Experience in construction and operation of sewerage networks in areas with deep seasonal ground freezing across different regions of the Russian Federation

S.B. Mayny[1], *N.A.* Chernikov[1], and *N.V.* Tvardovskaya[1*]

[1]Emperor Alexander I St. Petersburg State Transport University, 190031, 9 Moskovsky pr., Saint Petersburg, Russia

Abstract. Reviewing the experience in construction and operation of sewerage networks in areas with deep seasonal ground freezing across different regions of the Russian Federation. Methods: analyzing the sewer pipeline laying, in-situ observations of wastewater temperature regime at sewer outlets from residential buildings. Results: designs of sewer pipelines laid in different regions are presented, as well as their dependence on the depth of seasonal ground freezing in different regions of the Russian Federation. The actual values of sewage water temperature at sewage outlets from residential buildings are established. Practical significance: In a number of regions the laying of sewerage pipes at a depth of 1.5-1.8 m led to normal and stable operation of sewerage pipelines. In terms of capital expenditures, sewer pipelines account for more than 50% of the estimated cost of the entire wastewater disposal system. Their operation claims a significant share of the costs. Key words: sewerage; sewer pipes; temperature, frozen ground; harsh climate, wastewater.

1 Introduction

A significant reserve for increasing the economic efficiency of construction is the improvement of engineering solutions for designed facilities [1]. Such issues include reducing the depth of sanitary and technical utility lines and, in particular, sewerage networks, primarily for areas of deep seasonal ground freezing [2, 3]. These areas occupy a very large territory of the country and are distinguished by regional specifics, e.g. natural-climatic features such as strongly pronounced continentality and a significant duration of the frost period.

In areas of deep seasonal freezing of the ground on the external networks and sewerage facilities it is allowed to lay gravity sewerage pipelines with a diameter of up to 500 mm at a depth of 0.3 m, and for pipes with a diameter of more than 500 mm at a depth of 0.5 m

* Corresponding author: shonchikspb@mail.ru

above the greatest depth of penetration of the zero isotherm into the ground. The length of sewerage networks in the city of Kyzyl is 88.3 km, the depth of seasonal frost penetration in Kyzyl is 3-4 m, the average depth of pipeline laying is 4-6 m, taking into account the necessary slope, which results in a significant increase of construction costs.

Our country has the experience of laying pipelines in frozen ground. Such pipelines are operated in Krasnoyarsk Territory, Magadan, Irkutsk, Chita, Tyumen regions, Khabarovsk Territory, Ulan-Ude.

Reducing the depth of sewerage networks while maintaining the reliability of operation in a normal operating mode and ensuring non-freezing in possible emergencies are components of the current acute problem of ensuring technical and economic efficiency in the water management system of cities, industrial complexes and production enterprises [4-11].

2 Materials and methods

Given below are the data on experience in the design and operation of sewer pipelines laid in the layer of seasonal ground freezing across different regions of Russia.

The city of Krasnoyarsk

In Krasnoyarsk the depth of seasonal frost penetration is 3.0 m. The initial sections of sewer pipes in a number of routes are laid by builders at a depth of 1.8 m from the first manhole; according to the data of the operating company there were no cases of shallow sewerage network icing. As a rule, the shallow laying of sewerage is something done involuntarily, whenever it is necessary to connect a building or a group of buildings to an already laid collector. When such works are performed by the joint-stock company Territorial Town Planning Institute Krasnoyarskgrazhdanproekt, they provide insulation of sewerage networks laid at a depth of less than 2 meters. In some cases, sewerage insulation is carried out without a reinforced concrete channel, so that a pipeline in the trench is simply backfilled with expanded clay concrete.

