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INFLUENCE OF FLOW ON THAWING OF UNDERWATER SLOPES AND THE PACE COASTAL EROSION OF RIVERS, OCCURRING IN THE PERMAFROST ZONE

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ABSTRACT

In the hydraulic laboratory of department of architecture & civil engineering RUDN University was performed studies of destruction of underwater and above-water coastal slopes in conditions simulating permafrost, depending on the soil type, the initial slope, and the slope angle. It was shown by authors, the speed of erosion of the underwater slope lags behind the speed of thawing of frozen ground. Water flow's influence is much higher than the impact of other factors (temperature, effect of wind, solar radiation), resulting in the formation of the washout niches. Thus, the main goal of the work was to identify the most important factors that affect on the changes of the river bed in permafrost zone.

Keywords: experiment; frozen ground; erosion; water flow; permafrost zone.

1. INTRODUCTION

Permafrost is both the cause of extreme stability in channel flow due to its binding and cementitious properties and the cause a certain instability (for example, anthropogenic load) in a permafrost zone. This leads to the fact that a huge number of studies carried out at

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different times, has given spectrum of contradictory results, even within the same geographical area, and even in the same river. It is likely that a combination of different factors can lead to different ratios of speeds of seasonal thawing of the soil and erosion, which requires particular care and caution, especially in the engineering design. It is not always possible to conduct field observations, and even more so to compare the absolute speed of the lateral erosion of various frozen riverbeds unregulated streams, but it is possible to assume that the impact on the erosion of the external environment is a stabilizing factor in the permafrost zone than in areas that do not belong to the permafrost zone. Therefore, the authors of the paper performed the experiments with the frozen soil of different composition in the hydraulic circulation tray (Fig. 1) in the laboratory «Hydrological and technical safety of hydraulic structures» of the «Hydraulic and hydraulic structures» Department of the Engineering department of the People's Friendship University of Russia (RUDN University). That work is a continuation of the study of the dynamics of the coastal slope of the water bodies in the conditions of permafrost zone [1-5].

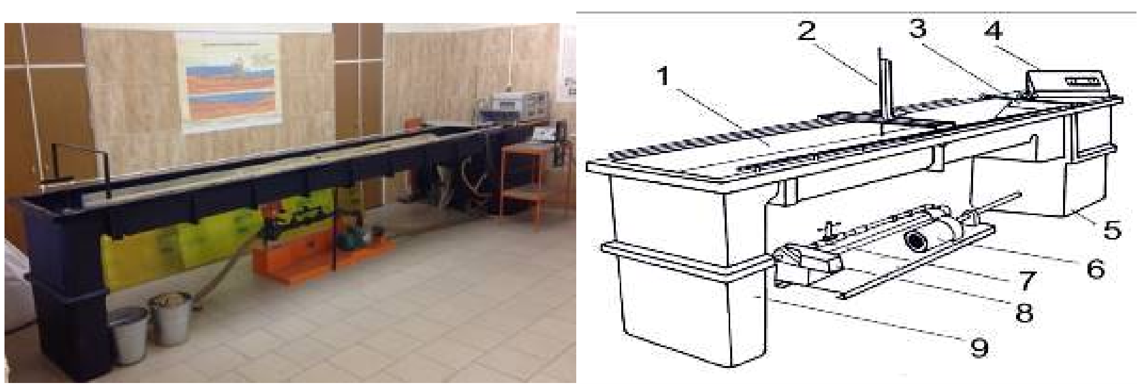


Fig.1. Scheme of installation:
1 – working tray; 2 – spreader scale; 3 – weir; 4 – control unit;5 – storage tank; 6 – circulating pump; 7 – flow meter; 8 – valve; 9 – the device that soothes the flow

2. RESULTS AND DISCUSSION

Although permafrost is extremely unstable, as can be unstable such substance as ice, however, there is no reason to believe that the river beds in permafrost from a physical point of view are different from the same channels in the temperate latitudes. Just in the first case, in the equation is added an additional variable - ice content, after that the equations are solved by taking into account real indicators of the environment (wind speed, temperature, light).

That results of the research of one of the components of a single process thermo hydrodynamic (radiation, snowmelt) are a necessary part of the overall prediction of climate change impact on the course of destructive cryogenic processes in the area of permafrost.

