ANALYSIS OF THE CHANGE IN THE DEPTH OF FROZEN GROUND IN DIFFERENT SOILS UNDER LITHUANIAN CONDITIONS

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Abstract. Lithuanian climatic conditions make a large influence on road design, construction and repair. Climatic conditions include amplitude and speed of temperature variation, maximum and minimum temperatures, precipitation, wind direction and speed, thickness of snow cover, depth of frozen ground. The depth of frozen ground depends on a negative temperature and its stability, thickness of snow cover and the beginning of its occurrence, vegetation, properties and composition of soils, etc.

In Lithuania the ground gets frozen in the first decade of December on the average and continuous until the middle of April, sometimes until the beginning of May. The highest depth of the frozen ground is achieved at the end of winter (in February-March). In especially severe winters the depth of frozen ground reaches up to 1 – 1,5 m. In warm and snow-free winters the ground could not freeze at all or the frozen ground could be not deep (10 – 20 cm) and varying.

The deepest frozen ground could be found in the soils of dry and dusty sand and sand loam of the south–south eastern Lithuania and in the soils of clay in Biržai environs. The lowest depth of the frozen ground could be found in sandy and marshy soils prevailing in the Šilutė environs and in the soils of moraine sand loam and loam of Žemaičių Highland.

The action of frost changes the structure of soil, influences surface and underground water interchange, therefore, investigations and analysis of the changes in the depth of frozen ground is important from the theoretical as well as practical point of view.

Keywords: Soils of Lithuania, meteorological stations, frozen ground, the depth of frozen ground.

1. Introduction

Lithuania is a country of plains where flat lowlands are changed by hilly highlands.

Almost two thirds of the country’s territory are occupied with lowlands, the remaining part – with highlands. To the east of Pajūris Plain the Žemaicių Highland lies, in the eastern and southern part of Lithuania from the northeast to the southwest the Baltic Southeast Highlands stretch: Aukštaitių, Dzūkų and Šūduvos. From the southeast the Aukštaitių Highland is leaned by the Svenčionių Highland and from the territory of Belarus Lithuania is intervened by the Ašmenos Highland.

Approximately 10 – 13 thousand years ago after the end of the last glacial period (Valdai) the majority of soils started to get formed. Only in the south-eastern part of Lithuania the older soils could be found haven’t been affected by the last glaciation [1,2].

A mineral part of soil formed from pedogenesis rocks is very different – the soils of clay, loam, sand loam and sand could be distinguished.

The climate of Lithuania is formed under the effect of global factors and local geographical conditions. Lithuania is located in the northern part of the mean climatic zone.

One of the main factors characterizing Lithuanian climate is frozen ground. Frozen ground is very important for the design, construction and operation of engineering structures, roads and other urban structures. The depth of frozen ground depends on many factors: air temperature, average annual soil temperature, the form of relief’s salience, buildings and planting of the territory, mineralogical content and humidity of soils, their thermo-physical properties, thickness of the snow cover and the course of its formation.

Frozen ground covers nearly the whole territory of Lithuania, at the earliest it can appear in October and remain even until the beginning of May.

The soil temperature and the frozen ground depend not only on temperature-influencing factors but also on the type of soil and its mechanical composition, humidity, vegetation and snow cover. If compared to the air temperature the surface of soil is on average 3 – 6 °C
warmer in summer and in several tenths of a degree colder in winter.

A vertical distribution of the soil temperature is highly dependent on vegetation and snow cover. Beneath a vegetative cover the daily amplitude of the soil surface temperature in summer is 6 – 10 °C lower than that of a bare soil and the ground under the snow cover not only cools down but also becomes less frozen. In the beginning of winter when the daily average air temperature falls below -0,5...-1,5 °C, the soil is getting frozen from the northeast to the southwest. The depth of frozen soil, its duration and temperature depend on the duration of winter, air temperature, thickness of snow cover, vegetative cover, thermal properties and humidity of soil, the depth of the ground water.

