



EVALUATION OF POSSIBILITIES FOR THE CLIMATIC DISTRIBUTION OF REGIONS FROM THE POINT OF VIEW OF ROAD CONSTRUCTION

Lina Juknevičiūtė-Žilinskienė¹✉, Alfredas Laurinavičius²

Dept of Roads, Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania

E-mails: ¹lina.juknevičiute-zilinskiene@vgtu.lt; ²alfredas.laurinavicius@vgtu.lt

Abstract. Seeking to reduce a negative impact of unfavourable weather conditions on road traffic, many countries introduce modern technologies allowing to objectively assessing meteorological conditions of roads. The world over, data from the automated meteorological stations of Road Weather Information System have been long ago used on a significantly larger scale than only for the organization of road maintenance works. International experience of introducing Road Traffic Information Systems in European Union and other countries of the world shows that Road Weather Information Systems give good results for increasing road safety, improving the level of road user information and solving the road construction issues. Road Weather Information System is a system of technologies and decision-making using historical and real-time data of roads and weather conditions. The collected and processed multi-year data from meteorological stations is a great assistance in designing or reconstructing road pavement structures. Road pavement structure is highly affected by a negative air temperature and frozen ground. The impact of negative temperature is expressed by the thickness of frost blanket course. The thickness of frost blanket course depends on a frost susceptibility of soil. To determine the thickness of frost blanket course it is necessary to assess the frost impact, therefore it was up to the purpose – climatic distribution of regions the territory of Lithuania according to the distribution of frost impact and the depth of frozen ground. Based on climatic maps compiled, a correction of the thickness of road pavement structure was suggested.

Keywords: air temperature, climatic distribution of regions, depth, frozen ground, Freezing Index, frost, frozen ground, road pavement structure, Road Weather Information System, thickness.

1. Introduction

Road construction and the effect of climatic factors are inseparable from each other, therefore, more and more attention was started to be paid to the research, evaluation and forecasting of different climatic elements and their impact.

Based on temperature and precipitation data, the whole Earth is divided into climatic regions (Chen, D., Chen, H. W. 2013; Peel *et al.* 2007), since only distribution allows to take into consideration the influence of different forms of relief on climate. Many countries in the world attempt to region their territory according to the climatic factors that are characteristic for that particular location.

Lithuania is situated in such geographical position, the climate of which is affected by Maritime and Continental air masses, thus, the climate of Lithuania belongs to the climate of Mid-Latitudes of transitional type from Maritime to Continental. With this type of climate, the weather conditions have a large influence on the condition of motor roads. During the periods of unfavourable weather conditions a certain testing takes place of the reliability of

the whole road as of the structure, its project, construction works and maintenance quality.

When designing, building, maintaining and using roads it is very important to take into consideration the multi-year data of climatic factors. Temperature is one of the main factors affecting road pavement structure. Temperature variations cause road pavement deformations and worsen subgrade condition therefore it is essential to determine the soil properties and their resistance to frost when designing or reconstructing road in a certain location. Temperature variations in road structure create specific thermal regime which differs from the thermal regime of the surrounding area. Heat exchange, taking place in the road structure, is the complicated diffusive process related to moisture exchange in subgrade and pavement structure (Darrowa *et al.* 2009). The temperature of road pavement structure during its interaction with other factors (moisture, traffic) influences the stability of road structure. A negative temperature is one of the factors causing frost heaves in road pavement structure, deformations of subgrade or even pavement,

besides, in high as well as low temperature the deformation properties of road materials change. The depth of frozen ground also depends on a negative temperature of the air. In the process of freezing and thawing, the frozen ground changes its structure, affects surface and underground water circulation, etc., therefore research and analysis of the change in the depth of frozen ground (Riehma *et al.* 2012) are important from both theoretical and practical point of view.

When designing or reconstructing road it is very important to know how the values of negative temperature and frozen ground distribute within the territory of Lithuania. Depending on the frost impact and possible depths of frozen ground, it is possible to properly select the thickness of road pavement structure. An especially large attention shall be paid to designing or reconstructing a frost blanket course.