3. EXPERIMENTAL

3.1 Experimental studies of the effect of the flow on the erosion of the underwater slope

The intensity of the destruction of the shores of northern water bodies is connected the fact that the erosion of the underwater coastal slope, folded of frozen icy rocks, is carried out under the influence of not only mechanical but also thermal energy of moving water. The intensity of erosion of permafrost depends on the temperature [1,2] and iciness species [3,4].

Previously [1] was obtained the formula for ability of mass transfer in water flow, taking into account changes of ice content in slope :

$$S = 2{,}4 \cdot 10^{-9} \cdot \frac{U^3}{g \cdot h \cdot w \cdot (i^2 + 10^{-6})} \quad (1)$$

where S - the transporting ability of flow, the U is the mean flow velocity, h - depth of flow, w - hydraulic size unfrozen material, i - ice content in slope (in fractions unit).

From the sediment transfer formula (1) and formula Darcy-Weisbach of flow on a slope with an accounting of iciness obtained the formula erosion solid surface runoff from slope [6]:

$$S = \frac{6 \cdot 10^{-9}}{w \cdot \left(i^2 + 10^{-6}\right)} \cdot \frac{\sqrt[3]{g \cdot q_{ск}}}{\lambda^{4/3}} \cdot \mathrm{tg}\,\alpha^{4/3} \quad (2)$$

where q_{ck} - specific consumption of slope's flow; unfrozen material, λ - the resistance coefficient or friction loss along the length - is determined experimentally; α - angle of the shore slope.

Thus, we find that the dependence of the solid erosion from the angle of the shore slope will have a type of degree (ceteris paribus) (4/3) (Fig. 2).

In the hydraulic laboratory RUDN University series of experiences with polystyrene and with a different angle of inclination was conducted to determine the influence of flow on the rate of erosion.

Polystyrene has a lower density and a greater buoyancy than sand. Therefore, we can choose the speed for it to be critical for polystyrene, but a non-blurry sand. Thus, we were able to simulate a two-layered solid layers which have different physical properties (similar to natural conditions: the seasonally movable layer and frozen).

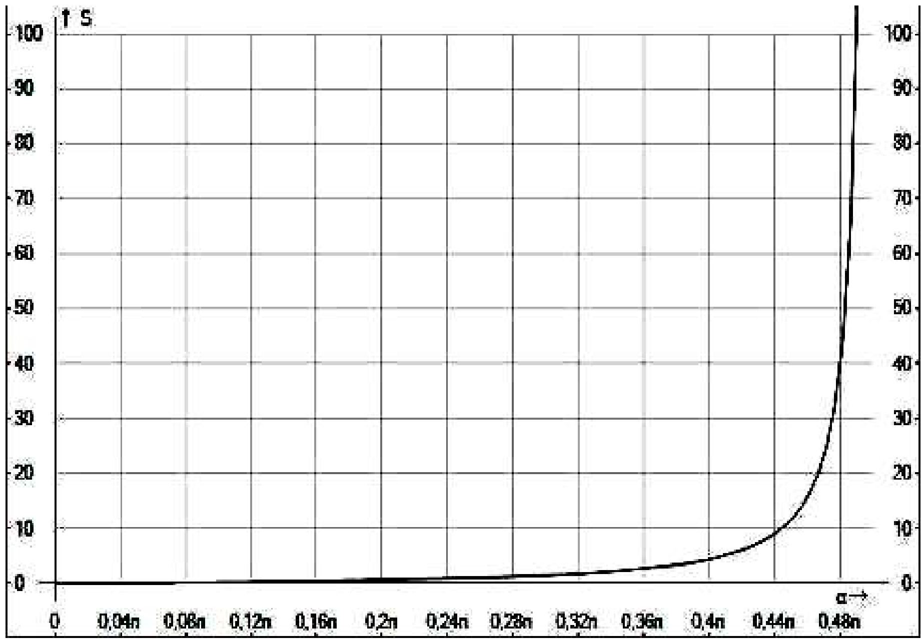


Fig.2. Dependence of erosion solids from the shore slope angle (ceteris paribus)

Pre polystyrene wetted with water so that the water fills the entire space between the particles (saturated soil moisture) and frozen. After all we put the frozen form to the slope, having a natural angle of repose for the sand.