The least depth of frozen soil is usually found in Žemaicių Highlands due to the largest thickness of the snow cover (25 – 30 cm). The highest thickness of the frozen soil is in the southern Lithuania where dry and sandy soils prevail, the ground water lies deep and the snow cover is usually 5 cm less than in Žemaicių Highlands. The depth of frozen ground in the Middle Lithuanian Lowland is mostly determined by the snow cover the thickness of which normally does not exceed 20 – 25 cm. Therefore the depth of frozen ground is relatively high here. The highest depth of the frozen ground is achieved at the end of winter (in February-March). In especially severe winter the depth of frozen ground reaches up to 1 – 1,5 m. In warm and snow-free winter the ground could not freeze at all or the frozen ground could be not deep (10 – 20 cm) and varying. In spring, somewhere in about the first decade of April, the freezing goes out [3].

2. The prevailing soils in Lithuania

A geological structure of the location is determined by engineer-geological surveys. For general characteristics of the region the geological maps could be used that are made according to the data obtained in the course of laboratory testing and under the field conditions using the methods of penetrating geophysical investigations and static exploration of ground. When designing concrete objects a special soil investigation is carried out by cutting or drilling pits.

After the last glaciation the majority of soils started to get formed within the territory of Lithuania. Many older soils haven’t been affected by the last glaciation could be found in the south-eastern part of Lithuania (Fig 1, table 1) [3].

![Fig 1. The map of Lithuanian soils](image_url)
The largest part (56%) of Lithuanian territory is covered by moraine sediments. They could not be found only in the eastern and south-eastern part of Lithuania and in the deep valleys of large rivers. According to their mechanical composition they are light loam and averagely heavy sand loam with fine sand and pebble. In the Middle Lowland and seldom in other places the soils have been mostly formed from moraine sand loam. The average thickness of bottom moraine sediments is 8.6 m, the layer of edge moraine sediments – 44.9 m.

Limnoglacial sediments have been formed in aglacial affluent lakes and take about 18% of the territory. These sediments are widely spread in the southern, south-western, central and western part of Lithuania. The largest areas lie in the vicinities of Šakiai, Jurbarkas, Joniškėlis, Pasvalys, Kaisiadorys. These are dusty loam of different heaviness, layered clay, more seldom sand loam, fine and dusty sand. Frequently a thin layer of limnoglacial sediments is covered with moraine and in between them a sandy and gravelly layer lies. In higher places of the relief, mostly in the Baltic Highlands, very heavy limnoglacial clay is spread the large areas of which lie in Utena, Ignalina, Telšiai and Zarasai regions. The thickness of these sediments varies from 2 to 18 m and the average thickness is 3-7 m.

A flowing water of melting glaciers laid the fluvioglacial sediments. The soils of these rocks take 14% of Lithuanian territory. Most of them lie in the South-eastern sandy Plain and Baltic Highlands, in the environs of Molėtai, Vilnius, Trakai and other. In the Žemaičių Highland and the Middle Lowland this type of rocks is found more seldom. The sediments are formed of sand and gravel of different grading, more seldom - sand loam. Lithuania has a number of areas where a moraine is covered with a thin layer of namely these sediments. The thickness of these sediments varies from 1-10 to 30-40 m.

In some territories of Lithuania one can also find the alluvial, derruvial and organogenic sediments. However, the alluvial sediments are more widely spread and have a larger thickness (7-18 m) only in the valleys of large rivers. Of these sediments the most widely spread are gravelly, coarse, of average course, fine and dusty sand and gravel.

In the territory of the Republic of Lithuania the following geological groups and sub-groups of soils are differentiated – especially compressible; adhesive soils – weak, of average strength, strong and very strong; powdery soils – weak, of average strength, strong and very strong.

The territory of Lithuania is divided into 30 engineer-geological regions with the typical engineer-geological sections. Based on the complexity of engineer-geological conditions, the prevailing different engineer-geological groups of soils, physical and mechanical properties Lithuania has six groups of engineer-geological regions. The regions where the engineer-geological conditions are most suitable for mass construction are located in the south-eastern part and middle part of Lithuania. The weakest soils of the worst quality (due to carstic processes and the occurrence of phenomena) lie in the north-eastern part of the territory of Lithuania. (in the environs of Biržai) [8].

