detailed description of intersection points is carried out. Pipeline sagging and a depth of a layer of ground above the pipelines are measured.

The data obtained are used in calculations of stress-deformation state of sagging of underwater pipeline sections at the intersection points.

<u>Example of calculation</u>

The maximum equivalent stresses in a pipe wall of a sagging pipeline section at the intersection point with a lower pipeline, laid at the bottom without penetration, have to be estimated.

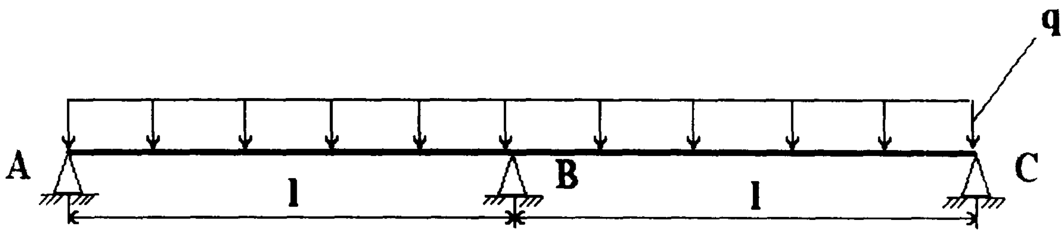
Proceeding from a level of equivalent stresses, an examination of a possibility of formation of plastic deformations along the low generating line of a pipe wall in a point of support onto an intersected pipeline according to Mizes-Henky criterion is required.

<u>The initial data</u>

Parameter	*Value*
environment of pumping	oil
working pressure	1,0 MPa
testing pressure	2,0 MPa
pipe diameter	D=0,325 m
pipe wall thickness	δ=0,016 m
pipe material	Steel 20 by the State Standard (ГОСТ) 1050-88
Depth	48 m
point of support elevation to an inter-sected oil pipeline above the sea level	0,3 m
Maximum distances from the sea bottom surface to the low generating line	0,6 m
Length of a sagging section	not determined by the data of diagnostics, supposedly - more than 45-50 meters on both spans

<u>*Calculation procedure*</u>

First the maximum possible length of a sagging section from the condition of a free bend of halves of two-span continuous beam is estimated. (see Fig.)



Estimated diagram of pipeline sagging section at the intersection point with a lower laid pipeline

In view of a large extension of adjacent sections and uncertainty of a place where a pipeline penetrates the ground, fixed + pivoting supports are introduced.

The points of support onto the intersected oil pipeline are elevated above the sea bottom by 0,120÷0,500 m, which is negligibly small in comparison with the length, that is why the supports in the diagram are introduced as situated at the same height.

The maximum possible length of a span is defined by the formula

$$l = \sqrt[4]{\frac{384 EJf_{\max}}{2q}}, \qquad (1)$$

where $f_{\max}$ - is at maximum possible pointer of the bend in the middle of the span, introduced with consideration of an elevation of a point of support from the bottom, of an outline of the axis of the pipeline and materials under research; q - load on 1 m of the pipeline determined with consideration of the weight of a pipe itself together with insulation, weight of a product, of a hydrodynamic effect of current and waves, of buoyant force of water.

Load and effect determination

Load from waves («СниП» - Construction Norms and Regulations (CN&R) II-57-75)

Inertia component of a horizontal constituent

$$P_{xu} = \frac{1}{2}\gamma \cdot \pi^2 \cdot D_н^2 \frac{h}{\overline{\lambda}} K_v \theta_x \beta_u \ , \tag{2}$$

where γ - is specific gravity of water, N/м^3; γ=1,3 N/м^3; D_o - outside diameter of the insulated pipeline, m, D_o =0,345 m; h - calculated wave height, introduced as equal to maximum, m, h=7,5 m; $\overline{\lambda}$ - average wave length, m, =121,24 m; K_v - factor, introduced by a relative parameter $D_o/\overline{\lambda}$ =0,345/121,24=0,003, K_v=1; θ_x - is introduced by nomographs CN&R II-57-75 depending on relative depth $\overline{Z} = \frac{H-z}{H} = \frac{0,472}{48} \cong 0,01$; θ_x=0,5; β_i - inertia factor of the form of a barrier, which is introduced by nomographs CN&R II-57-75 depending on a ratio of dimensions of a barrier, for a circle β_i=1.

Velocity component of a horizontal constituent

$$P_{x-} = \frac{2}{3}\gamma \cdot \pi \cdot D_o \frac{h^2}{\overline{\lambda}} K_\gamma^2 \varepsilon_x \beta_v , \tag{3}$$

where ε_x - is introduced by the diagram of CN&R II-57-75 depending on $\overline{Z} \cong 0,01$, ε_x= 0,1; β_v- is a velocity factor used for the circular form by the diagram of CN&R II-57-75, β_v =1.

