The deployment of the collapsible piping through a large water obstacle

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Abstract. Portable pipelines have been used in the Armed Forces of our country since the early 1960s to transfer light oil products. They are used to pump light oil products in large volumes for considerable distances in any climatic and geographic conditions. Portable pipelines were successfully used to eliminate natural and technogenic emergencies. The paper presents an overview of the deployment of portable pipelines across water barriers. It shows the organization and technology of works during the deployment of a pipeline across the 2700 m barrier of the Volga River.

1. Introduction
Portable pipelines of the Armed Forces of the Russian Federation have gained prominence as a mobile and high-performance mode to transport low-viscosity fluids (light oil products, water). They are used to pump light oil products in large volumes for considerable distances in any climatic and geographic conditions. The efficiency of portable pipelines is most clearly confirmed by their large-scale use to supply fuel to the Limited Contingent of the Soviet Troops in Afghanistan. During 1980-1989, more than 5 million tons of light oil products, or 80% of the total volume of deliveries, were transferred to the territory of Afghanistan through portable pipelines with a total length of more than 1200 km [1].

The successful use of portable pipelines in emergency response is also well known, e.g. in Chernobyl [2], after the earthquake in Armenia [3], in the suppression of mass forest and peatland fires [4], to supply water to the population of the Republic of Crimea [5].

The advantage of using them is the ease of assembly. The pipes are connected without welding. This allows constructing a line with high productivity. Due to such capabilities, the portable pipelines are used in hard-to-reach locations. One of them is water barriers, including large ones.

2. Materials and methods
In order to develop skills to cross large water barriers using portable pipeline, the task was set to deploy a line to pump light oil products across the Volga River (Figure 1).

In order to select the method of crossing the water barrier using portable pipelines, the water area and coastal areas were explored along with the study of the river fleet documents.

According to survey results, the main characteristics of the water barrier were determined as follows: the width of the Volga River in the area of the construction of the underwater crossing of a portable pipeline amounted to 2,700 m, while at the distance of 500 m from the left bank there was a boggy island with shrubs and canes with a width of 350 m; the bed profile had a very uneven relief with sharp depth drops of up to 27 m and a flow rate of 1.4 m/s; intensive navigation.
During the preparatory period, the accumulated experience of pipeline deployment across water barriers was studied.

The first known case – field collector pipeline laying with a diameter of 75 mm in 1937. The total width of the crossing area was 940 m, including across the Saifun River – 120 m, Smerinka duct – 125 m, the rest – across the boggy floodplain [3].

Further accumulation of experience in pipeline laying across water barriers took place during the Great Patriotic War. The examples of such works include the following: across the Volkhow River (280 m) with a carrier wire in spring 1942; across the Oka River in spring 1942; two lines on rafts across the Onega River in 1942; across the Don River in 1943; across the Dnieper River in the Dnepropetrovsk area (total 2720 m, including directly across the river 1070 m on rafts from empty metal barrels) in 1943; two lines with a length of 1120 m across the Visla River in 1945, first on ice, and with the onset of spring – with pipeline suspension to the pillars of the destroyed bridge [3].

A special place belongs to the pipeline laid during the Great Patriotic War across the Shlisselburg bay of the Ladoga Lake to supply fuel to besieged Leningrad. The pipeline represented a welded assembly. Its construction lasted 50 days, which at those times was quite short. During that time, a line of 21 km under water and 8 km on the shores of the lake was laid. During the period of operation, more than 40 thousand tons of light oil products were pumped through the pipeline [3].

The experience of laying pipelines across water barriers has not remained unused. Already in 1953 the pipeline crossings through the navigable Klazma River (width 135 m) and six non-navigational rivers (width up to 35 m) were laid during the maneuvers. The main method of laying is to pull pre-assembled and plugged lines afloat with their subsequent flooding. A year later, the Dnieper River and the Volga River, as well as the Minsk Reservoir, were crossed in the same during the maneuvers. Thus, the simplest way to cross water barriers, i.e. floating with subsequent flooding was initially used in practice [3].