3. Methods of measuring the depth of frozen ground

3.1. Meteorological stations

Instrumental metrological observations were was started in 1770 in the Observatory of Vilnius University. Since meteorological observations in other places of Lithuania were started much later, temperature fluctuations of the last two centuries in Lithuania have been studied according to the observations carried out and being carried out in Vilnius. The temperatures taken in other places of Lithuania closely correlate with the temperatures in Vilnius – \( r = 0.96 \ldots 0.98 \).

The climatic information, based on which climatic parameters for road construction are calculated, and various quantitative indicators are obtained from different sources. Primary meteorological information is the data obtained during the observations of meteorological stations. At present, 21 meteorological stations and 32 posts are in operation in Lithuania, where standard observations are carried out according to the common
program: at 03, 06, 09, 12, 15, 18 and 21 h Greenwich Mean Time. Indicators of the air temperature and humidity, precipitation, cloudiness, atmospheric pressure, wind, solar radiation, atmospheric phenomena, snow cover, soil temperature are observed [4].

The depth of frozen ground in Lithuania was started to be measured in 1923 – 1924, the measurements were taken once a month by cutting monoliths of frozen ground up to the limit of unfrozen ground. It is obvious that such measurements were complicated and inaccurate. In 1955 – 1957 the depth of frozen ground was started to be measured by A. Danilin’s frozen ground gauge. These measurements in the meteorological stations were carried out daily. Since 2000 the measurements of frozen ground are being taken in 21 location: in Biržai, Rokiškis, Utena, Ukmerge, Panevėžys, Dotnuva, Šiauliai, Radviliškis, Raseinai, Telšiai, Tauragė, Šilutė, Vėžaičiai, Kaunas, Trakai, Vilnius, Švenčionys, Kybartai, Marijampolė, Varėna and Lazdijai (Fig 2) [6].

In 1999 Lithuania started to develop the Road Weather Information System based on the meteorological stations located at the roads. The main parameters recorded by the RWIS are as follows: air temperature, road surface temperature, subsurface temperature at a depth of 7, 20, 50, 80, 110 and 130 cm, wind speed and direction, amount and type of precipitation. It is very important to know derivative characteristics of these parameters – the number of cycles of the shift of substructure temperature over 0°C at a different depth as well as a total depth of frozen ground.

In a cold period of the year, from November 1 to March 31, data are recorded every 30 min, in a warm period, from April 1 to October 31 – every 12 min. This is carried out automatically using a GSM data transmission. All the parameters are measured on a continuous basis every 0.5 s and within a chosen time interval the average value of the parameter is measured (of the majority of parameters).

This database accumulates and processes climatic and road condition data continuously measured by the Lithuanian Road Administration under the Ministry of Transport and Communications of the Republic of Lithuania. The current number of meteorological stations is 45 (Fig 3) [7].

Fig 2. The network of observation stations of the Hydrometeorological Service [5]

3.2. Lithuanian Road Weather Information System (RWIS)

Lithuanian climatic, hydro-geological and geological conditions have a large influence on road design, building, repair and maintenance. Therefore, in 1999 Lithuania started to develop the Road Weather Information System based on the meteorological stations located at the roads. The main parameters recorded by the RWIS are as follows: air temperature, road surface temperature, subsurface temperature at a depth of 7, 20, 50, 80, 110 and 130 cm, wind speed and direction, amount and type of precipitation. It is very important to know derivative characteristics of these parameters – the number of cycles of the shift of substructure temperature over 0°C at a different depth as well as a total depth of frozen ground.

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4. Changes in the frozen ground depth

Soil temperature depends not only on climatic factors but also on the type and mechanical composition of soil, humidity, vegetation and snow cover. If compared to the air temperature the surface of soil is on average 3 – 6 °C warmer in summer and in several tenths of a degree colder in winter.

Dynamics of soil temperature is influenced by water evaporation from soil. A humid soil surface, having the inflow of humidity from the deeper layers, is intensively evaporating, thus, the largest part of solar radiation is consumed for water evaporation. Such soils before they get dry are usually cool. In a warm period of the year (May-August) the soil temperature reduces with the depth and in cold period (November-February) – increases.

In spring a surface layer of sandy soils gets warm more quickly but in autumn it gets cool more quickly also, therefore, in October the temperature of loam and sand loam is only slightly different.

