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ANALYSIS AND EVALUATION OF DEPTH OF FROZEN GROUND AFFECTED BY ROAD CLIMATIC CONDITIONS

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Abstract. Climatic factors are divided into more equable and more variable. More variable factors include a multi-year weather regime of a particular region or country. Climatic information, based on which climatic parameters and various quantitative indicators are calculated, is obtained from diferent sources. Primary meteorological information is the data obtained during the observations in meteorological stations. Another meteorological information especially important for road design, construction and maintenance is obtained from the Road Weather Information System (RWIS). Lithuania belongs to a number of countries experiencing a large effect of climatic conditions on road design, construction and repair. Climatic conditions is the amplitude and speed of temperature variation, temperature max and min, precipitation, wind direction and speed, thickness of snow cover, depth of such ground**.** One of the most important climatic factors in winter is a frozen ground. The depth of such ground depends on a negative temperature and its stability, thickness of snow cover and the start of its formation, vegetation, soil properties, composition, etc. The action of frost changes the structure of soil, affects the surface and underground water interchange, etc. Therefore, investigations and analysis of the change in the depth of frozen ground is important from both the theoretical and practical point of view.

Keywords: climatic factors, meteorological stations, frozen ground, depth of frozen ground.

1. Introduction

Since the 20th century already all over the world a quantitative evaluation has been carried out of climate dependence on radiation balance, atmosphere circulation and surface covering; atlases and directories of worldwide and different-country climate are developed, new climate classifications are created, methodology for processing meteorological data is improved. As Beck *et al.* (2006) has it, that today climate classification by Köppen and Geiger is considered to be one of the highest perfection. This classification has been improved and supplemented by the scientists up to now.

It is difficult to precisely forecast the climate of larger regions or the global climate, since there is a variety of climate-characterizing factors and their interaction is complicated. The following factors are attributed to more equable:

1) geographical latitude;
2) height above the sea level;
3) proportion of overland and water areas;
4) existence close to the oceans and/or mountains;
5) relief, structure of top surface.

Other factors are more variable:

1) thermohaline circulation (THC) which transports a thermal energy between the equator and the poles;
2) other ocean currents, performing the same action on a regional scale;
3) vegetation influences absorption of solar heat, water interception and rain characteristics on a local scale;
4) changes in the greenhouse gas amount in the atmosphere – influences the solar energy interception what could cause global warming or glaciation.

Attribution of a climatic factor to the category of global or local factors does not show its significance. Bukantis (1994) reported that frequently climatic differences, caused by local geographical conditions, are more pronounced than those formed by global factors.

The current division of climatic lanes and types uses *climatic regions*, especially based on temperature and precipitation data, since the division by latitudes alone does not take into account the effect of different forms of relief (mountains, mountain ranges, large lakes, seas and rivers) on climate. Each country or region regionalizes its territory according to the variable climatic factors characteristic namely of that locality.

More variable factors include a multi-year weather regime in a particular region, country. In spite of large weather fluctuation, certain regularities could still be noticed characteristic of that region. The main variable

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factors affecting climate are: solar radiation, air and soil temperature and humidity (Witzany, Zigler 2007), cloudiness, atmospheric pressure, wind speed and direction, quantity and character of precipitation, etc.

Leonovich (Леонович 2005) stated that in road design, construction and maintenance Belarus first of all makes the evaluation of the annual precipitation sum and its monthly distribution, annual regime of air temperature, snow cover formation regime, wind strength and direction, regime of the depth of frozen ground. In Great Britain the most important climatic factors are air temperature, precipitation and wind. In Sweden (Eriksson, Lindqvist 2001) an especially large attention is paid to information about road climatic conditions in winter (precipitation > 0 mm, air temperature > 0°C, road surface temperature ≤ 0°C).

Lithuania belongs to a number of countries experiencing a large effect of climatic conditions on road design, construction and repair**.** One of the main factors characterizing the climate (especially in winter) 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 snow cover and the course of its formation.

Frozen ground covers nearly the whole territory of Lithuania, at the earliest it can be formed in Oct and remain even until the beginning of May. Soil temperature and 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, while the soil 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 smallest depth of frozen ground is usually found in the western Lithuania due to the largest thickness of the snow cover (25–30 cm). The highest thickness of frozen ground is in the southern Lithuania where dry and sandy soils prevail, ground water lies deep and the snow cover is usually 5 cm less than in the western Lithuania. The depth of frozen ground in the North and the Middle Lithuanian territory 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 Feb–Mar). In an especially severe winter the depth of frozen ground reaches up to 1–1.5 m. In warm and snow-free winter the soil could not freeze at all or the frozen ground could be superficial (10–20 cm) and variable. In spring, in the 1st decade of Apr on average, the freezing goes out (Lietuvos žemės gelmių raida ir ištekliai 2004).

