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Scour Characteristics of the Underwater Crossing of Trunk Gas Pipeline Across the River Lena

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Abstract. The design data of the underwater crossing of the trunk gas pipeline (TGPL), which is an extension of the main gas pipeline of Hatassy GDS-2, for gasification of regions on the eastern side of the river Lena of the Republic of Sakha (Yakutia) are considered. Scours behaviour of the underwater crossing of TGPL across the river Lena is examined taking into account hydromorphological factors. The influence of hydrological and exogenous processes on the state of the underwater passage of Hatassy-Pavlovsk TGPL is shown by the example of the line-II. Changes of the river bottom profiles in the area of TGPL fixed at four discharge section lines, as well as water consumption were analyzed. It is shown that the presence of the underwater gas pipeline significantly affects the nature of the movement of micro- and meso-forms of the river bottom. It has been established that the constantly changing hydrological and hydromorphological processes resulted in sagging of the inverted siphon section in the line-II of the underwater crossing of Hatassy-Pavlovsk TGPL. During the designing and construction of the first line of the underwater gas pipeline across the river Lena, major omissions were committed, the peculiarities of the hydromorphological and hydrologic features of the river bed evolution in the section of the underwater passage of Tabaga-Kangalassy TGPL across the river Lena had not been taken into account. The effects of hydrodynamic and permafrost processes, heaving phenomena on floodplain and shore slope together increase the non-functional loads on the underwater gas pipeline. As a result of these factors, high longitudinal tensile stresses arise, especially in the welded joints of the inverted siphon pipes, and lead to accidents and incidents at the underwater gas pipeline across the river Lena.

1. Introduction

According to statistics, more than 20% of pipelines of underwater crossings are in the irreparable state [1]. The main reason is connected with the reorganization of the morphology of the water body bottom, hydrological processes and the occurrence of free spans in certain sections of the crossing with subsequent violation of the stability of the entire crossing.

Similar processes stood as the main cause of two accidents and several incidents at the underwater crossing of the trunk gas pipeline (TGPL) of Hatassy-Pavlovsk GDS-2 across the river Lena built by the trench method and put into operation in September 2003 with a length of 16.96 km. The reserve line, which was laid in April 2009, is 16.26 km [2].

On the basis of generalization of the design data, the scours behaviour of the underwater gas pipelines across the river Lena is investigated below taking into account hydromorphological factors.

From the left bank, the route of the submerged crossing of TGPL across the Lena river crosses the Tabaginsky channel, several lakes, streams and lake basins. It turns 68° to the main river bed On Uluu Aryy island and then goes straight crossing the main channel, Bergehe Uehe and Manastyyr islands, and the Haptagaj channel to the village of Pavlovsk.

On the floodplain sections of the underwater passage, the soils at the depth of gas pipeline laying are mainly represented by fine hard frozen sand with an insignificant admixture of organic matter with ice content less than 10%.

The route of the underwater gas pipeline is located in the area of permafrost with a depth of more than 250 m. Standard thawing depth at terraces above flood plain is ~3 m, on the second bottom it is ~3 m.

According to the project at the water crossing, the outer generating line of the gas pipe should have a minimum depth of at least 1 m from the natural bottom levels and 0.5 m below the predicted marginal profile of the river bed erosion, taking into account possible river bed deformations during 25 years of operation.

The width of the water surface during the low water period is 1120 m (at an average low water level of 86.3 m according to BES). The river bed width between the left and right bedrock coast is 1782 m. There is a sandy island (midstream sandbank) about 700 m wide along the left bedrock coast. Its maximum height above the average low water is 2.4 m. Part of the island is flooded with a high water level.

According to M.V. Lomonosov Moscow State University, the maximum possible erosion of the bedrock coast can be 140 m on the left bank, 240 m on the right bank in 30 years of the pipeline operation.