When solving the issues of road construction the Road Weather Information System (RWIS) is used, and the multi-year data recorded and collected by the meteorological stations are invaluable for seeking possibilities for its practical use in road construction. One of these possibilities is to compile climatic maps (of frost impact and of frozen ground) of the territory of Lithuania enabling to select more accurate thickness of pavement structure.

2. Experience of climatic distribution of regions

Road construction requires huge resources especially in those countries where climate is severe. Weather conditions and their forecast are very important information for all road organizations, design companies, road maintenance services, etc. In order to effectively solve the problems of road construction, it is necessary to develop effective strategies and methods of works. All these are implemented having studied how this kind of problems are fought and what road maintenance methods are used in other countries, having similar climate to Lithuania, when seeking to find optimal alternatives for low expenses and the lowest possible environmental impact. When designing, building and maintaining roads many countries analyse weather information and weather forecasts.

There are different principles for classifying the world's climates (Chen, D.; Chen, H. W. 2013; Peel *et al.* 2007). Climatic regions are identified not only by individual meteorological elements but also by their combinations. General theoretical climatographical schemes are developed also a climatic zoning of applied nature is carried out. Each country has specific climate, characteristic only to this particular country, for example, the most topical data for Great Britain is air temperature, precipitation and wind. Sweden (Eriksson, Lindqvist 2002) pays large attention to information about specific climatic conditions in winter when at the same time precipitation and positive air temperature are observed, and a road surface temperature is lower or equal to 0 °C. Road organizations of many countries use maps compiled by meteorological services based on the multi-year data of World Meteorological Organization (WMO). The climate atlases of the period 1961–1990 are used in Germany (Schönwiese, Janoschitz 2005), Iceland, Denmark, Finland, Norway, Sweden (Tveito *et al.* 2000, 2001), Slovenia, Canada, and of the period 1971–2000 – are used in Great Britain and Finland.

Some countries (Great Britain, Scandinavian countries) have created websites where, having indicated a desirable period (month, quarter, year, etc.) or a desirable climatic factor (air temperature, precipitation, and wind) the climate atlases are given according to the submitted query. This Internet access is available for everybody.

The largest attention is paid to winter season when weather conditions are especially complicated. For this purpose Canadian territory is additionally divided into 6 regions according to the average maximum depth of snow cover (1979–1997) based on the *Snow and Ice Databook of 2014 by the World Road Association (PIARC)*. In the neighbouring Belarus, when solving general issues of road construction, climatic factors are determined based on the adopted road atlas (Leonovich, Čygas 2006). The territory of Belarus, based on the depth of ground water, air temperature, precipitation amount and vaporization processes, is divided into three climatic regions: Climatic Region I is described as being on average warm and humid, Climatic Region II – warm, of average humidity, Climatic Region III – warm, of variable humidity. All those three climatic regions are also divided into six climatic sub-regions and nineteen climatic areas based on particular climatic factors.

Japan divides its territory into four winter regions based on the *Snow and Ice Databook of 2014 by PIARC*:

- of frost and snow;
- of snow where the average maximum thickness of snow cover is higher than 50 cm;
- of frost where the average monthly temperature in January is 0 °C and lower;
- the regions with other meteorological peculiarities.

In the *Snow and Ice Databook of 2014 by PIARC* notes the territory of Norway in winter season is divided into five regions which are described by the following climatic factors: winter duration, thickness of snow cover, average temperature in January and March.

The territory of Germany according to climatic multi-year data is divided into three zones according to the Freezing Index (*FI*) which depends on a negative air temperature. In Germany, the dividing into frost zones is used for determining the thickness frost-resistant road pavement structure.

Various climatic distribution of regions based on the specific climate of each territory helps much in every step of road construction.