Polystyrene was immersed in a flow on 5.5 cm, and on the surface was 2 cm. It was possible to observe a different rate of thaw of frozen pieces of polystyrene and air flow. After 20 minutes, submerged part was completely thawed and washed away, while the upper part remained icebound for another 20 min., and only under the influence of subsidence and immersion in the stream it was destroyed (Fig. 3).

In areas of the coastal slope, lying above the water line, the flow haven't of influence, and in the absence of any external conditions (rain, snow melting, any other factors that cause slope streams) soil thawing causes no material progress, and the only partial subsidence.

The effect of velocity on the longitudinal sediment transport (see the washout in the underwater part and canopies over the water where the flow rate is zero) - Thus, the formula

(1) was tested.

Fig.3. Influence of the flow on the underwater erosion of thawed material

3.2 Experimental study of interdependence the defrosting of underwater slope and the rate of coastal erosion

In [7] carried out the most comprehensive to date theoretical study of the movement of the front thawing, depending on the depth of erosion unfrozen soil under typical values of thermal parameters for different speeds of erosion progression and base laws of process was set.

The thawing over the coastline increases with erosion. This speed increase of erosion leads to a decrease in the thickness of the melt layer. The main mechanism for this type of erosion is "maximum thermal erosion" type of erosion. Later, however, he goes into "thermal erosion" type, nature of water flow interaction with the rock in this case is already determined by mechanical factors (mechanical properties of permafrost, the kinetic energy of the water flow). With the growth of the ice content in frozen soil the thawing front speed slows down, melted layer thickness decreases.

The Increasing of the temperature of the water flow that is interacting with the frozen ground, promotes the growth of the melting layer as ground is thawing faster. Thawing speed is far ahead of the intensity of erosion and takes place a gradual increase in melting layer and is the erosion and removal of softening of the soil.

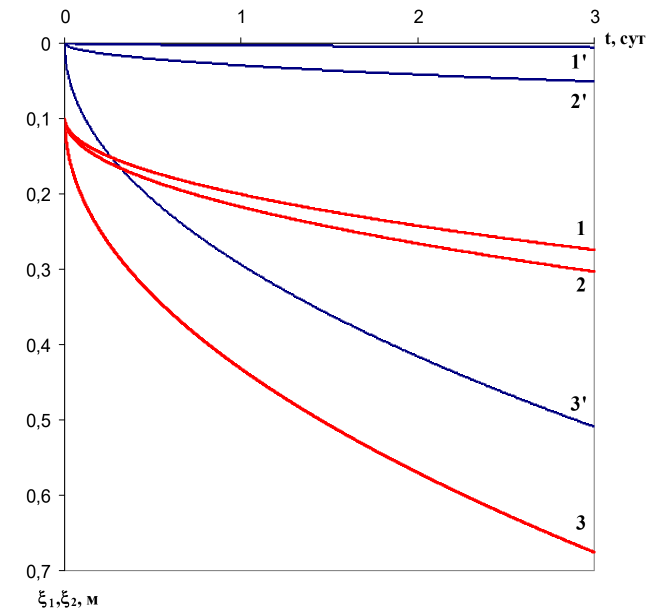
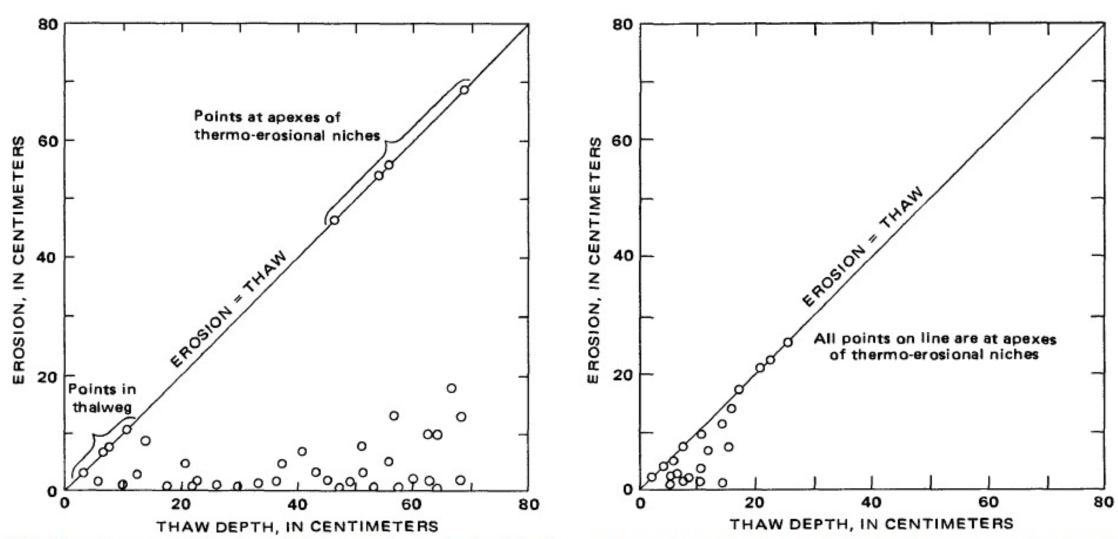