The length of the underwater crossing of the trunk gas pipeline is 2,297 m and the length of the reserve line is 2,245 m taking into account the predicted erosion of the coast in 30 years.

The maximum depth of the river bed in the low water period is 10 m (average low water level is 86.3 m by BES). The average current velocity on the verticals along the hydrodynamic flow axis is 0.8÷1.0 m/s during the low water period and 1.5÷2.0 m/s during the flood period. Surface current velocities may reach 2.5÷3.0 m/s during the flood.

These speed ratings increase significantly with ice jams and a sharp drop of water level when the jam is cleared [3].

An unnamed island opposite the Tabaginsky Cape splits the main river bed into two branches in the direction of the right bank. One of them is the Haptagaj channel, which has a rather strong current and a large amount of water flow discharge during the period of spring floods and summer-autumn floods. Hatassy-Pavlovsk TGPL crosses these two channels, the depth of which increases annually. Consequently, the erosion of the bottom and the island slopes in these channels increases.

2. Research materials and methods

The influence of hydrological and exogenous processes on the state of the line-II of Hatassy-Pavlovsk TGPL for 2014 is presented.

Consider the change in the bottom profiles of the river Lena in the area of underwater gas pipelines fixed at four discharge section lines. From the left bank side, the profiles at discharge section lines No.1 and No.2 are more uniform and gradually deepen as they approach the right bank. The existing uniformity of profiles deteriorates sharply at discharge sites No.3 and No.4 from the left bank. The bottom profile of the left bank changes sharply at discharge sites No. 3 and No. 4, the depth of the channel near the left coast increases to 5.7 m at discharge section lines No.3 and 5.0 m at discharge sites No.4. There is significant unevenness of the bottom profile at the section No.3 approximately corresponding to the position of the line-I of TGPL. The profile of the river bottom drastically changes on all these four profiles near the right bank (the left banks of Ues Kumah and Bergehe Uehe islands), lowering further down to a maximum of 76.5 m by BES (Figure 1).

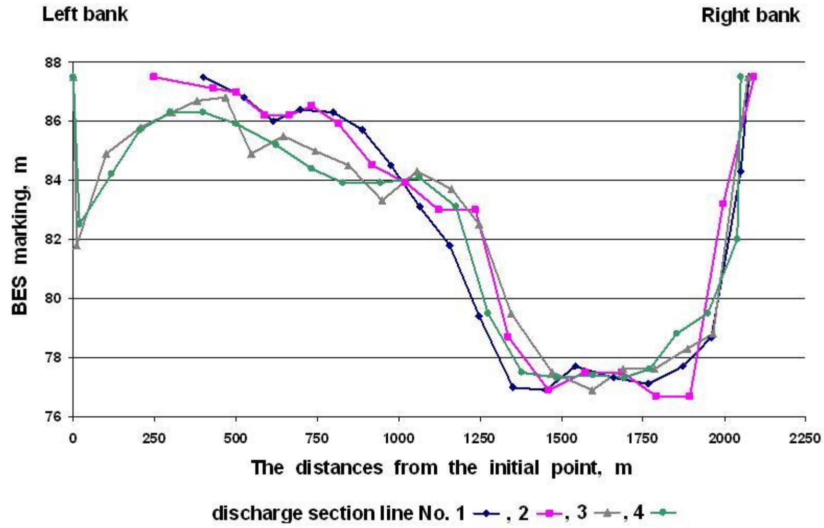

Figure 1. Cross section of the river Lena at discharge section lines No. 1, 2, 3, 4 of the gas pipeline.