3 Results of in-situ observations

Observations of the ground temperature regime in Krasnoyarsk around the sewerage network laid from the house with hot water supply for more than 10 years allow us to draw the following conclusions:

1) the size of the thawed zone around the pipeline is significant, on top of the pipe under the minimum ground temperature the thawed zone has the size of about 20-30 cm;

2) daily fluctuations of outdoor air temperature in winter practically do not affect the temperature regime of the talik (an unfrozen thaw bulb);

3) the presence of a thawed area under the pipe was observed throughout the entire period of research;

4) emergency stoppage of the pipeline for 1-2 days is not dangerous, since its freezing during this period is excluded;

5) reducing the depth of sewerage networks extending from the buildings equipped with hot water supply is possible to the minimum level (with the mechanical strength of the pipe h3 = 0.8 m) under the thermal engineering justification or rational.

In-situ observations of the wastewater temperature regime allow us to draw the following conclusions:

- the minimum temperature of wastewater at the outlet from the building with hot water supply is about 15°C, the maximum is 26°C;

- the change of wastewater temperature within the specified limits (15-26°C) can occur by leaps and bounds when the hot water consumption decreases (measurements were performed every hour during a day);
- the lowest water temperature is more often the case during the hours of minimum water draw-off [12-16].

Irkutsk Region

In Irkutsk as well as in Krasnoyarsk there are sections of the shallow gravity sewerage system, the shallow network embedment being a forced measure there to get connected to the existing network. In addition, there are areas where the initial burial of the network is less than 1.0 m deep (up to the pipe flume). These sections, as well as sections with a laying depth of up to 1.6 m, according to the project of the joint-stock company Irkutskgrazhdanproekt, are laid in a heating reinforced concrete channel (the smallest size is assumed) with perlite backfill, the pipe being pre-wrapped with roofing felt. According to the information from employees of the Irkutsk municipal unitary enterprise Vodokanal, the builders often backfill small sections of the sewerage system with expanded clay concrete or wrap it with mineral wool.

According to the data of the Irkutsk Water Supply and Sewerage Department, the lowest depth of gravity sewer laying, at which no through freezing of pipelines is observed, is 0.7-1.0 m, provided that it is filled to a certain part of the diameter exceeding 0.2 m and in the presence of hot water supply to consumers (the average temperature of wastewater entering the treatment facilities changes insignificantly during the season in the range of 13-16°C).

In the city of Cheremkhovo shallow sewerage embedment is used. For example, on Kirov Street cast-iron sewage pipeline without insulation, 200 mm in diameter, is laid at a depth of 1.4 meters from a two-storey kindergarten (the building has hot water supply). The laying was carried out in dry loamy soils with no groundwater on the site. The sewerage system has been in operation since 1972 and there have been no accidents registered during this period. Shallow burial was adopted at the initiative of a building contractor [2].

Ulan-Ude

In Ulan-Ude the depth of seasonal ground freezing is 3.6 m.

In dry soils gravity sewerage networks made of asbestos-cement ceramic pipes are laid in a layer of frozen ground, the minimum depth of embedment presumably starting from 1.7 m in the presence of centralized hot water supply, without insulation.

In areas where there is groundwater and sporadic permafrost, sewerage is laid in reinforced concrete trays, while in dry soils there is insulation made of clay concrete or bituminized loam expanded clay is provided for the pipes. In practice, the said insulators without trays are not used by builders, sometimes they use slag with sawdust or without sawdust. When pipes of 200 mm in diameter are laid, the depth of laying to the channel flume is 1.22 m, i.e. 0.70 m to the top of the channel. The networks are laid in tray-like channels, thermally insulated with 60 mm thick mineral wool mats. Supporting wooden beams are placed under the pipe sockets at 1 m intervals. Ground cover is provided around the wells (manholes).

Tyumen Region

In the city of Nefteyugansk sewerage networks are laid with a reduced depth of burying the flumes of first manholes, starting from 1.6 m, whereas the normative depth of ground freezing is 2.6 m in this area. Operational experience shows that no cases of pipelines icing or through freezing have been recorded. It should be noted that St. Petersburg-based NIIPgradostroitelstva developed Technical Conditions in 1981 for the design of sewerage networks in Nefteyugansk, which proceeded from a reduced depth of embedment – 2.0 m to the pipe flume – as compared to the normal depth [1, 2].