Fig.4. The dynamics of erosion of ground (1 ', 2', 3 ') and thawing (1, 2, 3) for various values of the thermal conductivity coefficient

K. Scott [8] carried out field studies on several rivers in Alaska. He came to the conclusion that the rate of thawing underwater coastal slope depends on the texture of the material and temperature of the water. The results of his observations show a general tendency the erosion to lag behind of thawing. However, comparison of the rate of erosion and thawing speeds on two specific rivers of Alaska showed the same results, regardless of soil properties (Fig. 5).



Plot of erosion versus thaw for points in noncohesive bed and bank material. Points without detectable erosion (41) are excluded.

Plot of erosion versus thaw for points in cohesive bed and bank material. Points without detectable erosion (25) are excluded.

Fig.5. Comparison of the rates of the thawing and the erosion on the example of Alaska rivers

These are the cases where a negative temperature plays a dominant role, not allowing the ground to thaw.

In the hydraulic laboratory RUDN were performed studies with different angles of repose for frozen soil moistened (analogue underwater slope in a permafrost zone) and usual frozen (analogue of a surface slope in the same conditions) [9, 10]. Were carried out measurements of the change of coastal line in time for three cases: 26 (a natural angle of repose of occurrence), 40 and 50 degrees. Thawing and erosion measurements were conducted, and graphics for each experiment as a function of time were made. These charts is clearly interpolated of logarithmic dependence. For shore slope 40 degrees logarithmic approximation these curves shown in Fig. 6. For other angles of inclination this graphs have a similar character.

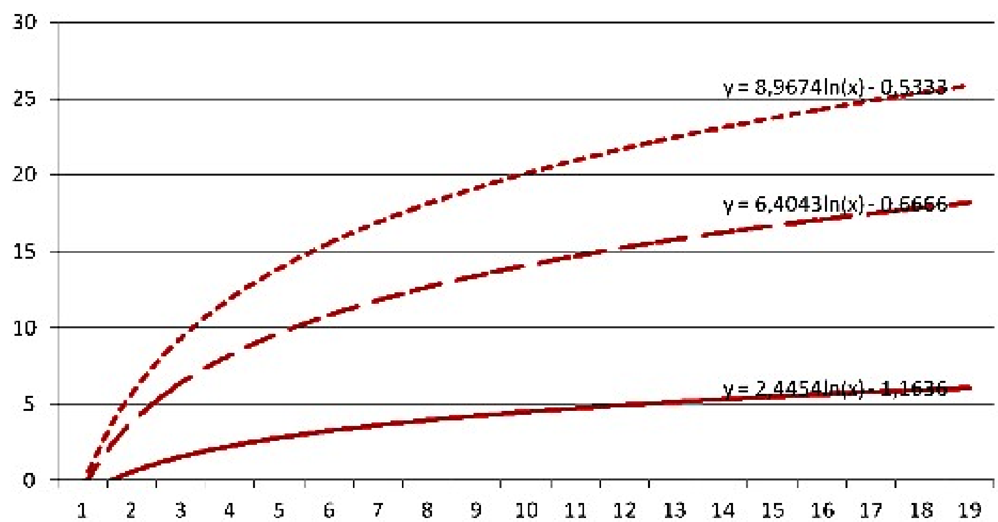


Fig.6. Change of thawing depth (logarithmic approximation): dotted line – for the wetted soil, pointed line **-** for usual wet; solid line – erosion

The graphs show that the onset of erosion (scour) occurs, some time, after the beginning of the soil's thaw, and the rate of erosion is far behind the thawing rate at least twice. Thawing of usual frozen soil and of moistened frozen (for example such ground is forming below the water line in the stream, freezing with this) differ by about half.