Based on the multi-year data, the territory of Lithuania is also divided according to various climatic factors. One of the most interesting factors for the road specialists is the distribution of the depth of frozen ground (Fig. 1) (Bukantis, Bartkevičienė 2005). Fig. 1 gives the depths of frozen ground (1960–1991) compiled according to the values recorded by the field stations of Lithuanian Hydro-meteorological Service. However, when solving the road construction issues, it would be advisable to divide the territory of Lithuania according to the values and their distribution of the depth of frozen ground recorded by Road Weather Information System (RWIS).

In many countries the RWIS data is modelled in various ways and used for forecast of weather conditions, however, historical data, collected many years, gives large

possibilities for compiling climatic atlases intended namely for the road construction.

3. The impact of negative temperature on road pavement structure

The road in operation is periodically humidified, dehumidified, affected by the negative and positive temperatures. The change in these processes during different periods of the year is called hydrothermal regime. With the changing humidity and temperature, the physical and mechanical characteristics of the road structure also change. Subgrade soils and road foundations are porous bodies containing a certain number of pores (Lisøa *et al.* 2007). Humidity, accumulated in pores, migrates. Due to the change in road surface temperature and due to the air circulation in soil, humidity migrates vertically. In a warm period, the air travelling from below upwards leaves space for humidity, therefore, humidity accumulates below. In a cold period, with the falling temperature the process takes place in an opposite direction: the cooled air drops down and humidity rises up. Humidity rises by soil capillaries up to the zone of frozen ground and turns into ice. Formation of ice increases the volume up to 9%, and soil gets auxiliary stresses that influence road deformations (Darrowa *et al.* 2009). Frost heaving is caused by intensive humidity accumulation during freezing, especially in soils having many fines (Fig. 2). A physical essence of this process is water accumulation, redistribution and freezing in soil pores due to the changing hydrothermal regime of subgrade.

With the increasing amount of air pores in soil, the thermal conductivity of soil decreases, and with the increasing humidity – increases. In this case the thermal conductivity becomes stronger because of two reasons:

- the contact between moist soil particles becomes better, and
- water pushes out from pores the air, the thermal conductivity of which is about twenty-two times lower than that of water.

With depth the maximum and minimum of soil temperature is late. This lateness is directly proportional to depth (Riehma *et al.* 2012). A significant effect on soil temperature is made by snow cover. Snow is a good thermal insulator therefore soil under the snow cover is less cooled and less frozen.

In clay and loam soils water contained in thinner capillaries freezes in a lower temperature.

On the other hand, humid soil is less freezing in, since during water freezing the heat of water crystallization is exuded which slows down a further drop in soil temperature.

The thickness of road pavement structure shall ensure not only sufficient resistance to loads but also resistance to frost. When road pavement structure layers contain water permeable materials or when subgrade is constantly or periodically moistened and is constructed from fines or clay soils a frost blanket course is laid (Tighe *et al.* 2007).

The major factors to determine the required frost resistance of subgrade and road pavement structure are as follows:

- the use of soils unsusceptible and less susceptible to frost for the upper part of subgrade situated in a freezing zone;
- assurance of the required elevation of road structure above the ground water or surface water level;
- laying of a frost blanket course layer the volume of materials of which does not change under the effect of frost and humidity; also the use of heat insulating materials which retain frost penetration into the underlying layers and decrease the depth of frozen ground in subgrade;
- laying of draining or insulating layers.

Soils, based on their frost susceptibility, are classified into frost unsusceptible soils, soils of low-average frost susceptibility and of high frost susceptibility. When frost unsusceptible soils, situated under the road pavement structure, lie above the soil of average and high frost susceptibility, a frost blanket course layer is not necessary. When the thickness of frost unsusceptible soil layer is lower and together with the road pavement structure the required frost resistance cannot be achieved, then the effect of the deeper-lying more frost susceptible soils on the lowest thickness of frost-resistant road pavement structure is determined. Frost resistance is achieved by changing soils, laying a frost blanket course or an overlay from frost unsusceptible materials.

