Ground Distortion in the Sredneamurskaya Lowland Caused by Seasonal Freezing

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Abstract. We undertook a field survey of ground surface deformation under the influence of the frost heave process. The study has been conducted on the testing sites located in the different areas of the Sredneamurskaya lowland terrain (South of the Far East). It has been established that there is the most advanced alteration of the surface in the flood plains and broad water course valley bottoms, and there is a minimal alteration aslope and at the nearby water-dividing flat areas. Ground surface deformation is more active in the areas where the earthworks had been executed in comparison with the natural areas.

1. Introduction

Southern regions of the Far East of Russia are characterized by extra harsh weather conditions in comparison with the other areas of this region. Utilization of mineral and land resources of the area, road traffic safety and safe utilization of gas- and oil pipelines are obstructed by the widely spread longstanding frozen ground and deeply frozen ground. (Sobin, 1975, Kiselyov, 1985 etc.).

Frozen rock is spread at an immense distance to the south along the top of the mountains and along the Sea of Okhotsk coast. There are no longstanding frozen grounds within the flat lands in the southern part of the Khabarovsk Territory. However, the grounds in the zone of seasonal freezing, and also on the surface of the natural bluffs, open trenches and ditches are exposed to the frost heaving forces. Depth of frost penetration is significantly large because of the harsh weather conditions.

A lot of research workers of the Far East did research on the peculiar features of the soil freezing processes. It is worth mentioning the following authors of the research: L.I. Sverlova, (1967, 1967а, 1975), T.N. Chekhonina (1973), O.S. Popov (1971), V.A. Primak (1973), A.Ya. Deev (1971) and others. They found out time periods, speed and depth of freezing in different conditions, as well as the main factors influencing the above mentioned characteristics. However, deformation peculiarities of ground surface of the territory under consideration stay almost unexplored.

Work objective is to evaluate the size of ground surface deformation caused by its freeze-up, basing on the instrumental measurements taken on testing sites that include both natural areas and disturbed lands. The measurements were taken on different relief elements which are closely connected with the physical properties of the grounds. The following area has been researched as a disturbed land: area of the pipeline laying, Eastern Siberia - Pacific Ocean.
2. Objects and methods

Grounds of the territory under consideration are diverse; they vary from nonfrost-susceptible soil to strongly swollen one, depending on the certain location. [Kiselyov, 1975]. Heaving soil swells out during the seasonal freezing which causes upheaval and development of frost heaving forces. During the subsequent defrosting there is a settlement of ground and degradation.

Frost (cryogenic) heaving is usually defined as a deformation of the soil within itself leading to the increase in its volume during freeze-up. It happens due to the softening of the mineral constituents during the process of various ice inclusions formation in the ground. Frost heaving can be seen externally by local, usually irregular surface lift of the freezing ground, designating the value of its longitudinal deformation; after the ground melts, the lifts of the ground are substituted by settlement (Recommendations…, 1986).

The researched areas are located on the territory of Vyazemsky and Bikinsky Districts of Khabarovsk Krai. We have researched potential frost heave places on different relief elements with a certain lithological composition and humidity of the grounds. When making the route, we chose the sites that were geographically overviewed - topographic features, composition of the ground, type and degree of coverage.

Ground surface deformations caused by frost heaving were defined with the help of instrumental monitoring over the position of deep bench marks (marks), installed in the pre-winter period. The installation of the marks took place in the period from November, 15th till November, 18th on seven sites. They were located on different relief elements such as floodplains, bottoms of small river valleys, slight steep slopes and on the flattened fields near the water-dividing areas or on the softly dissected ancient plain of accumulation. Soft sediments included absorbings of various granulometric composition. The majority of them were argillaceous, covered with ballast layers of slope detritus and argillaceous-sand alluvial sediments in the bottoms of river valleys.

Atmospherical temperature in the mornings during the period of marks installation was around minus 21°C daily, in the day time it rose up to minus 7 – 9°C. However the weather in the southern regions of the territory before November, 13th was warm, with positive daytime temperatures (fig 1). That is why on November, 15th the depth of the ground freeze-up was 5 – 10 cm only, depending on their composition and location of the site on the relief elements.