Although the rate of thawing of frozen and wetted soil are different, erosion exposed to only a portion of which is in the water. The upper, above-water part of the slope, exposed to subsidence. It should be noted in the case of the 50 degree angle the logarithmic dependence of erosion was observed until a certain time (after 2 hours 30 minutes). Then there was landslip of a large piece of ground from top. This is exactly the case when formed, except solifluction, superficial landslides.

Plots of the erosion rate with different angles of inclination are shown in Fig. 7.

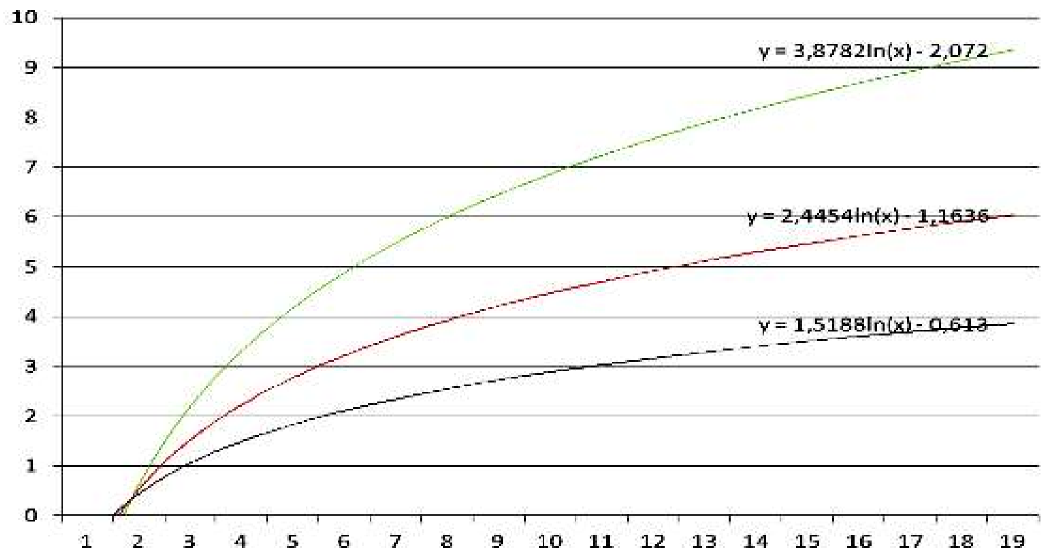


Fig.7. Plots of the erosion rate in the time for an angle of 27 degrees – the bottom line; of 40 degrees – the middle line; of 50 degrees – the upper line

If we compare the values of erosion for various slope angles in equal times, we can see that the dependence of these values will be described by a function with a certain ratio. The value of this coefficient is calculated according to the equation (2). Thus, the dependence of experimentally confirmed, previously obtained in a theoretical form.

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The erosion of the underwater coastal slope in a permafrost zone - a complex physical process, the final result depends on many factors. Only by considering all of these factors together, we can predict with some certainty the behavior of rocks in a certain part of the world at a certain time of the year and, under certain weather conditions.

4. CONCLUSION

- The intensity of the destruction of the shores of northern water bodies is connected the fact that the erosion of the underwater coastal slope, folded of frozen icy rocks, is carried out under the influence of not only mechanical but also thermal energy of moving water. The intensity of erosion of permafrost depends on the temperature and iciness species.
- The rate of erosion is lags behind the rate of thawing at least twice.
- Thawing of usual frozen soil and of moistened frozen (for example such ground is forming below the water line in the stream, freezing with this) differ by about half.
- The amount of erosion thawing rocks directly related to slope angle due to the addition to the main effects of the flow of events such as landslides and solifluction. At increasing the slope angle, the melting soil easily slides over a layer of still frozen soil.
- Soil layers lying deeper, will experience the same strain with some delay (depending on the thawing rate). Thus, as a result of long-term erosion will be a continuous thawing of rocks and washout newly formed active layer at a rate corresponding to the mechanical properties of the underlying soil. The deformations will occur as long as the naked rocks will appear or eroded layer will have a slope angle, which is a natural for the type of soil.
- It is shown experimentally that the dependence of the solid erosion from the angle of the shore slope will have a type of degree (ceteris paribus) (4/3). Thus, the dependence, that was previously obtained in a theoretical form, is experimentally confirmed.

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