2. Meteorological stations

2.1. The network of observation stations of the Hydrometeorological Service

Instrumental metrological observations were started in 1770 at the Observatory of Vilnius University. Since meteorological observations in other places of Lithuania 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 – $r = 0.96 \dots 0.98$.

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, atmospferic pressure, wind, solar radiation, atmospheric phenomena, snow cover, soil temperature are observed.

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 Danilin‘s (Masaitytė, Rimkus 2002) 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, Ukmergė, Panevėžys, Dotnuva, Šiauliai, Radviliškis, Raseiniai, Telšiai, Tauragė, Šilutė, Vėžaičiai, Kaunas, Trakai, Vilnius, Švenčionys, Kybartai, Marijampolė, Varėna and Lazdijai (Fig. 1).

2.2. Road weather information system

Design, construction, repair and maintenance of roads cannot be planned without taking into consideration climatic conditions and factors affecting these conditions. For this purpose in 1999 Lithuania started to develop the RWIS on the main and national Lithuanian roads, the basis of which is meteorological stations installed on roads. RWIS is a computer-based system which automatically registers the physical parameters of road pavement as well as road meteorological conditions and informs about the driving conditions. The RWIS allows to measure air temperature and relative humidity, the dew point temperature, number, quantity and type of precipitation, road surface temperature, pavement structure temperature at a depth of 7, 20, 50, 80, 110 and 130 cm, wind direction and speed,

Fig. 1. The network of observation stations of the Hydrometeorological Service (Juknevičiūtė, Laurinavičius 2008): ⁎ – weather station, ✈ – aero-weather station, ▲ – simple climatology station, ● – hydro-weather station, □ – water measuring station, ⚓ – coast-weather station, ⌖ – weather, climatology stations of other institutions

visibility, freezing possibility/state and separates data by date, time and stations. It is very important to know a derivative characteristic of these parameters – the number of cycles of the road pavement structure temperature variation over 0°C at various depths as well as the total freezing depth. All the obtained data is stored and processed in the data base of the Lithuanian Road Administration under the Ministry of Transport and Communications of the Republic of Lithuania which is added with data several times per year.

The current number of meteorological stations is 45 (Fig. 2) (Laurinavičius *et al.* 2007).

RWIS supplements and specifies the network of hydrometeorological stations, existing for many years, the RWIS data facilitates activities for the road maintenance enterprises – gives information on road condition, helps to better and more efficiently maintain roads, to manage unfavourable situations for the road users caused by traffic accidents, ensures traffic safety on roads of state importance, especially in a cold period of the year.

3. Changes in the depth of frozen ground in Lithuania

Soil temperature depends not only on climatic factors but also on the type and mechanical composition of soil, humid-

Fig. 2. Distribution of RWIS stations (Laurinavičius *et al.* 2007): ⬟ – RWIS

ity, 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.

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

In road design it is necessary to take into consideration soil humidity, also to predict humidifying conditions of a constructed road. With the increasing soil humidity and the corresponding change in its consistency from hard to fluid, deformation of soil increases, whereas strength, which is expressed by the deformation modulus *E*, decreases. For this reason, when erecting subgrade, it is recommended to use insensitive soils, or soils of low or average sensitiveness to frost.

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. Natural humidity *w* varies around 30%, deformation modulus *E* varies from 1.5 to 4.0 MPa. These soils, according to *LST 1331:2002 Automobilių kelių gruntai. Klasifikacija (Soils for Road Construction. Classification)*, are of low or average sensitiveness to frost.

Limnoglacial sediments have been formed in at-glacial 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. These are dusty loam of different heaviness, layered clay, more seldom sand loam, fine and dusty sand. Natural humidity *w* varies from 15% to 50%, deformation modulus *E* – from 2.5 to 20 MPa. These soils are of low or average sensitiveness to frost.

A flowing water of melting glaciers laid the fliuvioglacial sediments. The soils of these rocks take 14% of Lithuanian territory. Most of them lie in the South-eastern sandy Plain, in the environs of Molėtai, Vilnius, Trakai and other. The sediments are formed of sand and gravel of different grading, more seldom – sand loam. Natural humidity *w* is small, deformation modulus *E* varies from 5 to 20 MPa. These soils are of especially small sensitiveness to frost.

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 6 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).

3.1. The depth of frozen ground in the territory of Lithuania based on data of meteorological stations

Due to a large number of factors influencing the frozen ground, a variegated map of the max 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 of depth of frozen ground in Fig. 3 shows a rather generalized distribution of max depth of the frozen ground.

The lowest depth of frozen ground is in the western Lithuania 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.