Fig 1. Average daily temperature, according to station of Khabarovsk, period from October, 21th, 2011 till April, 30th 2012
We installed 75 cm-long metal rods into the ground at a distance of 1.5 - 3.5 meters from each other on each site endwise and across the pipeline bank. The top of the rod was located on the ground surface level. Some of the rods were driven so deep in the ground that not more than 2 cm of the rod stayed above the surface. Each site contained totally 14-15 rods. Five rods have been installed in the cross-section of the pipeline bank. The first and the last rods of the cross-section were located on the surface of natural ground on the both sides of the pipeline bank, not on the soft sediments above the pipe. Some rods were installed on the surface without higher level of topsoil; it was missing due to the ground works during the pipeline laying.

After the installation of the rods the surface leveling in the cross- and longitudinal sections of the bank has been executed. Repeated surface leveling based on same marks has been executed in winter time (in the beginning of March) and in the beginning of spring (April) after the snow has melted.

Winter works on all seven sites have been carried out in the period from March, 5th till March, 7th 2012. Atmospherical temperature in the morning was minus 22-23°C, and it rose up to minus 15-16°C in the day time. Depth of snow cover on all sites was from 15 up to 25 cm. Repeated surface leveling, made according to the foundation of the embedded rods, allowed to estimate the value of the deformation of grounds surface during the freezing process, from November till March.

In spring the measurements have been made in the period from April, 16th till April, 18th 2012. Day-time atmospherical temperature was 7-8°C, and in the morning it used to drop till minus 7°C. Snow cover was totally gone, the ground top layer (width from 3 up to 30 cm, depending on place) was in the thawed state. The temperature conditions in the winter period were complying with the long-time average annual values. This refers to the depth of snow cover in both open and wooded areas.

3. Environmental conditions of territory

Geomorphologically, the territory is located in the north-eastern part of the Sredneamurskaya lowland and on the western slopes of spures in the of north of Sikhote Alin. Terrain that plays the main role in the landscape formation consists of combination of low-mountain areas with roundish forested peaks and water-parting lines, with gentle kettle backs and flat water-logged bottoms of river valleys. The low-hill terrain in the very southern part of Sikhote Alin are devided by the mountain stream valleys.

The environmental conditions of the southern part of the Khabarovsky Territory are diverse. Temperate continental climate with clear monsoon features defines specific temperature scenario in the area: winter is cold and dry, summer is hot and humid. Circulation of the atmosphere plays a critical role in the formation of thermal regime, it causes the change of average monthly temperature during the year (Petrov, Novorotskiy, Lenshin, 2000, Petrov, 1967).

Long-time average annual atmospheric temperature according to the weather bureau of Khabarovsky is plus 1,6°C. It changes from plus 3,6°C in the warmest years to minus 0,3°C in the coldest years. The average temperature of the coldest month January is minus 21,6oC, with maximum variations from 16,4°C till minus 28,6°C, and the average temperature of the hottest month, which is July, plus 21,1oC with maximum variations from 18,0oC up to 23,7oC. Absolute minimum of the temperature, registered here during the entire observation time, is minus 48oC, and absolute maximum is plus 37oC. As can be seen from the above, the maximum amplitude of variations in temperature reaches 85oC.

The atmospheric temperature in the mountains located in the researched area drops on average 0,5° by every 100 m of going up. That is why the lowest temperatures in summer time are registered on mountains tops and slopes. A very cold air gathers in the topographic lows and intermontane valleys in winter time.

The first month with a positive mean monthly air temperature is April, last month is October. Duration of the frostless season lasts on average 159 days long, changing from year to year from 133 up to 180 days. The largest daily ranges of temperature, exceeding 10°C usually take place in spring and in the beginning of summer. Small ranges of daily temperatures are typical for the cold period.
They are stronger in the plains and river valleys than in the highland areas. A small amount of snow in winter and strong longstanding frost cause the deep freeze of the ground, up to 1.5 m penetration. 

Mineral soil in the open areas start freezing steady simultaneous on all kinds of relief when the daily temperature passes through 0°C (Goryainov, 1973). The depth of freezing depends on a large amount of factors, namely on mechanical composition and humidity of the ground. Well-drained soil with a light mechanical composition freezes faster, then the soil with a heavier mechanical composition and a water-logged soil. The depth of the ground freezing, depending on the conditions, can reach 1.5 – 2.5 m.

