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Research Influence of Hazard on the Subsea Pipelines in the Caspian Sea

Yuri M. Fedorchuk[a,*], Jiří J. Klemeš[b], Petar S. Varbanov[b], Vladimir V. Matvienko[a]

[a]Tomsk Polytechnic University, 30 Lenin Avenue, Tomsk, Russian Federation
[b]Sustainable Process Integration Laboratory – SPIL, NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology - VUT Brno, Technická 2896/2, 616 69 Brno, Czech Republic
ufed@mail.ru

The area of the Continental Shelf of the World Ocean and closed seas, which is promising for oil and gas, covers 20 Mkm^2, but nowadays it's developed only up to 1 Mkm^2. It is known that the remaining larger part is highly perspective. There are colossal volumes of oil and gas in entrails of Russian shelf. About 90 % of shelf's area are perspective for hydrocarbon production – this is 2/3 of envisaging further development stocks on the land. Currently there are 9 large open fields within the shelf of the Russian waters in the Caspian Sea, but only one is equipped – the Yuri Korchagin field. In the next 10 y has been planned to equip four more fields, to build 1,500 km of undersea trunk pipeline. Caspian Sea can freeze – there is an ice season – usually from November to March, and in freezing seas the main danger for the undersea pipeline are the keels of hummocky formations. Underwater pipelines built in the Russian Federation (RF) and Kazakhstan sectors of the North Caspian Sea lay on the ground without embedment. As the result, in the winter seasons of 2012-2013 subduction and layering of ice, which thickness reached several tens of cm, led to the accident at the oil field "Kashagan" in the Kazakh sector of the North Caspian Sea. The four threads of the pipe, laying on the seabed without embedment, were damaged by ice. The same phenomenon happened in the Korchagin oilfield and caused not only economic losses, but also brought environmental damage to the Caspian Sea ecosystem. To study the influence of ice formations and evaluation of the interaction of marine pipelines with slack soils is a necessary condition for designing, constructing and operation on the shelf sea infrastructure (Klemeš, 2015).

1. Introduction

The key factors in the design of offshore oil and gas infrastructure are the requirements to ensure reliability while minimising environmental impacts throughout their design life (RMRS, 2009).

Pipelines in the Russian Federation Caspian Sea partly lay at a shallow depth, facing a very harsh climate. This trend underlines the need to improve the understanding of the pipeline behaviour under the varying conditions – especially loads.

At present, most of the research work in the field of offshore pipeline design is aimed at studying the pipeline's behaviour during construction. Such an important factor arising in the process of exploitation, as well as ice exposure to underwater pipelines, has not been studied enough, therefore in this work a model of interaction of pipelines with icebergs was developed, taking into account different types of soils of the Caspian Sea and various forms of the keel of the iceberg. The modelling of the iceberg-primer-pipeline system has been going on for a long time, but due to large assumptions during the design process, the results do not converge with the real ones. Recently, procedures have been optimized to simulate the impact of icebergs on underwater pipelines and an agreed and compatible reference framework is being created to assess the effectiveness of modelling (Kenny and Pike, 2016).

Recently models have been developed for testing gouging for different types of soil, for example, sand, clay, gravel, etc. (Eltaher, 2014). Development of rational simplified analytical ice gouging models that are better tested and applicable to wider ranges of conditions and parameters (Liferov, 2014).

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The software package ANSYS has been widely accepted as a reliable and proven tool for mathematical modelling of fluids behaviour (Alawadhi, 2010). At the core of this software is the finite element method. That is a method of modelling the object load conditions and the of the object response to these conditions. The object is modelled using several areas of finite size, called finite elements. For each element, equations are formulated, describing its response to a particular load. The sum of reactions of the finite element model constitutes the overall reaction of the object.