A significant influence on soil temperature is made by snow cover. Snow is a good thermal isolator, thus, the underlying soil does not get so cool and becomes less frozen. In the beginning of winter when the daily average air temperature falls below -0.5…-1.5 °C, from the northeast to the southwest from December 5 to 25 (average multiyear dates) the soil is getting frozen. The depth of frozen soil, its duration and temperature depend on the duration of winter, air temperature, thickness of snow cover, vegetative cover, thermal properties and humidity of soil, the depth of the ground water.

In open areas the depth of frozen ground is higher than in the forest. Dry soil freezes more deeply than the humid one, since dry soil has a lower thermal capacity, therefore, it gets cool more quickly. In case if the ground water lies not deep a capillary humidity can very quickly reach the soil and vegetation. Therefore, in summer a low-lying ground water cools the soil and in winter, on the contrary, warms and prevents soil from deep freezing.

Due to a large number of factors influencing the frozen ground a variegated map of the maximum depth of frozen ground could be made. The average multiyear depth of frozen ground as well as the depth of one winter even in a small territory can differ by several tenths of centimetres. The map in Fig 4 shows a rather generalized distribution of maximum depth of frozen ground.
The lowest depth of frozen ground is in Žemaičių Highlands due to the thickest snow cover (25-30 cm). The most deeply frozen ground could be found in the Southern Lithuania where dry and sandy soils are prevailing, ground water lies deep and the snow cover is about 5 cm thinner than in Žemaičių Highlands. In the Middle Lithuanian Lowland the frozen ground depth is mostly determined by a snow cover which usually does not exceed 20-25 cm. Therefore, the frozen soil here is comparatively deep. The largest depth of the frozen ground is reached at the end of winter (February-March).

Depending on meteorological winter conditions the frozen ground depth is highly different in different years. In severe winters (1953/1954, 1968/1969, 1986/1987) the depth of frozen ground comes to 1-1.5 m. In warm and snow-free winters the ground could not freeze at all (1989/1990 m.) or the frozen ground could be not deep (10-20 cm) and varying (1952/1953, 1974/1975, 1988/1989) [9, 10].

In spring, on the average in the first decade of April, the freezing goes out. At the earliest the soils unfreeze at the seacoast and in the southwest, at the latest – in the northeast. When spring is very cold and the frozen ground is deep the soils unfreeze only at the end of April.

The certain literature sources [4] indicate that the most deeply frozen ground in Lithuania could be found in the sand loam of Vilnius environs (170 cm) and in the loam of the environs of Biržai (154 cm). It was indicated that the lowest depth of frozen ground could be found in sandy and marshy soils of Šilutė environs (108 cm). However, the measurements of frozen ground taken by the Lithuanian Hydrometeorological Service show that a deeply frozen ground is a very rare phenomenon, and the frozen ground with the depth of more than 150 cm has never been measured in Lithuania. Most probably this was the calculated value of low probability frozen ground or the depth was measured in the building sites with the “moved” soil. The largest depth of frozen ground was measured in 1966 in Dusetos – 1.46 m (Table 2) where the moraine loam and sand loam with gravel and gravely sand lentils prevail [11].

In practice there is a lack of data on the frozen ground depth representing the current period. In recent years more and more winters chance to have a short-period and not deep frozen ground.

When comparing the largest depth of frozen ground measured until the year 1957 [11] to the subsequent measurements of the Hydrometeorological Service [10] the largest frozen ground depth nearly in the whole Lithuania was determined in 1960–1979 (Table 2). In this period the deepest frozen ground was determined in the environs of Biržai, Raseiniai, Ukmergė, Lazdijai, Dusetos and Trakai. In the latter three environs the prevailing soils are moraine loam and sand loam with gravel and gravely sand.
Table 2. The largest measured depth of frozen ground indicated in different sources during various periods

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The especially low depth of the frozen ground took place in 1980 – 2000. In the period 1960–1979, if compared to 1948–1957, the largest depth of frozen ground has increased by about 27 cm on the average, and in 1980–2000 it has decreased by approximately 6 cm. When comparing the largest depth of frozen ground in the last two decades of the 20th century to the period of 1960–1979 it is obvious that the depth has decreased by about 33 cm. It can be stated that in the fifth and sixth decades the maximum depth of frozen ground was very similar to the depth determined in the last two decades of the 20th century.