In locations where road pavement structure is constructed on frost susceptible subgrade, when designing road pavement structure, the thickness of frost-resistant road pavement structure is determined. Calculations of frost-resistance of road pavement structure are carried out for the characteristic road sections or their groups having similar ground and hydrological conditions, similar humidification of subgrade, and the same road pavement structure.

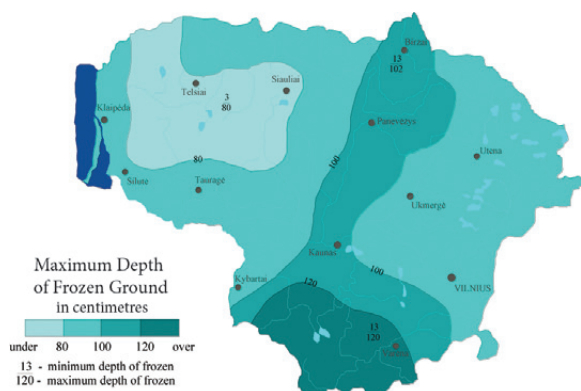


Fig. 1. Map of frozen ground

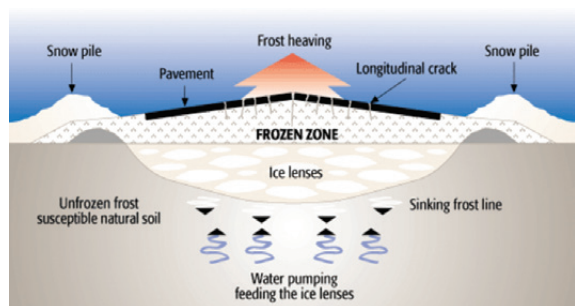


Fig. 2. Freezing of soil in road structure (Tighe *et al.* 2007)

The road pavement structure is frost resistant if the following condition is met (Fedotov, Pospelov 2009):

$$l_b \leq l_p \tag{1}$$

where l_b – the design heaving of subgrade during freezing, cm; l_p – the permissible heaving during freezing, cm.

The permissible heaving of road pavement structure l_p during freezing in winter is:

- for monolithic concrete pavement structure – 3 cm,
- for precast-element concrete pavement structure and asphalt pavement structure – 4 cm,
- for improved pavement structure – 6 cm, for un-surfaced pavement structure – 10 cm.

In locations where groundwater lies deep, the design heaving is determined by the formula:

$$l_b = k_i z_{fr.d.} \tag{2}$$

where $z_{fr.d.}$ – maximum frost depth, cm (determined according to the maps of frozen ground by adding 50 cm; the frost depth in road pavement structure is larger than in the surrounding locations due to snow cleaned from the road surface, and subgrade is laid above the ground surface); k_i – frost heaving coefficient (k) depending on the type of soil (i).

When the calculated frost heave exceeds the permissible one, the road pavement structure must be provided with an overlay from frost-resistant granular materials (sand, gravel, crushed stone) which prevents from heaving. This overlay as if replaces the certain layer of frozen soil where the heaving z_o is larger than the permissible one. Thickness of this overlay is determined by the formula:

$$[l] = \frac{z_{fr.d.} k_i}{100} - \frac{z_o k_i}{100} \tag{3}$$

The thermal conductivity of road pavement structure usually differs from the thermal conductivity of subgrade, therefore when describing road pavement structure resistance to frost, the equivalent thickness of the road pavement structure is determined according Fedotov *et al.* (2009):

$$H_{eq.th.} = h_1 \varepsilon_1 + h_2 \varepsilon_2 + \dots + h_n \varepsilon_n \tag{4}$$

where $H_{eq.th.}$ – equivalent thickness of the road pavement structure, cm; h_1, h_2, \dots, h_n – thickness of structural pavement layers, cm; $\varepsilon_1, \varepsilon_2, \dots, \varepsilon_n$ – thermal conductivity equivalents of the materials of structural pavement layers.

Under different local conditions, it is advisable due to constructional and technical reasons to use the same thicknesses of road pavement structure layers in longer as possible road sections.