2. Methodology

The underwater oil and gas pipelines and the optimal depth of penetration have the focus of this study. They should ensure as much as complete elimination of the causes of the current destruction and deformation of unburied pipeline in the Caspian Sea. It has been necessary to study the interaction with the pipeline soils with poor strength properties, as well as the dynamic effect of drifting icebergs on the seabed. Unlike the cases of complete destruction of the underwater pipeline with a one-time release of massive quantities of oil through its small leak corrosive fistulas are difficult to observe and then to localize. The volumes depend on such leakage and pressure drop fistula sizes between the flow in the pipe and the outer hydrostatic pressure at the depth of the pipeline arrangement. If the damage at large distances from the leakage of forcing pumps are small, and their appearance on the sea surface in the form of spots will be inconspicuous. Damage has been defined by classification approved by the RF Ministry of Energy (1995). The degree of pollution of water surface is determined by the mass of dissolved and (or) water emulsified in oil. The weight of oil (in t), taken for the calculation of fees for pollution of the water body in accidents on main pipelines M_y, is calculated according to the formula:

$$M_y = M_p + M_k \tag{1}$$

Where M_p [t] - weight oil spilled on the surface of the water body

M_k [t]- is the mass of the film of oil remaining on the surface of the water after a spill event;

M_y [t]- weight of oil, taken for the calculation of fees for pollution of the water body in accidents on main pipelines,

Calculation of damage from water pollution by oil spills when carried out according to the formula:

$$Y_k = 5 \times C_V \times M_y \tag{2}$$

Where Y_k - damage from water pollution by oil spills, RUB;

Deposit Rates C_V fees for surface water pollution layer of 1 t of dissolved and emulsified oil within the established limit, RUB/t (RF Ministry of Energy, 1995):

$$C_V = N_b \times K_v \tag{3}$$

Basic standard fee coefficient N_b = 44,350 adopted within the established limits (temporarily agreed discharges standards), environmental conditions factor coefficient K_v - to accept the Caspian Sea 1.30 in accordance with the basic norms of payments for emissions, discharges of pollutants into the environment and waste disposal (RF Ministry of Energy, 1995). According to Patin (2014). in the pipeline accident in the middle when the accident poured 788 t of oil. About 90 % is possible to collect spilled oil, and about 0.5 % is dissipated in the form of a thin film on the water surface

$$M_y = 788 \times (0.1 + 0.005) = 82.74 \text{ t} \tag{4}$$

Payment rate is calculated as follows:

$$C_V = 44{,}350 \times 1.30 = 57{,}655 \text{ RUB/t} \tag{5}$$

The total damage is:

$$Y_k = 5 \times 57{,}655 \times 82.74 = 5{,}485{,}930{,}905 \text{ RUB } (\sim \$\ 91{,}432{,}181) \tag{6}$$

The main causes of accidents underwater pipelines in the area:

- Damaging tube ice formations (hummocks, ridges);
- The additional stresses in areas where there are free spans (Ogorodov and Arkhipov, 2010).

Bottom currents erode the bottom, so that there are local free spans by not flush the pipeline, and they quickly develop along the pipeline, resulting in the formation of considerable length flown. The emergence of a large free span length can lead to dangerous for the integrity of the pipe line of stress-strain state in the local areas of the pipeline, especially on the edges of the span and in the middle.

Drifting iceberg performs mechanical work on the deformation and destruction of bottom soil as a result of consumption of the initial kinetic energy of the iceberg, as well as through its swap the outside due to the impact of external driving forces - currents, wind, approaching the ice fields (Ogorodov, 2014). It is necessary to simulate the original data - the physical and mechanical properties of the bottom soil to a depth of about 7 m, and the physical and mechanical properties of the backfill soil. This data is used to construct the FEM model of the soil surrounding the pipe and in contact with the keel of the hummock (Table 1).

There are various mathematical models of soil using different sets of characteristic parameters for a number of the following parameters of the mechanical properties required of the most common soil models: E modulus, cohesion c and angle of internal friction φ. icebergs parameters are also important input data for the calculations (Table 2).