It is worth mentioning another method. In 1959, during the maneuvers, a suspension cable was pulled across the Daugava River, to which a line was attached on safety hooks [3].

In 1960, when crossing the Volga River (about 1000 m wide), the floats from barrels on anchors were installed along the intended line of laying, which prevented the demolition of a pipeline by flow and breakage of pipes. After the floats were installed, the upstream pipeline was pulled afloat, then pressed against the floats by its current, and flooded with water from the shore. The works were successful, but this method turned out to be too labor-intensive, and the installation of anchors much increased the time of laying. Besides, it was necessary to temporarily stop navigation [3].
However, the attempts to use it on water barriers at a flow rate of more than 0.5 m/s were not successful – the pipeline was demolished by high-speed flow of water from the supposed laying line to the bottom of the river and broke along its body or in the joint. It was necessary to find a new technical solution. An example of this is crossing the Elba River in the German Democratic Republic in 1960. The width of the river is 300 m, the current speed is up to 10 m/s. A new method has been proposed and implemented – pulling a line, previously assembled on the bank, along the bottom of the river with its simultaneous flooding. In 1961, this method, which was improved by a special crown, was successfully used in pipeline laying across the Dnieper River. A cable was attached to the crown, delivered to the opposite shore and attached to the tractor, which dragged the line across the river [3]. This method became the main in practice and was repeatedly applied during the maneuvers, as well as in crossing the Amu Darya River with a width of 860 m with a portable pipeline, when a Limited Contingent of the Soviet Troops entered Afghanistan. The assembly of the cable-connected line on the pontoon bridge was successfully tested here with its subsequent lowering into the river and flooding [1].

In the 1990s of the 20th century during the use of a portable pipeline to pump oil from the remote areas of Siberia such methods of crossing the water barriers, generally small water barriers, as the placement of a line in a bearing structure – a truss, bigger diameter pipes, etc. were used [3].

Unsuccessful attempts to use the method of afloat crossing include the maneuvers at the Volga Reservoir in 1979. The length of the crossing was 9.5 km. The flow speed was only 0.2 m/s, but the strong wind (13-16 m/s) and waves up to 1.8 m high presented serious difficulties. There was almost no flow in the nearby backwater, but the waves and wind were the same as on the main river line. With the use of a harbor pusher tug (power – 300 hp, afloat traction – 3 tf) it was possible to extend afloat a line of 5 km long in the backwater, but the pipes broke under the influence of wind and wave impact. The attempts to pull a line of up to 2 km through the channel were not successful either [6-8].

The review of the accumulated experience highlighted the following proven ways of routing a field pipeline through water barriers:

- afloat with subsequent flooding (with line support by floats);
- pulling along the river bottom with simultaneous flooding;
- using load-bearing structure (pillars of a broken bridge, a truss, bigger diameter pipes, suspension cable, etc.);
- on rafts (floats).

Each of them has certain advantages and disadvantages and is applicable in a purely specific environment.

The analysis of the above methods of crossing the water barriers taking into account local peculiarities showed that the most acceptable method is the method of laying a portable pipeline across the Volga River along the bottom with its simultaneous flooding.

Considering the longer length of the subsea part of a pipeline, a separate “preventer” was rigidly attached along the entire length of the pipeline in order to prevent possible rupture of pipe joints during pulling. The second cable was used as a traction cable to pull the pipeline from the left bank to the right bank using a heavyweight tractor. A float of empty barrels was attached to the head portion of the line to prevent the pipeline crown from catching underwater in the bottom relief roughness.

The new technical solution was the simultaneous connection of pumping and compressor stations to the drag line of the pipeline. This was ensured by filling the line with water to flood it (pumping station) or emptying from water with air to surface the line when pulled, when the situation on the navigation channel (compressor station) would allow.