Analysis of changes of the maximum depths at the discharge section lines reveals that it reaches 10.4 m at discharge site No.1, 10.8 m at No. 2, 10.6 m at No. 3 and 10.2 m at No. 4. It should be noted that on 13.10. 2012, the maximum depth of the river bed was fixed in the area of underwater gas pipeline on the right bank (off the coast of Ues Kumah and Bergehe Uehe islands) where a canal was laid for two offshore pipelines of the trunk gas pipeline (Figure 1 and Figure 3). Besides, as noted above, the left bank has a depth of 5.7 m at discharge section lines No.3 and 5.0 m at discharge site No.4. In this case, serious bank erosion is observed near the left shore (Figure 3). Consequently, the presence of the underwater crossing of the trunk gas pipeline significantly changes the nature of the movement of the micro- and meso-forms of the bottom and, thus, the direction of the river channel.

The data in Figure 1 is directly related to the water discharge at various exceedances. For example, the maximum urgent water discharges at Tabaga gauging station at 1, 3 and 5% of exceedance are 55000, 51300 and 49400 m^3/s, respectively. Herewith, the dominant formative discharge of the river Lena basin in the area of Tabaga gauging station is as follows: the upper discharge value is 24000 m^3/s at 7% exceedance at flooded floodplain, the average value is 16600 m^3/s at 14% exceedance within the river bed. The value of the upper interval of dominant formative discharges at Tabaga gauging station is 31000 m^3/s at the water edge, which is 7.6 m above the low water level, and the value of the lower interval of formative discharges is 10,500 m^3 /s at water edge equal to 2.0 m above the low water level. The system of the floodplain Haptagaj channels, which is crossed by the underwater passage of Hatassy-Pavlovsk TGPL, goes to the right at Tabaginsky Cape. In total, these channels take from 5 to 10% of the total river flow depending on the phase of the water regime.

The measurement results obtained on August 28 – September 7, 2014, revealed that the share of total water discharge is 5983 m^3/s (that is 51%) with a riverbed width of 1214 m, the area of the basic section is 5,592 m^2. The average current velocity is 1.07 m/s, the minimum is 0.01 m/s, the maximum is 2.17 m/s.

As a result of this, constantly changing hydrological and hydromorphological processes led to sagging of the inverted siphon of the line-II of Hatassy-Pavlovsk underwater gas pipeline (Figure 2). In this connection, the length of the sagging section is approximately 25–30 m (Figure 2). Here, the outer generating line of the gas pipeline is located at a depth of ~ 4.6 m from the water surface, and the height of the lower generating line is ~ 1.6 m from the river bottom. An intense erosion of the right bank of the channel is observed along the direction of gas transfer (Figure 2). On both sides of this section, the two gas lines are covered with a layer of bottom sediments and are located at approximately the same depth from 1.5 to 2.0 m, respectively, from the bottom surface at a water depth of ~ 4.0×5.0 m.