Table 1: Material characteristics of the keel and the pipe

Property	Young's Modulus, MPa	Poisson's ratio (1)
Material keel (ice)	$4.0 \cdot 10^3$	0.3
Pipe material (steel)	$2.07 \cdot 10^5$	0.3

Table 2: The characteristics of soils

Type of soil	Young's Modulus, MPa	Poisson's ratio	The angle of internal friction φ, °.	Specific adhesion c, kPa
Sandy loam sandy (TG-1)	4.3	0.3	12.5	40
Silty sand (TG-2)	12.0	0.3	26.9	36

In this work has been considered a simplified approach where the conditions in the case of a wide keel did not significantly change along the pipeline. Figure 1 shows a diagram of the design model ice gouging in the two-dimensional formulation for the case when the keel iceberg has a trapezoid shape. If the keel is shaped like a semicircle, come from the same model parameters except the keel options. Fin geometry in this case is characterised by a circle of radius R. In Figure 1, A and B are the dimensions of the ground array, H_m, and W_m - the dimensions of the additional grinding elements, modelling soil, D_p - external diameter of the pipeline, H_p - distance from the ground surface to the top of the forming pipe, D_g - penetration depth of the keel into the ground (gouging depth), W_k - the characteristic size of the base of the keel, H_k - the height of the keel, α - the angle of the front edge of the vertical fin, H_p - coordinates of the centre of the pipe. For convenience, we introduce the notation H_{kr} also equal to the distance from the top of the generator tube to the bottom of the keel, which characterizes the magnitude of the additional penetration of the pipeline compared with the calculated depth gouging furrows.

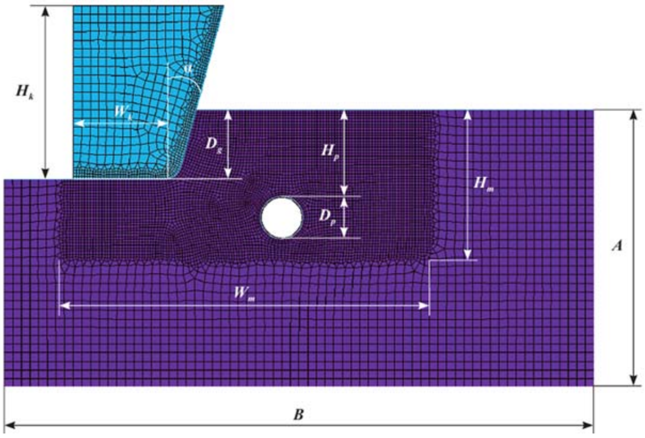

Figure 1: Diagram of the first calculation unit

The pipeline itself, undergoes spatial bending (as it operates in the lateral load gouging area and away from this area its displacement constrained non-deformed soil), offered separately to simulate linear beam type elements with the system of non-linear relationships with selected hardness. In the first settlement block flat solved the problem of the impact of the keel to the array of soil (pipe at the same time be included in the calculation scheme, but does not affect the overall picture of the ground deformation). In the second block as the estimated load on the pipe using the results of the first calculation. This circuit is conservative since it inflated deformation and piping voltage, but it allows to perform a detailed analysis of the pattern of soil deformation in the keel zone of contact with the ground and the ground with a pipe through the application of a flat case of very small computational grids and requires essentially less effort, which makes it possible to perform multi-parameter analysis of the problem.

3. Results and discussion

Table 3: Geometric parameters of the problem

B, m	A, m	H_k; R, m	D_g, m	H_{kr}, m	D_p, m	δ, m	W_k, m	α, °
15	10	5	0.5; 0.7; 0.9; 1.1	0.25; 0.5	630	0.027	4	15; 30

In Figure 2 by a dotted line has been shown sealing the kernel, which is clearly visually identified by the equality and soil displacement keel. Figure 3 shows the intensity of the deformation field for the contact area with the ground keel. A noticeable line slip corresponding stage of plasticity.