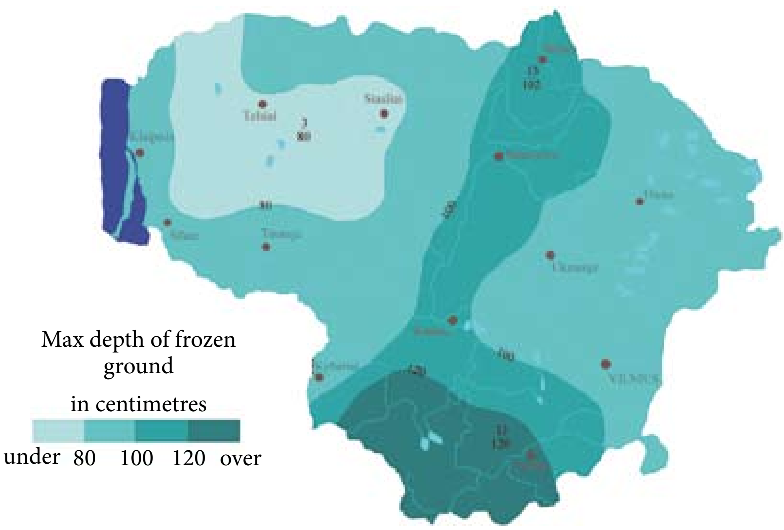

Fig. 3. Max and min depth of frozen ground in centimetres (Juknevičiūtė, Laurinavičius 2008): $\frac{13}{120}$ 13 – min depth of frozen; 120 – max depth of frozen

Therefore, the frozen soil here is comparatively deep. The largest depth of the frozen ground is reached at the end of winter (Feb–Mar).

According to *RSN 156-94 Statybinė klimatologija (Construction Climatology)* the lowest depth of frozen ground could be found in sandy and marshy soils of Šilutė environs (108 cm), while the most deeply frozen ground is formed in the sand loam of Vilnius environs (170 cm) and in the loam of Biržai environs (154 cm); however, this is the calculated value of low probability which is probable once per 10 years and 50 years (Fig. 4). However, the measurements of frozen ground taken by the Lithuanian Hydrometeorological Service (Agroklimato žinynas 1999) 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. The largest depth of frozen ground was measured in 1966 in Dusetos – 1.46 m (Fig. 4), where the moraine loam and sand loam with gravel and gravely sand lentils prevail (Taminskas *et al.* 2006).

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 to the subsequent measurements of the Hydrometeorological Service, the largest frozen ground depth nearly in the whole Lithuania was determined in 1960–1979 (Fig. 4). 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.

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 approx 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 5th and 6th decades the max 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 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 gravely, 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 Ukmergė.

3.2. The depth of frozen ground in the territory of Lithuania, based on data of RWIS

The depth of frozen ground is calculated by using the readings of sensors of a fixed depth. Based on the data of RWIS measurements, the map was made (Fig. 5) which shows that the lowest depth of frozen ground is found in

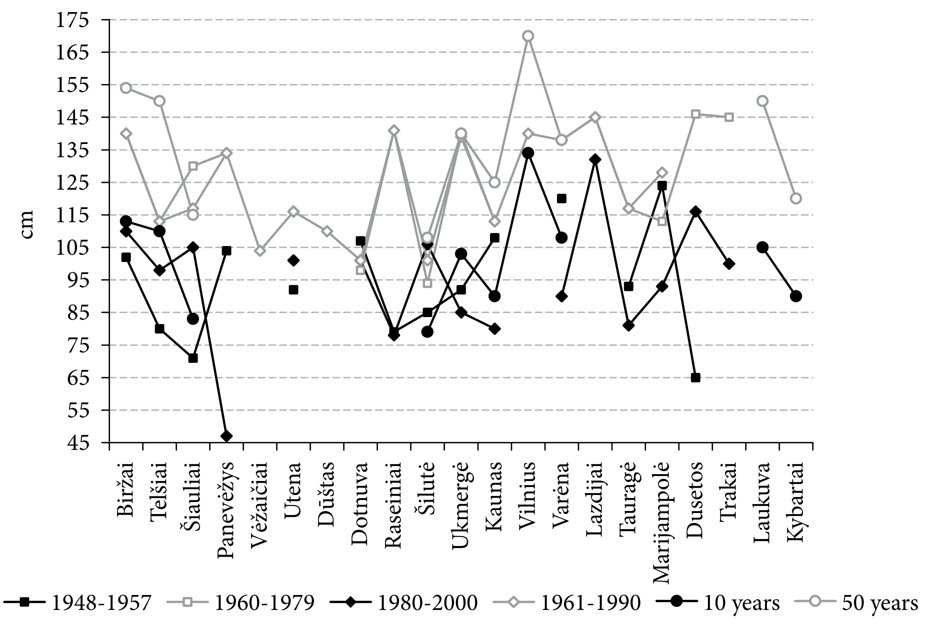

Fig. 4. The largest measured depth of frozen ground indicated in different sources during various periods