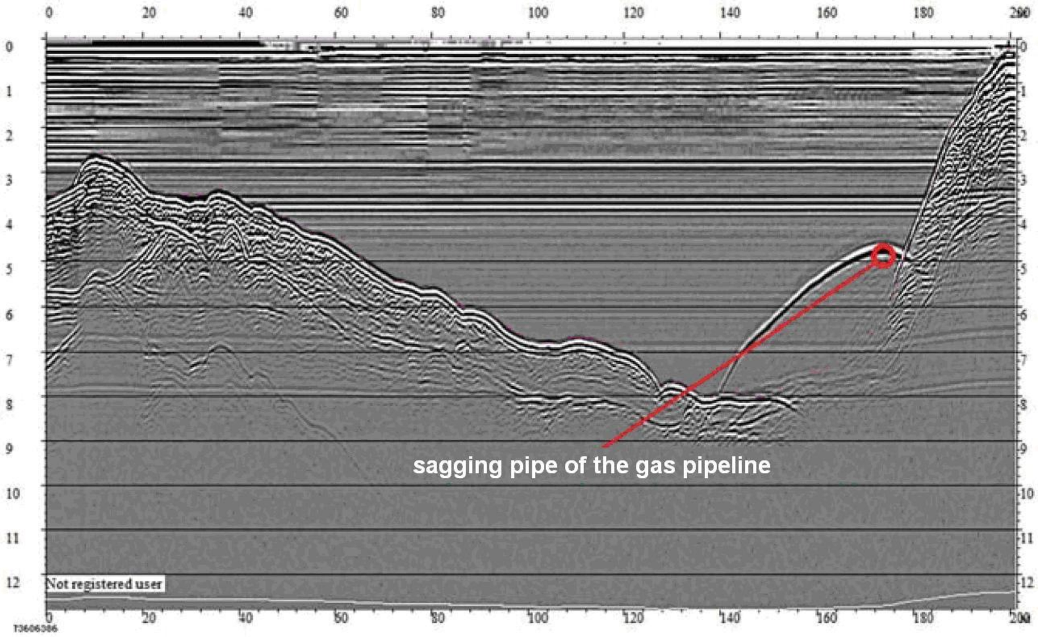

Figure 2. The sagging section of the line-II of the underwater gas pipeline in the right bank area of the river.

Ice gorging is observed on the river Lena and its major tributary streams during the spring ice drift. The formation of ice jams is accompanied by flooding of lower areas of the river valley. For example, in May 2010, giant ice jam occurred at Tabaga-Yakutsk site in the area of the underwater crossing of Hatassy-Pavlovsk TGPL, located ~9.0 km from Tabaga. The long-standing water level at Tabaga gauging station was exceeded by 1,11 m [4].

There are several modern developments on ice gorging [5, 6], describing its nature, physical-mechanical, hydrological and hydromorphological basis.

It should be noted that from 2007 to 2010, excavation works were performed year-round at the Hatassy-Pavlovsk section for post trenching of the first line, as well as construction and trenching of the second (reserve) line of the underwater crossing of the trunk gas pipeline across the river Lena. As a result of these lengthy excavation works, huge volumes of soil were withdrawn from the bottom of the river, most of which was left in the riverbed. These volumes deformed the morphology of the river bottom significantly, changed the natural formation of the river bed micro-, meso- and macro forms of Lena river on the Tabaga-Yakutsk site.

Moreover, three vessels were left at the section of the underwater gas pipeline after the excavation works in 2010. Two vessels carried an artificial blocking in the form of the sand mound and the third was inshore.

On May 18, 2010, the breakup of ice in Lena River occurred near the town of Pokrovsk and it reached the city of Yakutsk on May 19. In addition to that, an artificial blocking, which was created in the section of Hatassy-Pavlovsk gas pipeline caused powerful ice jam, which led to the flooding of settlements located on the floodplain of the river Lena from Hatassy village and above.

The planned-high-altitude position of the two underwater crossings of TGPL from the left bank also does not correspond to the design data due to the peculiarities of the hydrological processes in this section of the river.

The Tabaginskaya channel emerges below the Tabaginsky cape, i.e. the river channel expands from the left bank. The continuation of the Tabaginskaya channel is the Hatasskaya channel, which is crossed by two lines of the underwater gas pipeline. Further, the Hatasskaya channel joins the City channels system. Up to 4% of the river flow is diverted to the City channels in the period of summer low water with a total water discharge of about 3000 m^3/s. At a water content of approximately 7070 m^3/s, which corresponds to average annual content, 7.8% of water flows into the City channels. With an increase in the water level, the flow of the City channel system expands. Therefore, the channel-forming activity increases. With total water flow of 36,000 m^3/s in the river, 8.7% of the flow runs into the City channels system. Such a hydrological process significantly influences the overall condition of the underwater crossing of Hatassy-Pavlovsk TGPL across the Lena.