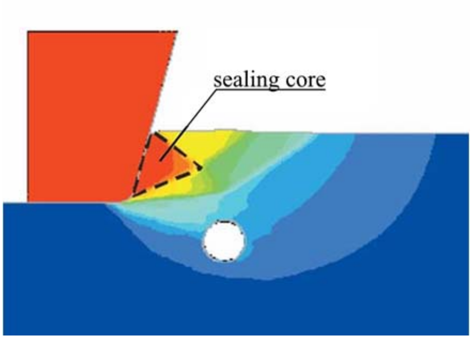

Figure 2: Field ground displacements under ice ridge (red colour corresponds to the maximum value)

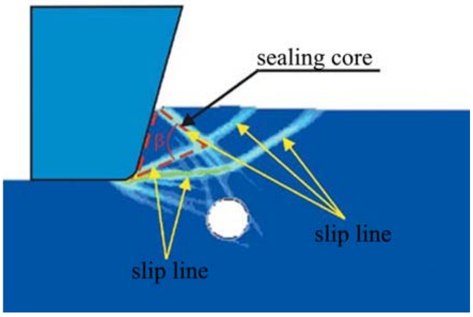

Figure 3: Field strain intensity (blue colour corresponds to zero strain)

After increasing strength of soil reaction to some initial portion of graphics gradually beginning to enter the horizontal ledge (Figure 4). This characterises the attainment of the ground state of limit equilibrium and transition to a state of fluidity.

For the material of the pipe and fin hummock used elastic model, characterized by standard parameters: E modulus, Poisson's ratio ν. For soil material used elastic-plastic model of Drucker-Prager with the following defining parameters: modulus E, Poisson's number ν, clutch c and angle of internal friction φ. Boundary conditions for ground array were set as follows: move the x-axis are forbidden for the left and right borders of the array of soil, moving along the y axis are forbidden for the lower bounds of the array of soil, and to the top of the keel of the border. Further, to determine the displacement of the pipe VAT calculated values are substituted into the model developed girder the pipeline, which is described below. In a one-dimensional model of the pipeline is simulated beam-type elements. Beam model allows to consider the stress-strain deformation, bending and shear in two transverse directions. Also, the plastic behaviour of the material can be taken into account. It is possible keeping the internal pressure in the pipe. Modelling the interaction of the pipeline with the ground is done by the use of non-linear relationships. Nonlinear Communication (simulating the interaction of the tube with the ground) defined in each node of the pipeline and sent in three orthogonal directions (longitudinal, vertical and transverse). Heat input longitudinal stiffness of the springs k1 for the TG-1 soil is 0.766 MN/m2 for the TG-2 ground: 1.148 MN/m^2. The corresponding values of the lateral stiffness of the springs sweatshop kn are defined as follows: for the TG-1 ground: 0.408 MN/m^2 for the TG-2 ground: 2.097 MN/m^2.