The thickness of frost blanket course depends on frost susceptibility of subgrade soil. To describe the frost impact the Freezing Index (FI) is used (Tighe *et al.* 2007). The FI is described as the average sum of days with a negative temperature (Juknevičiūtė-Žilinskienė 2010):

$$FI = \sum_{i=1}^n (0 - T_i) \tag{5}$$

where FI – Freezing Index, °C; T_i – mean air temperature (T) of i day, °C; n – the days of a definite period with a negative mean air temperature; i – number of days with a negative temperature.

In every step of road design, construction and maintenance it is a necessity to take into consideration climatic factors. Distribution of climatic factors is most distinctly represented by the maps of climatic distribution of regions.

4. Climatic distribution of regions of Lithuania from the point of view of road construction

To reduce a negative impact of severe weather conditions on roads and traffic, Lithuania, like many other countries, implements modern technologies, allowing to objectively assessing meteorological conditions of roads. The aim of technologies is to get ready in advance for unfavourable phenomena or to warn the drivers. The basis of these technologies is RWIS. RWIS is a system of technologies and decision-making which uses historical and real-time data of road and weather conditions. RWIS helps to facilitate road maintenance in a cold period of the year, and the data recorded and stored by the RWIS meteorological stations is invaluable seeking for their practice use in road construction. The main task of RWIS is to determine the distribution of frozen ground and of negative air temperature within the territory of Lithuania and to define their interrelationship.

Measurements of various climatic parameters in RWIS are carried out since 1999. For storing and processing a large amount of data the Dept of Road of Vilnius Gediminas Technical University has developed a special RWIS database sub-program within the environment of the database management system MS Access. The real-time data from RWIS stations are automatically registered every 30 min (in a warm period) and every 12 min (in a cold period), 7 days in a week and 24 hours per day. RWIS records the following parameters:

- air temperature;
- road pavement surface temperature;
- temperature of road pavement structure at a depth of 7 cm, 20 cm, 50 cm, 80 cm, 110 cm and 130 cm;
- wind direction and velocity;
- type and amount of precipitation.

The depth of frost is calculated by using sensors of fixed depth (Fig. 3).