Measurements of the frozen ground depth taken by the Hydrometeorological Service [10] show that the largest depth (141 – 145 cm) is found in the soils of moraine loam and sand loam with the seams and lentils of gravel and gravelly, coarse and averagely coarse fine and dusty sand and of dusty loam and clay prevailing in the Lazdijai environs, also in the soils of loam and sand loam prevailing in the Raseiniai environs. A slightly lower depth of the frozen ground (130 – 140 cm) is in the soils of clay and dusty moraine loam prevailing in Biržai environs, in Vilnius region – in the soils of fine and dusty, more seldom coarse and averagely coarse sand, gravel and sand loam, in the Panevėžys and Varėna environs – in the soils of fine and dusty, coarse and averagely coarse sand and in the prevailing moraine sand loam and loam in Ukmerge.

In the Lithuanian Road Weather Information System RWIS the depth of frozen road structures is recorded by 22 meteorological stations. Figure 5 gives the maximum depth of frozen ground in the cold seasons of 1999-2006. The graph shows the temperatures of frozen ground in 130 cm depth. Such depths of frozen ground could be predetermined by the snow cleaning since when the snow cleaning is carried out the surfaces become frozen more deeply. Receding from the sea the depth of frozen ground on Lithuanian roads varies from 80 to 130 cm (Fig 6).

Based RWIS data the minimum temperature (off -1 to -4.5 °C) of ground in 1,3 m depth is found in the soils of moraine loam, sand loam and gravel, gravelly sand in the Southeast Lithuania, and in the Middle Lithuania, where dominate soils of clay, dusty and moraine loam, sand loam.
Fig 5. Distribution of the maximum depth of frozen ground in Lithuania (in RWIS stations, 1999 – 2006) [12]

Fig 6. Maximum depth of frozen ground in Lithuania (data from RWIS)
5. Conclusions

1. The largest part (56 %) of Lithuanian territory is covered by light and averagely heavy loam and sand loam with fine sand and pebble. These sediments could not be found only in the eastern and south-eastern part of Lithuania and in the deep valleys of large rivers. Dusty loam of different heaviness, layered clay, more seldom sand loam, fine and dusty sand take about 18 % of the territory. The largest areas lie in the vicinities of Šakiai, Jurbarkas, Joniškėlis, Pasvalys, Kaišiadorys.

2. The frozen ground is important for the design, construction and operation of engineering networks, roads and other urban structures. The action of frost changes the structure of soil, influences surface and underground water interchange, therefore, investigations and analysis of the changes in the depth of frozen ground is important from the theoretical as well as practical point of view.

3. The certain literature sources indicate that the most deeply frozen ground in Lithuania could be found in the sand loam of Vilnius environs (170 cm), however, data from the meteorological stations of the Lithuanian Hydrometeorological Service show that a deeply frozen ground is a very rare phenomenon and the frozen ground with the depth of more than 150 cm has never been measured in Lithuania.

4. In 1960–1979 nearly in the whole Lithuania the largest depth of frozen ground was determined. The largest depth of frozen ground was measured in the environs of Lazdijai, Dusetos and Trakai in the prevailing soils of moraine loam and sand loam with gravel and gravely sand, and in the Biržai, Raseiniai and Ukmergė environs in the prevailing soils of clay, dusty and moraine loam and sand loam.

5. Based on multiyear observation data the largest depth of frozen ground (141 – 145 cm) is found in the soils of moraine loam and sand loam with the seams and lentils of gravel and gravelly, coarse and averagely coarse fine and dusty sand and of dusty loam and clay prevailing in the Lazdijai environs, also in the soils of loam and sand loam prevailing in the Raseiniai environs.

6. Based RWIS data the minimum temperature (off -1 to -4.5 °C) of ground in 1,3 m depth is found in the soils of moraine loam, sand loam and gravel, gravelly sand in the Southeast Lithuania, and in the Middle Lithuania, where dominate soils of clay, dusty and moraine loam, sand loam.

References