Starting in 1964, Glavtyumenneftegazstroy under the Ministry of Oil and Gas of the USSR had carried out the laying of sewerage networks in the layer of seasonal ground freezing in the city of Surgut; the depth of the first manhole is assumed to be 1.5 m from the planning mark. The depth of seasonal freezing in the territory of Surgut is 4.0-4.5 meters.

According to the data of operating companies in Surgut, provided by ZapSibZNIIEP, there have been no cases of icing of sewerage networks laid at a depth of 1.6 m or more, which have been in operation since 1970.

In 1986-1987 studies were carried out to determine the process of thermal interaction of sewerage networks in the Stroitel neighborhood of Surgut, built in 1964-1970 and laid in the zone of seasonal ground freezing [2].

Chita

The depth of seasonal frost penetration in the territory of Chita is 3 meters. Sewerage pipelines are operated in gravel, pebble and clay.

The initial sections of the network from buildings with hot water supply are laid at a depth of 1.5 to 2.5 meters.

Materials of sewerage networks are mainly represented by cast iron and asbestos-cement pipelines, which in case of hot water supply are laid using a ductless method without insulation at a depth of 3 m, with inspection manholes made of prefabricated reinforced concrete.

More than half of the sewerage network sections were laid in 1986 and have exhausted their resource or planned lifetime.

Magadan Region

In Magadan, a city with deep seasonal freezing of soils, most sewer outlets are installed at the recommended depth, but there are several areas of shallow laying in defiance of the design – at 1.7 m below the ground surface. According to the information received from the Magadan municipal unitary enterprise Vodokanal, there have been no cases of icing on these sections.

In a number of towns and settlements of Magadan Region there are also areas of shallow sewerage networks. These are the areas of permafrost soils with low (down to -50°C) outdoor air temperatures. For example, in Ust-Unchug settlement the sewerage network made of 150 mm diameter steel pipes with the depth of the first manhole flume embedment standing at 0.8 m has been in operation since 1977. During the entire period of operation there have been no through freezing or icing of sewers, nor other emergencies in the sewerage network.

According to the data provided by the Institute Dalstroyproekt LLC, in Susuman, Magadan Region, a section of the 150-mm sewerage network made of steel pipes without insulation was laid without any design: the depth of the first sewer manhole flume is about 1 m and it is meant to discharge sewage from a 5-storey building (with hot water supply). Since the beginning of residential housing construction and the sewerage pipeline operation (1978), in the absence of idle discharges, no accidents have been registered on this site either.

According to the conclusions of operating companies, practically all settlements in this region have similar sites and terrain, but no cases of sewage freezing in sewer pipelines have so far been recorded. All accidents both at outlets and initial sections of sewerage networks are related to the poor quality of construction works, resulting in leaks, irregular subsidence and ruptures of pipelines.

Khabarovsk

On the territory of Khabarovsk, the depth of seasonal ground freezing is 2.9 m with clay soils dominating.

Sewerage networks made of ceramic and cast-iron pipelines are partially buried in a layer of frozen ground.

The initial sections of the network, extending from buildings with hot water supply, are laid at a depth of 1.7 to 2.0 meters. Furthermore, the pipe section laid to a depth of 2 m is insulated. Figure 1 shows the design of pipeline insulation in Khabarovsk.