The maximum value of a horizontal constituent from waves is defined by formula

$$P_{xm} = P_{xi} \cdot \delta_{xi} + P_{xv} \cdot \delta_{xv} , \tag{4}$$

where δ_{xi} и δ_{xv} - are factors of a combination of inertia and velocity components of the load from waves introduced by charts 1 and 2 of Fig. 18 of CN&R II-57-75 depending on relative distance $\overline{X}$ from a crest of a wave up to an axis of a pipe along the horizontal line (item 3.1 of CN&R II-57-75); for calculated - $\overline{\lambda}$=121,24 m, h =7,5 m and others, at the depth of H=48 m, it results in: δ_{xi} =0,7; δ_{xv} =0,55.

The maximum value of a vertical constituent of the load from waves is defined by formula

$$P_{zm} = -P_{zi} \cdot \delta_{zi} + P_{zv} \cdot \delta_{zv} , \tag{5}$$

where P_{zu} and P_{zc} - are inertia and velocity components of a vertical constituent of the load from waves, N/м, defined as

$$P_{zi} = \frac{1}{2}\gamma \cdot \pi^2 \cdot D_o^2 \frac{h}{\overline{\lambda}} K_\gamma \theta_z \beta_i \, , \qquad (6)$$

$$P_{zv} = \frac{2}{3}\gamma \cdot \pi \cdot D_o \frac{h^2}{\overline{\lambda}} K_\gamma^2 \varepsilon_z \beta_v \, , \qquad (7)$$

where θ_z and ε_z - are factors of the load introduced by the charts of Fig. 19 CN&R II-57-75 at $\overline{z}$ =0,01, $\theta_z \cong 0$; $\varepsilon_z \cong 0$; as a result P_{zi} =0 and P_{zv} =0, that is there will be no vertical constituents from wave load because of a close disposition of a washed-out pipeline from the bottom.

Load from sea currents

Based on the data of hydrodynamic research of the water area the change of the main trends of the current from N-E-E (achieving a maximum velocity in July) to S-S-W (maximum velocities in October) has been established. Within the limits of the sagging section the pipeline is situated at the distance of 0,3÷0,6 m from the bottom, that is why, apart from the horizontal force of head resistance, defined by formula

$$P_x = \frac{1}{2} C_x \cdot \rho \cdot V^2 \cdot D_o \, , \qquad (8)$$

it undergoes a lifting force

$$P_y = C_y \cdot \rho \cdot V^2 \cdot D_o \, , \qquad (9)$$

where C_x - is a head resistance factor dependent on Reynolds number; C_y - a lifting force factor, dependent upon distance S between the low generating line of the pipe and the bottom; ρ - density of water, kg/m^3, ρ =1,3 kg/m^3; V - velocity of the current, m/s; D_o- outside diameter of the pipe with insulation, m.

Reynolds number

$$\mathrm{Re} = \frac{V \cdot D_o}{\nu} \, , \qquad (10)$$

where ν - viscosity of water introduced as equal to ν =100 m^2/s.

Own weight of the pipeline with consideration of buoyancy force

One meter of a pipe's own weight with a diameter of 0,325 m and with pipe wall thickness of 0,016 m is 1,22 kiloNewton (kN).

Weight of an empty pipe with insulation in the air is defined by formula

$$q_{p.i} = q_p + q_{ins} \, , \qquad (11)$$

where q_{ins} - is weight of insulation defined by formula

$$q_{ins} = \frac{\pi}{4}\gamma_i (D_o^2 - D) \, , \qquad (12)$$

where γ_u - is specific gravity of insulation; *D* - outside diameter of the pipe, m.

Weight of the empty pipe with insulation with consideration of buoyancy force

$$q_{bf} = q_{p.i} - \frac{\pi D_o^2}{4}\gamma, \qquad (13)$$

where γ - specific gravity of water.

Load per unit of length of the sagging pipeline

The load is defined by formula

$$q = \sqrt{q_{vert}^2 + q_{hor}^2}, \qquad (14)$$

where q_{vert} - vertical constituent of the load per unit of length; q_{hor} - horizontal constituent of the load per unit of length of the pipe.

The vertical constituent of the load is defined as the sum of all vertical components by formula

$$q_{vert} = q_{bf} + q_p - P_y, \qquad (15)$$

where q_p - weight of a product in 1 m of the pipeline, defined by formula

$$q_p = \rho_p \cdot g \cdot \frac{\pi \cdot D_{in}^2}{4}, \text{ kN/m} \qquad (16)$$

where ρ_p - density of a product, kg/m^3; g = 9,81m/s^2; D_{in} - the inside diameter of the pipeline, defined by formula

$$D_{in} = D - 2\delta,$$

where δ - is a pipe wall thickness, m.