The required traction effort was calculated taking into account the following factors:

- the greatest traction force will be required when the whole line has crossed the river and each bank has 100 m of pipeline;
- the total length of the laying line is assumed equal to 2900 m;
- the length of the line located at the river bottom by the moment of laying completion is 2350 m;
- the length of the line on land (including an island 350 m wide) is 550 m.
Based on the above factors, the required traction force $F$ (kgf) is determined by the formula [6]:

$$F = 10(l_d + 2l_s),$$

where $l_d$ and $l_s$ – length of lines at the bottom and on land respectively, m.

The design value of the maximum required traction force at the moment of laying completion was 34,500 kgf or 338,100 N. A metal cable as per GOST 7688-80 with the 33 mm diameter was used to pull the pipeline, which withstands breaking strength equal to 588,000 N. safety factor made 1.74. The traction cable was connected both to the crown and to the safety cable of the portable pipeline (diameter – 22 mm, breaking strength – 26,370 kgf or 258,500 N).

The preventer was designed to reduce the longitudinal load from the pipes of the laying line, which reduced the possibility of rupture of their joints. The cable was attached to pipes by couplings (Figure 2).

The calculations also took into account the permissible breaking strength not only of the cable, but also of the pipes made of 16GS steel with the allowable stress $[\sigma] = 490$ MPa. Taking into account the thickness of the pipe walls and the tensile strength of the 16GS steel, the maximum breaking strength of the pipe by metal made 196,710 N. Thus, the total breaking resistance of the cable with the diameter of 22 mm and the pipe metal equals 455,210 N, which is 1.35 times the maximum required strength for pipeline laying thus guaranteeing its protection against breakage.

![Figure 2. Attachment of the preventer cable to the pipeline](image)

Thirty people were laying the pipeline through the water barrier. Mobile pumping units MPU-100/200M and fuel-transfer stations FTS-160 were used as pumping facilities. The floating transporter PTS-2, four push boats BMK-MT and pontoons were used to carry out the work on the water. The track plotter BAT-2 was used as a tractor.

Pipes and pipeline equipment loaded into cars were transported through the Volga River by ferry. The delivered equipment was placed on special sites where it was prepared for deployment, including the completion of pipe joints with removable parts.

At the first stage of the pipeline crossing the water barrier, the works were carried out to prepare the traction cable with a total length of 3000 m for pulling to the opposite bank of the river. The cable sections with the length of 500 m using the crane-manipulator of the maintenance workshop were unwound from bays and laid on shore, after which they were fixed to each other.

A complex barrier to pulling the cable was the boggy island, which required the use of a floating transporter and a boat. The cable of the original length of 1000 m was laid on two pontoon sections
and transported by boat to the island with simultaneous laying on the bottom of the river. The boggy section, which in some places was filled with canes up to 3 m high, did not allow getting into the island neither a floating conveyor, nor a boat, so the cable was pulled by hand, and where it seemed possible a conveyor hoist was used. The end of the cable was taken to the opposite shore of the island (Figure 3).

Figure 3. Dragging of a traction cable through the boggy island

Eight pontoon sections were required to lay and transport the remaining 2000 m long cable (Figure 4). Using four boats it was towed to the opposite bank of the island and after fastening the sections of the cable to each other the pontoons were transferred to the right bank of the river with simultaneous laying of the cable to the bottom.

At the same time, the works were carried out on the shore to deploy the pump station. The minor depth of the river at the shoreline required the installation of FTS-160 (for hydraulic pipeline testing) on a three-section pontoon (Figure 5).

Figure 4. Laying of a traction cable on pontoon
The process diagram of the fuel transfer station consisting of one MPU-100/200M and FTS-160 pumping station ensured stable operation of the pipeline, as well as provided the possibility of its pneumatic and hydraulic unloading.

Pipe sections were installed on the shore in advance. The area allowed to mount 8 sections up to 120 m long (20 pipes in each). To ensure pipeline tightness, all sections were hydraulically tested using FTS-160 (Figure 6).