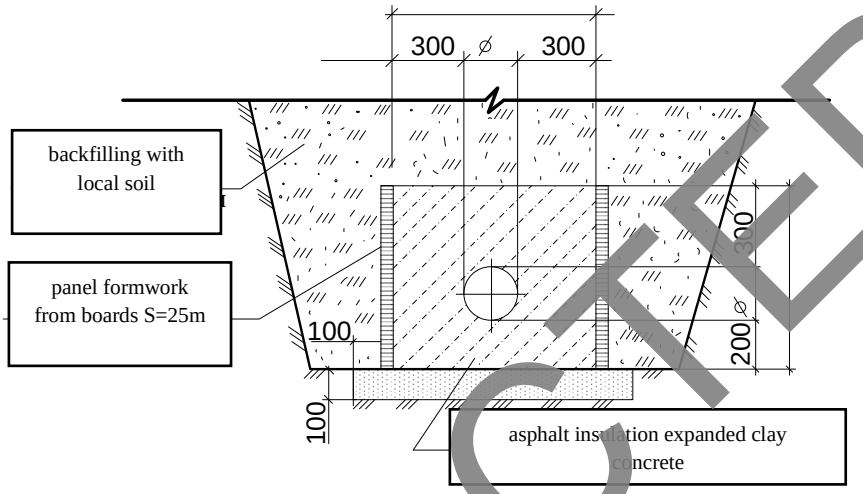


Fig. 1. Pipeline insulation (Khabarovsk) Filling with local dirt (soil) Board sheeting S=25 mm Asphalt insulator – expanded clay concrete

Reinforced concrete pipes should not be used in the shallow laying design, as noted by the staff of the directorate of the Khabarovsk municipal unitary enterprise Vodokanal, because the destruction of concrete does not take a long time, severe frosts degrading concrete rather quickly. In addition, the concrete rings of wells (manholes) are destroyed, so in Khabarovsk the latter are insulated with bitumen expanded clay concrete to a height of 30-60 sm.

In Khabarovsk, work was carried out to study the specific conditions arising during the operation of sewers laid in the zone of seasonal ground freezing, and to determine the reliability of operating such pipelines. The main criterion for determining the optimal depth of embedment is the reliability of network operation with respect to the conditions causing accidents. To assess the reliability of pipeline operation, indicators such as the accident rate, the permissible duration of accident response effort and the permissible decrease of water temperature in the pipeline were considered. Table 1 shows the data on sewage network laying in the city of Khabarovsk.

Table 1. Laying of sewage networks in Khabarovsk

Street / neighborhood name	Depth of burying the first manhole flume, m	Pipe diameter, mm	Pipe material	Laying design	Residential or public building	Year of commissioning
Soyuznaya	1.77	200	Cast iron, asbestos cement	Filling with expanded clay	Hostel with 216 beds	1974
Parkovaya	1.29	200	Cast iron	No insulation	129-unit residential building	1973

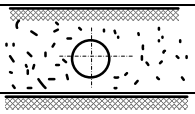
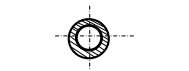
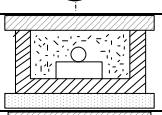
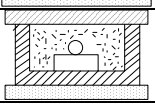
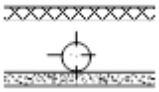
Soyuznaya	1.54	200	Asbestos cement	Fig. 1.1	Kindergarten	1982
Pionerskaya	1.1	200	Expanded clay concrete	Fig. 1.1	9-storey house	1979
Soyuznaya	1.76	200	Expanded clay concrete	No insulation	Health and recreation resort	1972
Bolshaya Vyazemskaya	1.24	200	Cast iron	Fig. 1.1	Residential building	1982
Industrialnaya	1.01	300	Cast iron	No insulation	Residential building	1985
Shimanovskogo	1.14	200	Cast iron	Fig.1.1	Kindergarten	1989
Vyborgskaya	1.21	250	Expanded clay concrete	No insulation	60-unit residential building	1989
Northern neighborhood	1.3	150	Cast iron	Fig. 1.1	10-unit residential house	1988
Gamarnika	0.85	200	Cast iron	Fig. 1.1	ATS	1989

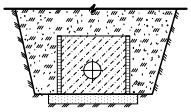
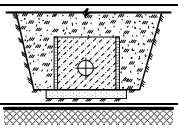
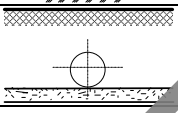
The existing experience in construction and operation proves the possibility of shallow buried pipelines and the efficiency of shallow embedment.