The horizontal constituent of the load is defined by formula

$$q_{hor} = P_{xm} + P_x, \qquad (17)$$

where P_{xm} and P_x - forces calculated by formulas (4) and (8).

<u>*Sequence of calculation*</u>

In accordance with the calculation scheme by the initial data and with consideration of certain loads a bending moment in the most hazardous cross-section of the pipeline - on support B is calculated.

$$M_B = -0{,}125 q \cdot l^2. \qquad (18)$$

Bending stresses in the section of support B are calculated by formula

$$\sigma_b = \frac{M_B}{W}, \qquad (19)$$

where W - moment of resistance of circular cross-section.

If the research has detected the presence of a turn of the pipeline in a vertical plane with radius r ≥ D, then stresses from elastic bending have to be defined by formulae CN&R 2.05.06-85 with consideration of a direction of the curvature.

For the subsequent calculation of longitudinal stresses in a pipe wall the highest stresses are introduced, comparing $\boldsymbol{\sigma_b}$ defined by formula (19), with stresses, defined by CN&R 2.05.06-85 for the turn in a vertical plane.

In detecting a turn in a horizontal plane the corresponding stresses of the bend have to be defined by formulae CN&R 2.05.06-85 and they have to be considered separately.

The circular stresses in a pipe wall caused by internal pressure under the test are calculated as

$$\sigma_{cs} = \frac{p_t \cdot D_{in}}{2\delta} , \tag{20}$$

where p_t - is testing pressure.

The longitudinal stresses in a pipe wall caused by internal pressure and by a bend are calculated as

$$\sigma_{lsN} = \mu \cdot \sigma_{cs} \pm \sigma_b . \tag{21}$$

The octahedral tangential stresses for a plane stressed state are calculated as

$$\tau_{oct} = \frac{\sqrt{2}}{3} \cdot \sqrt{(\sigma_{cs})^2 + (\sigma_{lsN})^2 - \sigma_{cs} \cdot \sigma_{lsN}} . \tag{22}$$

The condition of absense of plastic deformations in a support cross-section in accordance with Mizes-Henky criterion is checked

$$\sigma_{eq} = \frac{3}{\sqrt{2}} \cdot \tau_{oct} = \sqrt{(\sigma_{cs})^2 + (\sigma_{lsN})^2 - \sigma_{cs} \cdot \sigma_{lsN}} \le \sigma_{\text{y}} . \tag{23}$$

where σ_{y} - yield stress.

Results of the calculation

The calculation is made for July, when the velocity of the current is at maximum and it reaches 1,4 m/s. The height of the wave is introduced as equal to the maximum value, corresponding to January - 7,5 m. The results of the calculation are illustrated in the Table.

Parameter	***Dimensions***	***Calculated value***
1	**2**	**3**
P_{xi}	kN/m	0,24
P_{xv}	kN/m	0,43
P_{xm}	kN/m	0,404
Re	-	$4{,}83 \cdot 10^5$
C_x	-	1,2
S/D_0	-	0,87
C_y	-	0,012
P_x	kN/m	5,27

1	2	3
P_y	kN/m	0,105
q_{ins}	kN/m	0,12
$q_{p.i}$	kN/m	1,34
q_{bf}	kN/m	0,12
q_p	kN/m	0,595
q_{vert}	kN/m	0,610
q_{hor}	kN/m	5,674
q	kN/m	5,71
M_B	kN/m	447,9
W	m^3	$0{,}1144 \cdot 10^{-2}$
σ_b	MPa	391,52
σ_{cs}	MPa	335,35
σ_{lsN}	MPa	492,12
$\sigma_{eq}"+"$*	MPa	435,44
$\sigma_{eq}"-"$**	MPa	638,04

* $\sigma_{экв}"+"$ - stresses in an extended zone;

** $\sigma_{экв}"-"$ - stresses in a contracted zone (low generating line).

For Steel 20 $\sigma_y = 250$ MPa, $\sigma_u = 420$ MPa - ultimate stress.

$$\sigma_y < \sigma_{eq},$$

250 MPa < 435,44 MPa,

250 MPa < 638,04 MPa.

The calculation is made for maximum velocities of the current at the surface, equal to 1,4 m/s (July) with repetition of 0,07 % and ensuring 0,1 %, i.e. for too overrated values of loads at probability equal to 0,1 %; the corresponding height of waves is introduced as equal to 5,0 m with probability of 0,1 %.

The level of force effect of currents of waves is also overrated by approximately 30 % in view of the fact that the angle between the direction of an axis of the pipeline and the direction of the current makes about 60 degrees.

Possibilities of the procedure at overrated levels of loads from currents are demonstrated in the article. However, it should be noted, that with probability of 5,2 % the velocity of the current in July may reach 0,9 m/s, and it can result in additional increase of loads on the pipeline.