To avoid burying the pipeline crown into the bottom ground while it was being pulled through the water barrier, an original float consisting of four empty 200-litre barrels with a bottom-welded metal sheet that served as a kind of sleds was applied. Considering the weight of the entire structure, the total design load capacity of the float was 535 kg. In order to determine the location of the crown taking into account the maximum depth of the channel, two buoys were tied to the float with 20 m long cables (Figure 7).
Another new technical solution was the use of an insert-trap to fill the pipeline with water, which was mounted after the first two hermetically sealed pipes. The tightness of the two pipes ensured their positive buoyancy (38 kg). Thus, the total load capacity of the float was 573 kg, which allowed the crown of the pipeline to be kept in the floated state [9-13].

The BAT-2 track plotter (Figure 8) was used as a tractor to pull the pipeline. Taking into account the connection of a hoist, its characteristics met the design requirements.

On the pontoons, the track plotter was transferred to the opposite bank of the river. The construction of the crossing across the Volga River using portable pipelines began after connecting the hoist of the tractor with the traction cable and its tension.

The pipeline entered the water along sections for the length of the unwound cable of the tractor hoist. After the end of the next section of drawn pipes reached the water line, the next section was connected to it, which was successively attached to the safety cable.

In order to reduce the weight of the pipeline and reduce the coefficient of friction against the soil during the period of pulling through the water barrier, water was displaced from its inner cavity by the
compressor station, as a result of which the whole line was afloat (Figure 9). This significantly reduced the load on the tractor hoist.

![Figure 9. Pulling the portable pipeline afloat](image)

After passing 500 m of clean water, the crown of the pipeline reached the boggy island. The sunken tree roots and the beds of canes created some difficulties in overcoming the island (Figure 10), which caused the need to increase the traction force on the tractor to 50 tons by connecting the pulley block tackle to the hoist.

![Figure 10. Pipeline crown inlet to boggy island](image)

A compressor station was also used during piping through a 1850 m wide section of large water. When the water was replaced with air, the crown of the pipeline floated thus making it easier to pull the entire section (Figure 11).

The organization of works when crossing of the navigable channel required particular attention, which was caused by the need to fit within short intervals between ship journeys.

After the crown reached the right bank of the river, the entire undersea part of the 2,700 m pipeline was subjected to a hydraulic test.

During the pipeline closing period, we faced considerable difficulties in removing it from the water, so the operations were carried out in two stages [14,15].
At the first stage, a short section of 500 m was pulled. Near the water line on the nearby shore of the island, one connection was dismantled, and water was displaced from the inner cavity of the pipeline by means of a compressor station, as a result of which the afloat pipeline was easily pulled to the land.

Due to a combination of negative factors, the second stage proved to be more difficult. The navigation intensity on the river prevented the method of pulling the entire pipeline afloat. The length of the pipeline section was 2,200 m, of which 350 m laid on the island was almost completely tightened into the boggy soil, which affected the increase in the total pipeline weight, and the limited terrain prevented the tractor from pulling the sections of more than 50 m from the water. The sections of pipes pulled from the water were dismantled, and to secure the traction cable the crown was re-connected to the next section.

After dismantling, the pipes were loaded on pipe trucks and taken to their storage site.

3. Conclusion

Complex work related to the deployment of a portable pipeline across a large water barrier with a width of 2700 m was performed successfully. A number of new technical solutions, which had never been previously used in portable pipeline practice, contributed to this success:
- connection of a pulled line along its entire length to the safety cable;
- use of original float fixed on a pipeline crown;
- periodic flooding and lifting of the line to the water surface depending on the time of ship journeys along the navigable channel.

During the maneuvers, due to the introduction of new technical solutions, for the first time a portable pipeline was successfully laid across the water barrier with a width of 2700 m. Undoubtedly, the experience gained will serve to further improve the methods of crossing large water barriers with portable pipelines.

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