In the winter season the ground gradually freezes; depth of freezing depends on many lithological and climatic factors of the certain area. Standard depth of the seasonal ground freezing is an average depth of the annual maximum depths of the seasonal ground freezing defined from the decadal research on the open, cleaned of snow horizontal site, when level of groundwater is lower than depths of the seasonal ground freezing.

Depth of the ground freezing according to the data provided by G.F.Goryainov (1973) is calculated according to the depth of ground penetration by frost at the temperature 0°C (table 3). At this temperature humid, water-saturated, macrofragmental and light-textured soils become solidly frozen. The ground freezing depth map for the territory of the Far East was compiled in 1957 by professor A.V. Stotsenko and added in 1960 to DAL Research Institute for System Studies (fig. 2).

The beginning of thawing of soil takes place at approximately same time as the snow cover melting and the average temperature transition through 0°C. The speed of melting changes inversely with the speed of freezing because soils with a dryer and lighter mechanical composition melt faster, than humid and heavy ones.

**Fig. 2.** sketch map of the ground freezing depth (in cm) in the southern part of the Far East calculated according to the isotherm of the lower boundary –1°C: sh – southern border of the island frozen earth (according to Stotsenko, 1952).
According to the data of stationary research on Birskaya agricultural experiment station located in the Sredneamurskaya lowland in the similar conditions as the southern regions of the Khabarovsk Territory (Iosefovich, 1931), it has been discovered, that the depth of freezing reaches 1,5-2,0 m in the argillaceous grounds. Even in the coldest winter times it does not drop lower than 3,0 m. Herewith there is a definite consistent pattern: soil freezing in the autumn goes a lot faster than its thawing in the spring. Daily range of temperature stops at depth of 2-3 m, annual variations stop at depth of 7-8 m.

We found out that the ground freezing starts earlier in the valleys and at the footslopes, later it takes place at the medium and upper levels of the hills. That is why ground thawing begins faster in the upper parts of the slopes, and is slower in the lower parts of the hills, as well as in the valleys; this can be explained by the differences in the lithological composition of the soft sediments and by inversion (Gvozdetsky, 1956, Makhinov, Machinova 2011).

Silty-clayed soil becomes frozen at the temperatures minus 1–3оС, when the phase changes of humidity in the ground stop or significantly drop on the border between freezing and thawed front and when the frost heaving process is over. That is why the border of temperature distribution, equal minus 1оС, should be taken as a standard depth of freezing of argillic and powdery soils with a humidity up to 25 %. If the humidity of the ground is more than 25 % this temperature is 0,75оС, and for the coarse grit grounds with natural humidity this value is 1,33оС.

In summary, the depth of ground freezing depends on the geographic location of the observation sites, chilling degree of the air (sum of average monthly temperatures below freezing point) in winter time and the thickness of snow cover. By increase of the height, every 100 m the depth of ground freezing increases on 5 cm.

4. Results and discussions
Plain of accumulation. The research of ancient plain of accumulation terrain has been carried out on three sites, located within the wide flat area near the water-dividing lines. The surface of the areas is even, there are smooth small ups and downs with a range of altitude not more than 0,5 m. The soil is homogeneous, solid, sandy loam of light brown colour. This soil stays slightly dabbled during all warm season of the year, but if such a soil was compacted by heavy equipment, it almost does not weep. The ground water level is at the depth of more than 1,5 m.

Data of the repeated leveling in November-April on site 1 showed that there was a surface rise on 5-11 mm in the natural area, while as fault area had a reverse process – decrease of the surface on 12-19 mm. At site 2 there was a surface decrease from 27 to 41 mm on the disturbed land surface. At site 3, which was entirely located on the disturbed land there was a surface decrease from 20 to 44 mm.

Valley slope. The site is located in the medium part of the long steep slope at an angle of 4-60 in the valley of a small streamflow. The soil consists of soft sediments of defluxional slopes (slopes of massive material shift). Higher levels, 15-20 cm thick, consist of argilaceous material with a small amount of sand. Lower there is a rubble-loam layer with a granitic subsoil and a small amount of small rocks and broken stone. Ground humidity in general is not large. The level of ground water is located at the depth of more than 1,5 m.

Repeated leveling of the benchmarks showed that the degradation on the natural area was from 0 till 8 mm. The change on the disturbed land was multidirectional: there was an increase of the surface on 1-5 mm on the area without upper soil horizon; but there was a degradation of the surface on 1-13 mm on the bank above the pipe.