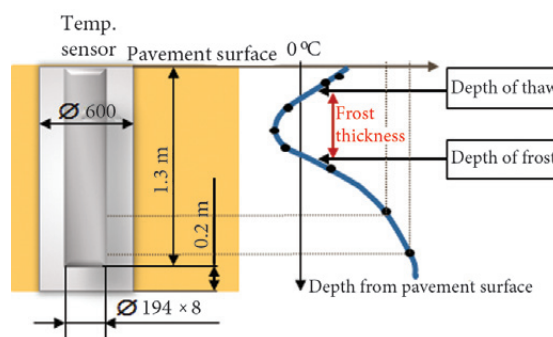


Fig. 3. Measurement of the frost depth

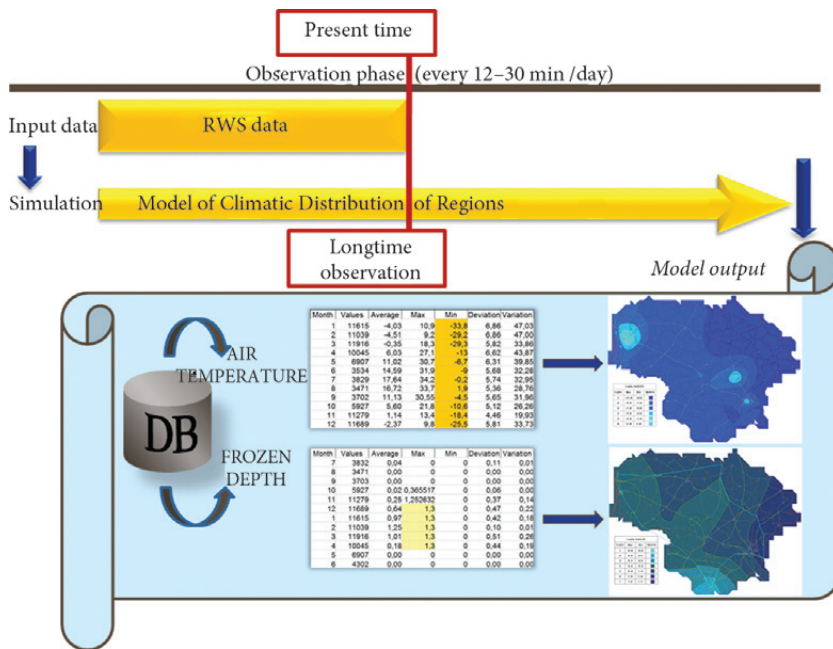


Fig. 4. Model of climatic distribution of regions

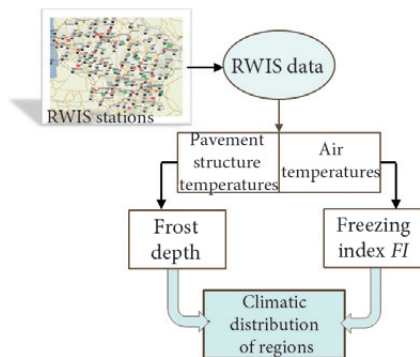


Fig. 5. The steps of frost depth calculation using the complete model

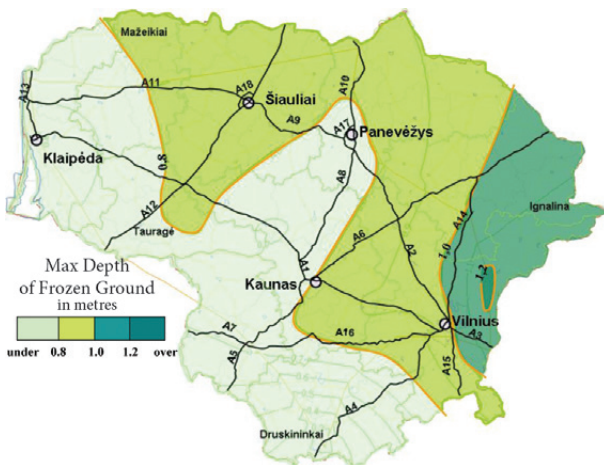


Fig. 6. Distribution of the max depth of frozen ground in the territory of Lithuania based on RWIS data (Juknevičiūtė-Žilinskienė 2010)

Currently, the database contains more than 5 mln data and is equipped with the data filtration function with the help of which data that does not meet the set limits is treated as errors and is eliminated during the initial data processing. Having supplemented data of meteorological stations with their coordinates, re-calculated from ellipsoidal to planar, and having processed them with AutoCad Civil 3D, the subject maps are compiled representing the distribution of values of the selected parameter within the territory of Lithuania (Figs 4–5).

Road pavement structure is highly affected by a negative air temperature. To calculate frost intensity the Eq (5) is used.

When compiling subject maps the *Kriging* interpolation method was chosen, the main feature of which is the estimation of values of unknown points by a mathematical variogram model (parametric function used to determine correlation between the adjacent values) (Pokhrela *et al.* 2013; Wua, Lib 2013; Zhang *et al.* 2015).

Based on the results obtained the maps of frost impact and of frozen ground were compiled.

When designing road pavement structure it is very important to know the depth of frozen ground and how it is distributed within the territory of Lithuania. Having analysed RWIS data (1999–2013), the 1.3 m depth of frozen ground was recorded at least once in almost all meteorological stations (except the Southern part – up to 1.08 m). Using the *Kriging* interpolation method for the determination of maximum depth of frozen ground, the territory of Lithuania was divided into four zones where the depth of frozen ground is up to 0.8 m, from 0.8 to 1.0 m, from 1.0 to 1.2 m and more than 1.2 m (Fig. 6).

