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ОСОБЕННОСТИ ОЦЕНКИ ВЗАИМОДЕЙСТВИЯ ДРЕЙФУЮЩИХ ЛЕДОВЫХ ОБРАЗОВАНИЙ С МОРСКИМИ ТРУБОПРОВОДАМИ

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ICE FEATURES-OFFSHORE PIPELINE INTERACTION ASSESSMENT CONSIDERATIONS

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Аннотация. В статье представлен анализ факторов, определяющих особенности функционирования морских трубопроводов в арктических условиях. Рассмотрены подходы к определению оптимальной величины заглубления морских трубопроводов. Приведены рекомендации по проектированию трубопроводов в данных условиях.

Ключевые слова: морские трубопроводы, ледовая экзарация, борозды выпахивания, глубина заложения, ледовые образования.

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Annotation. The article presents the analysis of the factors determining the peculiarities of operation of offshore pipelines in the Arctic conditions. Approaches to determine the optimal offshore pipeline burial depth are considered. The recommendations on pipelines design in the given conditions are described.

Keywords: marine pipelines, ice scour, gouges, burial depth, ice formations.

According to the USGS Circum-Arctic Resource Appraisal (CARA) mean estimates, oil and gas reserves in the Arctic region are about 1,7 trillion cubic meters of natural gas, 44 billion barrels of natural gas liquids, and 90 billion barrels of crude oil. Currently, the development of offshore oil and gas fields is impossible without pipeline systems construction. Offshore pipelines are designed not only for delivering hydrocarbons to the consumer and shipping products to tankers and barges but also for infield and interfiled transportation of raw materials. [5] In particular, offshore pipelines are used to collect well products from subsea wellhead complexes to platforms and transport hydrocarbons from platforms to onshore production facilities.

The Arctic is a challenging area with prevalent:

– harsh climate conditions;
– harsh working conditions;
– remote areas.

That factors leads to limited time for construction activities and challenges associated with pipelines operation and maintenance, leak detection and emergency response. The Arctic also has extremely sensitive ecosystems and unique natural phenomena (such as strudel scour, ice gouging) that significantly affect the pipeline systems life cycle. Permafrost, seasonal pack ice, and ice ridges present substantial challenges for offshore pipeline systems, especially in shelf areas.

Additional static and dynamic loads from waves, currents and ice formations can be noted among the operating conditions of the offshore pipelines. A particularly great danger for the pipelines laid in freezing seas is posed by drifting ice features and icebergs, the keels of which reach the seabed and displace soil mass, forming such forms of sea relief as ice gouges and pits. [2] Having rather large kinetic energy and strength, drifting ice formations are able to leave gouges with a depth of about 2–2.5 m. [1] In this case, the issue of ensuring a high degree of reliability of offshore pipelines throughout their entire service life, including maintaining the design load-carrying capacity of pipeline walls regardless of external influences, becomes extremely important.

Russian and foreign operation practice of sea pipelines in freezing seas is extremely limited, which leads to the absence of the unified standard base on pipelines design, construction and operation in such conditions.

Existing standards do not give strong recommendations to assess the pipeline loading conditions induced by ice gouging. The standards also do not offer any criteria or acceptable limits for offshore pipeline design.

In engineering practice, the pipeline trenching providing its safe operation is considered the most reasonable protection method against ice gouging. The main challenge is to determine the safe and cost-effective pipeline burial depth along the whole route. The design depth should provide sufficient clearance below the gouge for the pipeline to withstand the bending stress to a level that the design engineer considers acceptable; the shear soil deformations should be taken into account.

Safe and cost-effective pipeline burial depth should be determined according to the physical behavior of ice feature-soil-pipeline interaction process. In a natural environment, ice gouging scenarios are affected by various factors, among which three main groups can be identified: hydrometeorological conditions (wind, waves, currents, temperature, etc.), ice regime of the region and seabed soil characteristics.

The first two groups of factors determine the processes of ice features formation and drifting in the water area:

– the geometric parameters and distribution of strength characteristics of the ice feature body;

– formation mechanisms and separation of pressure ridges [3];

– the initial kinetic energy of the ice formation, as well as the depth where the most intensive gouging takes place, etc.

The underwater pipelines are also affected by coastal activities in the coastal and shelf zones. In this regard, if the factor is not gouging depths may be underestimated, which may lay to an underestimation of the required pipeline burial depth. [4]

Seabed soil properties determine the amount of energy required for the ice formation to left gouges of certain depths and lengths on the seafloor. The topography of the seabed also influences the possible gouge depth and geometry, creating additional resistance to the ice keel movement.

The design pipeline burial depth should be determined on the basis of seabed mapping data (geophysical, bathymetric), i.e., taking into account the existing local topography along with the gouges characteristics and frequency.

Geophysical and bathymetric surveys of the seabed is carried out using:

– single- or multiple-beam echo sounders;

– side-scans sonars;

– sub-bottom profilers.

The information obtained through the surveys includes gouge depth, width, length, orientation and density. Repetitive seabed mapping helps to distinguish young gouges from old ones and to determine gouging frequency.

The chosen assessment approach for pipeline burial depth determination may be a probabilistic one, for which seabed mapping data is collected periodically over a given number of years. As an additional approach for the determination of possible gouge characteristics a computer modeling may be used. In this case, the simulation of the most probable scenarios of ice features (with pre-set parameters) drifting can be carried out; the interplay of driven forces must be considered.

Determination of the clearance between the gouge and the pipe depends on the acceptable pipeline response to withstand some bending. However, when determining pipeline response, pipe properties and design features should be taken into account.

Thus, pipeline burial depth along the right-of-way should be set determined based on climate and environmental conditions of the considered region, as well as on the accepted “ice-seabed-pipeline” interaction model. For this purpose, it is necessary to determine the maximum gouges depths (excluding “extreme” values), estimate factors potentially involved in the interaction and, based on the sensitivity analysis, investigate how the set of factors affects the load transferred to the buried pipeline.

Offshore pipelines in the Arctic region must be designed to account for ice gouging; for that purpose:

– the pipeline burial depth should be determined by the maximum expected gouges depths in the considered area;

– certain engineering techniques have to be implemented to avoid interaction of pipelines with ice keels [5];

– ice gouging phenomenon should be investigated through complex methods, including field surveys, physical testing or numerical simulations.

As it was mentioned, there are several approaches to generate information on scouring phenomena and gain understanding of seabed response to ice gouging. These approaches can be divided into two following categories:

– real events observation which involve performing extensive site surveys, identifying gouges characteristics and frequency.

– artificial simulations that can bridge the knowledge gaps and provide better understanding of the complexity of «ice gouging-seabed-pipeline» interaction process.

All abovementioned indicate the necessity of further investigation in the area. Predicting the maximum possible gouge depth as well as soil deformation is connected with determination of the minimum required burial depth and ensuring pipe integrity. To adequately estimate the induced loads and the optimal pipeline burial depth, additional research on ice gouging phenomenon is essential. The coupled soil-pipe response when investigating displacement and the local buckling effect of the pipe is also in need of further studies.

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