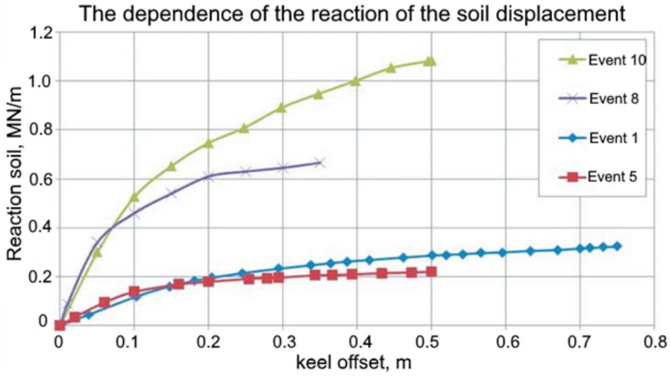

Figure 4: Dependence of the ground forces of reaction from the keel offset

Table 4: Summary of the results of calculations

Current event	Parameters keel	Type of soil	The depth of the furrow D_g, m	The distance from the keel to the top of the forming pipe, m	The maximum displacement of the pipe, m
1	15 °	TG -1	1.1	1.0	0.057
2	15 °	TG -1	0.9	1.0	0.048
3	15 °	TG -1	0.7	1.0	0.028
4	15 °	TG -1	0.5	1.0	0.022
5	semicircle	TG -1	1.1	0.5	0.123
6	semicircle	TG -1	0.9	0.5	0.143
7	semicircle	TG -1	0.5	0.5	0.119
8	15 °	TG -2	1.1	1.0	0.051
9	30 °	TG -2	1.1	1.0	0.052
10	semicircle	TG -2	1.1	0.5	0.115

In a first embodiment of the pipeline loading (conditionally kinematic) received within the estimated displacement block 1 ΔS_{max} set for a segment of the beam pattern at the site, the length of which is equal to the selected value of the active part of the keel width of the ice formation. When calculating the VAT pipeline following boundary conditions are accepted with non-linear relationships: the ends of the simulated pipeline is fully secured. To the boundary conditions do not affect the VAT pipeline in the area of interest to us, simulated the length is selected in such a way that the VAT disturbance in the soil from the impact of the pipeline is almost completely damped to the border area. In these calculations, the pipe length with a margin shall be equal to 200 m. Effective stiffness relations modelling of soil resistance to displacements of the pipe should be designed in accordance with the physical and mechanical properties of real soil surrounding the projected pipeline.

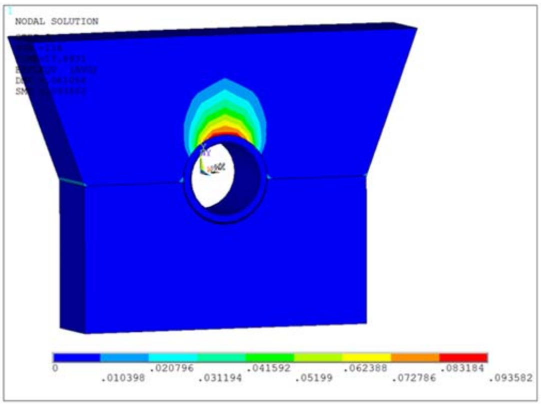

Figure 5: The resulting stresses in the soil array TG-2

4. Conclusions

The presented method for calculating the optimum depth of penetration to considerably reduce the environmental burden on the environment that will keep the flora and fauna of the Caspian Sea water area closed, and eliminate fines of up to 5.5·109 RUB (approx. 91 M $).

The advantages of the described approach are in a significant reduction of computational cost, ease of implementation and possible review of long pipe sections without a significant increase in the estimated time. The disadvantage of this approach is the inability to account for local processes in the pipeline, such as ovalisation, crimping etc. This is going to be implemented within the same model in which shell-type elements are used. The series of parametric calculations was carried out in which changed the soil type, the shape of the keel, the values of parameters and the depth of the furrow. Comparative analysis of the results at various values of parameters allows concluding that the impact on the intensity increases with decreasing tube gap over the pipe relative to the base fin, and the gap at a fixed value – gouging depth increases.

Consequently, it can be concluded that for the considered keel forms the greatest impact on the tube has a keel, the shape of which in the contact zone close to the circular arc. The optimum depth of the gouge with the maximum depth of 1.1 m, is 2.1 m from the top to the bottom of the pipe. It is necessary to consider in the design such a hazard as the iceberg interaction with the underwater pipeline and improve the current pipeline laying technology in the Caspian Sea. To determine the exact data required for the design and detailed understanding of the processes drift ice, a systematically and comprehensive study of the processes of the Caspian seabed gouging is necessary and should be delivered in a foreseeable future.

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