Food plain. We made two sites in the flood plains near the streamways. They had an even surface, with moist meadows of mixed herbs and small reeds. In some places there are marks of bogginess, with certain plants – sedgy tussock fields. There are small hills close to the streamways, covered with broadleaf oak and birch woods. The soil consists of homogeneous light sandy loams of red and grey colours, they are solid and humid. Ground waters are located close to the surface. According to the classification, the soft sediments belong to the average heaving soils.
There was an increase of the ground surface of the disturbed land part of the first site; it was caused by the frost rending of the ground within the limits 11-32 mm. The increase of the ground surface of the part of the second site disturbed by the ground work, located on the lower level and therefore more rich with water was in the range from 1 up to 18 mm; at the same time the increase of the surface of the natural area was significantly larger: from 22 up to 37 mm.

Valley bottoms. The site was located on an even surface of the wide decrease of the bottom of temporary streamflow with smooth small ups and downs with a very small range of altitude. The site was located within the decreasing area, covered with small reeds and water puddles among them. The soil consists of homogeneous sticky argillic loamy accretions without coarse deposit. The ground is very humid all year around, with water storage in some spots. The level of the ground water is located at the depth of 10-20 cm from the surface of the ground.

Part of the benchmarks was installed on the natural area, slightly disturbed by the tracks of the heavy equipment. Ground deformation by the frost influence on this resulted in the surface increase on 25-28 mm. There was an increase of the surface on the bank pipe on 21-38 mm. You can see the summarized data in the table below.

Table 1. Average values (in mm) of increase (+) and decrease (-) of ground surface as a result of frost heaving in the different relief elements

| relief                  | characteristics of the soil                                    | Natural area | Disturbed land |
|-------------------------|----------------------------------------------------------------|--------------|----------------|
| Flat fluvialacustrine   | homogeneous solid argillaceous deposits, yellow sandy loams    | + 8,0        | - 15,3         |
| plain                   | slightly humid                                                 | - 2,7        | - 30,8         |
|                         |                                                                  | -            | - 29,0         |
| Middle part of gentle   | light loam with a small amount of sand, lower - sand, lower -  | - 3,3        | - 4,8          |
| slope of the valley     | rubble-loam layer, slightly humid                               |              |                |
| Floodplain              | light sandy loams of red colour, solid, humid, without large   | -            | + 21,5         |
|                         | rocks                                                            | + 19,5       | + 12,1         |
| Wide bottom of floodpl  | homogeneous sticky argillic loamy accretions, very humid       | + 26,4       | + 28,8         |
| valley                  | without coarse deposit                                         |              |                |

The lithological composition of the soft sediments affects the ground if the following way: very argillic and humid grounds get a large deformation of the surface during winter time with a positive number, while the sandy argillaceous and covered with ballast grounds – mainly a negative number, or they have a small positive number. Geomorphologically, the first group of the grounds refers to the flood plains and water-logged bottoms of the large and small streamflows; the second group of the grounds refers to gentle slopes and levelled areas near the water-dividing lines.

Maximum deformation of the ground surface with a positive number caused by increase of their volume by freezing takes place in the bottoms of river valleys and streamflow flood plains. The values of the deformation of the ground surface on the areas near the water-dividing lines and long gentle slopes have close values with negative number, which can be connected with a small level of humidity and more coarse-grained ground composition.

The grounds with the mechanical alteration caused by economic activity are loose (bank over the laid pipeline in the trench) and they have a larger deformation in comparison with natural areas. The maximum value of deformation of the surfaces in such areas reaches 30 – 40 mm by the average numbers of 20-30 mm.

5. Conclusion
The results of the study of ground surface deformation in winter time based on the repeated levelling show that the process of ground surface deformation by the frost heaving takes place multidirectionally on the testing sites located in different geomorphological conditions and is characterized by a different lithological composition of soft sediments. The value of settlement is not
significant in the areas with natural soil with mainly argillaceous and crushed stony composition. Argillaceous clay-bearing soil with a high humidity, located in the bottoms of wide and water-logged river valleys is more exposed to ground deformation. Frost heaving of higher level of ground causes cracks formation along the bold river shors, deposits and also on the road topping, which requires further in-depth study of these processes activities depending on weather conditions, which vary a lot on the territory of southern regions of the Russian Far East.

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