During operation of the inverted siphons, bare and sagging sections of two gas pipelines appeared (Figure 3). Figure 3(a) demonstrates that the bare and sagging section of the first line lies slightly higher than the second line. Moreover, part of the bare and sagging section of the second line lies underwater at the minimum depth (Figure 3, b). The width of the Hatasskaya channel at the time of the inspection of the underwater gas pipeline was ~ 60 m. The visible part of the bare and sagging sections in this area of the route reaches ~ 30 meters. It should also be noted that in the section of the route adjacent to the left bank, the inverted siphons of the I-st and II-nd lines are elevated in comparison with their location in distant areas (Figure 3, a). Such planned-high-altitude position of the inverted siphons of the lines I and II is most likely due to the annual thawing and freezing of soils with their subsequent heaving.

(a)

(b)

Figure 3. Scours and denudations of the I-st and II-nd lines of the underwater gas pipeline across the Hatasskaya channel: – the position of the inverted siphons above the water surface, b) – line-II is visible through the water.

3. Results

Two streams (two arms) branch from the Haptagaj channel in the full-flowing period at a high water level. One of the streams starts from the section above the southern part of Pavlovsk, the second one is above Hoptoloh island. At high water levels and flooding, the water flow increases with a significant current velocity along these channels. The right bank of the river rapidly erodes in the southern part of the village Pavlovsk and opposite the island Hoptoloh.

The greatest erosion of the bottom and shore slope is observed from the right bank in the area of the Tabaginsky cape and below. Consequently, the reliability and durability, as well as the environmental safety of the underwater gas pipeline, will depend on these erosions ranging from the city of Pokrovsk to Namtsy village.

4. Discussion

The scours peculiarities of the underwater crossing of Hatassy-Pavlovsk TGPL across the river Lena and the weld failure of the joints of the inverted siphon pipes were discussed in [7] and it has been established that:

- from 2004 to 2012, the maximum length of denuded sections of the line-I of Hatassy-Pavlovsk underwater gas pipeline across the river Lena increases from 42 to ~ 931 m in the river bed, and sagging height of the siphons reaches a maximum of 80 cm to 2.2 m. Moreover, no trench was detected under the inverted siphon in the section with a length of ~400 m (from PK85+00 to PK89+00), which is due to a downstream axis displacement of approximately 14 m;

- in winter, at a temperature of the transported gas of approximately minus 12.5°C, water around the gas pipeline begins to freeze and the gas pipeline covers with ice, forming an ice "shell" up to 3-5 cm thick by the end of April;
- as a result of mutually unrelated climatic, hydrological and frozen ground processes, the gas pipeline is elevated due to heaving on the shore slope of the floodplain. Affected by the elastic strain of the gas pipeline, the section sagging up to 2.2 m in the riverbed is elevated. During the subsequent water freezing and ice thickening in November-March, the gas pipeline is completely seized with the freezing ice in the still unfrozen water and is rigidly clamped;
- for the inspection period from 2004 to 2012, violations of the lining and pipeline wrapping were observed in various sections due to the active moving layer of the river bottom (unlithified sludge and belt ridges), where periotic scours or denudations occur (or siphon sagging) if the project does not comply with the entire inspection area from PK85 + 00 to PK93 + 00. At the same time, the actual position of the trunk gas pipeline is higher than the projected one up to 3.9 m at PK92 + 25;
- the constant impact of hydrological and exogenous processes from 2006 to 2013 led to gas pipeline ruptures along the welded joints of inverted siphon pipes due to a significant accumulation of damage and low-cycle fatigue wear of the metal of pipe welded joints.

5. Conclusion

Thus, serious omissions were committed in the designing and installation of the underwater crossing of TGPL across the river Lena. Peculiarities of the hydromorphological and hydrologic features of the channel processes on the Tabaga-Kangalassy section were not taken into account. The underwater gas pipeline moves downstream affected by the most dynamic active layer of bottom sediments and is exposed to periodic scours.

The effects of hydrodynamic and permafrost processes, heaving phenomena on floodplain areas and shore slopes together increase the non-functional loads on the underwater gas pipeline. As a result of these factors, high longitudinal tensile stresses arise, especially in the welded joints of siphon pipes, and contribute to accidents and incidents at the underwater crossing of TGPL.

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