The stability of underground pipelines is ensured by a reliable foundation and measures against its thawing both from heat emission of the pipelines themselves and from the impact of surface and sub-permafrost water flow along the pipeline routes. In case of collapsible soils, when deformations of the pipeline foundation during thawing may exceed the permissible upper limits, the underground laying of pipelines should be accompanied by the construction of an artificial foundation. Soil looseness is of great importance for the stability of pipelines. Under the thawing and freezing ground there are forces that have a complex impact on pipelines [1, 2].

Designs for laying sewer pipelines in different regions are shown in Table 2.

Table 2. The designs of sewer pipelines laid in different regions

City / region	Material	Laying design
Nefteyugansk	Cast iron	
Surgut	Cast iron	
Krasnoyarsk	Cast iron	
Irkutsk	Cast iron	
Cheremkhovo, Irkutsk Region	Cast iron	

Ulan-Ude	Cast iron, asbestos cement	
Khabarovsk	Cast iron, expanded clay	
Magadan Region	cast iron, steel	

Technical solutions of underground laying are determined by permafrost-soil conditions and pipe diameter.

As the depth of embedment decreases, the cost of pipeline construction and repair goes down, and their operation gets easier [1-3].

Table 3 shows the minimum embedment depth of the first sewer manhole flume and the depth of sewer pipeline embedment.

Table 3. The depth of sewage pipeline embedment in different cities of the Russian Federation

City / region	Minimum depth of the first sewer manhole flume embedment, m	Depth of seasonal ground freezing, m
Nefteyugansk	1.7	2.6
Surgut	1.7	2.4
Krasnoyarsk	1.8	3
Irkutsk	1.7	3.5
Cheremkhovo, Irkutsk Region	1.7	3.6
Ulan-Ude	1.8	3.6
Khabarovsk	1.7	2.9

Figure 2 shows a histogram of the depth of seasonal ground freezing for different regions of the Russian Federation.

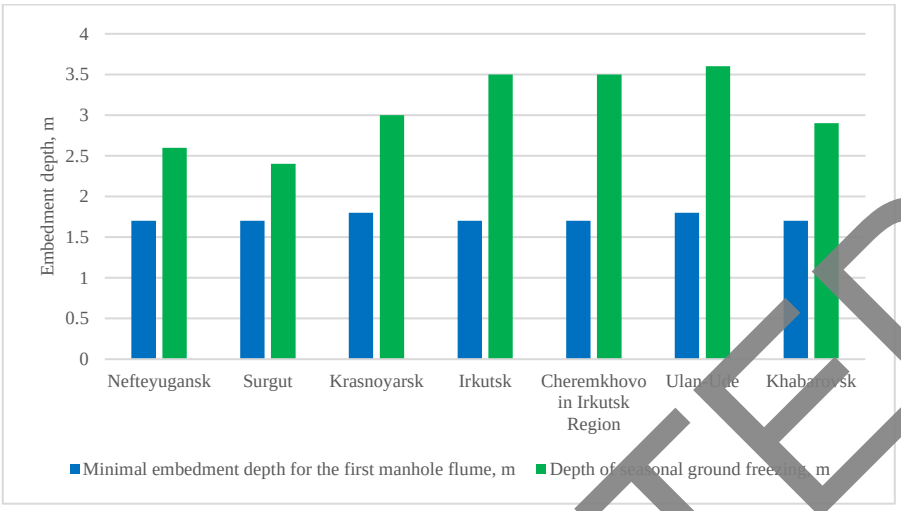


Fig. 2. Dependence on the seasonal ground freezing depth in different regions of Russia

A review of the obtained data, summarized in tables (1-3), reveals that in a number of regions the laying of sewerage pipes at a depth of 1.5-1.8 m did not compromise the normal stable operation of pipelines.

Analyzing the experience of laying sewerage pipelines in different regions of the Russian Federation has showed that in some regions laying sewerage pipes at a depth of 1.7-1.8 m does not detract from the normal and stable operation of pipelines. The maximum embedment depth for sewerage pipelines under the street and road grid may reach 6-9 m.

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