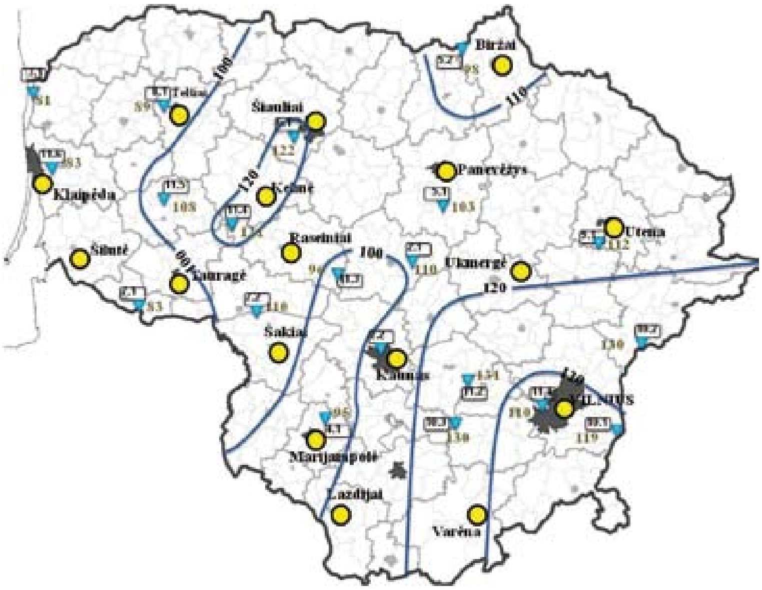

Fig. 5. Distribution of the max depth of frozen ground in the territory of Lithuania by RWIS (Juknevičiūtė, Laurinavičius 2008)

the Western Lithuania (80–100 cm), the highest – in the South-eastern Lithuania (120–130 cm).

Most frequently the soils of subgrade do not meet the existing soil properties of a certain location, the soils are mixed during a technological process when erecting subgrade. It can happen that one and the same road has various soils of different characteristics (Žilionienė 2003).

The maps on the distribution of the depth of frozen ground according to the data of meteorological stations and of RWIS show that the depth of frozen ground, recorded on the roads and measured in soils, is distributed rather similarly – in the Western Lithuania it is lower, while in the Southern territory of Lithuania it is higher. We see that according to RWIS the zone of the deepest frozen ground (120–130 cm) covers the larger part of Lithuanian territory – spreading from the Southern part of Lithuania into the South-eastern and Eastern part as well as the Western part of Lithuania around Šiauliai and Kelmė. Meanwhile, the zone of the deepest frozen ground, based on data obtained from the measurements of top soil, covers a small part of the Southern Lithuania (Varėna, Lazdijai) (Fig. 3).

A larger depth of frozen ground on the Lithuanian roads could be conditioned by snow cleaning, since, when cleaning snow, the surfaces freeze more deep.

4. Conclusions

1. Frozen soil, being important for the design, construction and use of engineering networks, roads and other city structures, in the process of its formation and vanishing changes the structure of soil, influences the circulation of surface, ground waters and the like. Thus, investigations and analysis of the change in the depth of frozen ground are important from the theoretical as well as practical point of view. Soil temperature depends on climatic factors, type and mechanical composition of soils, humidity, vegetation and snow cover.
2. 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.
3. 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 gravely, 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.
4. Based on RWIS data, 130 cm depth of frozen ground could be found in the soils of loam, sand loam and gravel, gravely sand in the Southeast Lithuania, and in the Middle Lithuania, where dominate soils of clay, dusty and loam, sand loam.
5. Most frequently the soils of subgrade do not meet the existing soil properties of a certain location, the soils are mixed during a technological process when erecting subgrade; therefore, the maps on the depth of frozen ground differ, and this is also influenced by the cleaning of snow from roads.
6. RWIS supplements and specifies the network of hydrometeorological stations, existing for many years, the RWIS data facilitates activities for the road maintenance enterprises – gives information on road condition, helps to better and more efficiently maintain roads, to manage unfavourable situations for the road users caused by traffic accidents and natural calamities, ensures traffic

safety on roads of state importance, especially in a cold period of the year.

7. Taking into consideration the possible depth of frozen ground, it is necessary, when designing roads to properly select thickness of the road pavement structure. A special attention must be paid when carrying out reconstruction of a frost-blanket course.

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