The average depth of frozen ground from 0.2 m to 0.8 m moves from the South to the West comprising part of the middle Lithuania, the depth from 0.8 m to 1.0 m

spreads from the North to the East. The deepest of frozen ground (1.0–1.3 m) prevail in the Eastern Lithuania.

If the map of frozen ground (Fig. 6), compiled from RWIS data, is compared with the map of Lithuanian Hydrometeorological Service (Fig. 1), the difference is obvious. One of the reasons: subgrade soils usually do not meet the properties of local soils since they are mixed during a technological process when laying road subgrade. The same road may represent various subgrade soils with various characteristics. The frost depth in the roads of Lithuania is caused by snow cleaning, since when snow is cleaned the road pavement structure freezes deeper.

Dependency of the depth of freezing is expressed by many criteria, however, one of the most important of them – a negative air temperature and its stability. The impact of negative temperature to the road pavement structure is minimized by the thickness of frost blanket course. The thickness of this layer depends on frost susceptibility of subgrade soil.

The thickness of frost-resistant pavement structure shall ensure distribution of traffic loads and protect road pavement structure from deformations caused by freezing/thawing impacts. In case if no special surveys were carried out or there is no experience in determining the minimum thickness of frost-resistant road pavement structure, the thickness of any class of road pavement structure is calculated according to the *Road Technical Regulation of Lithuania KTR 1.01:2008 Automobile Roads* based on:

- frost susceptibility of subgrade soil characterized by subgrade soil classification (*Building Regulations of Lithuania ST 188710638.06:2004 Installation of Automobile Road Subgrade*);
- correction of the frost blanked course thickness (*KPT SDK 07:2008 Design Regulations for the Standardized Road Pavement Structures*).

Under different local conditions, it is advisable due to constructional and technical reasons to use the same thicknesses of road pavement structure layers in longer as possible road sections. Such methods of determining thickness of frost-resistant road pavement structure are not valid for road pavement structures where due to frost impact the permissible gross vehicle weight is subjected to certain limitations.

When designing a new road and calculating the minimum thickness of frost-resistant road pavement structure, the *KPT SDK 07:2008* recommend to take into consideration the vertical alignment of road, road pavement gradients, zone of shoulders and road pavement structure service life. *KPT SDK 07:2008* require also consider the frost impact on road pavement structure which shall be assessed based on long-term experience and other local data. At present, the thickness of frost blanket course is corrected by value calculating an algebraic sum of the values of the certain (local) condition symbols *A*, *B* and *C* (Eq 6):

$$\begin{aligned} & \text{Increase or decrease of the thickness} \\ & \text{of the road pavement structure} = A + B + C; \quad (6) \end{aligned}$$

where *A* – level of the top of the road pavement structure; *B* – water impact, *C* – zone at the pavement.

Between all the included values, under severe climate of Lithuania, it is very important to assess the frost impact which has not been included yet. Having a long-term experience of storing the necessary climatic data it is advisable to calculate the impact of frost.

With the help of multi-year RWIS data (1999–2013) the *FI* (Eq (5)) was calculated and the map was compiled (Fig. 7). According to the *FI* the territory of Lithuania is divided into three more distinct frost impact zones.

The frost impact zone I represents the area with the freezing index up to –400 °C (Westernmost part of Lithuania); the frost impact zone II with the freezing index from –400 °C to –500 °C, and with more than –500 °C is the frost impact zone III. Based on the map of frost impact zones (Fig. 7) a correction of the thickness of road pavement structure is suggested (Table).

When determining thickness of frost-resistant road pavement structure in order to assess the impact of frost on road pavement structure, it is recommended to enter the frost impact (*D*) into the Eq (6):

$$\begin{aligned} & \text{Increase or decrease of the thickness} \\ & \text{of the road pavement structure} = A + B + C + D. \quad (7) \end{aligned}$$

D is selected from the map of frost impact (Fig. 7). The maps of frost impact and of frozen ground the frozen ground is deeper show evident similarity of distribution of zones: in locations with a longer period of negative air temperature the therefore, the criterion *D* can be also selected from the map of frozen ground.

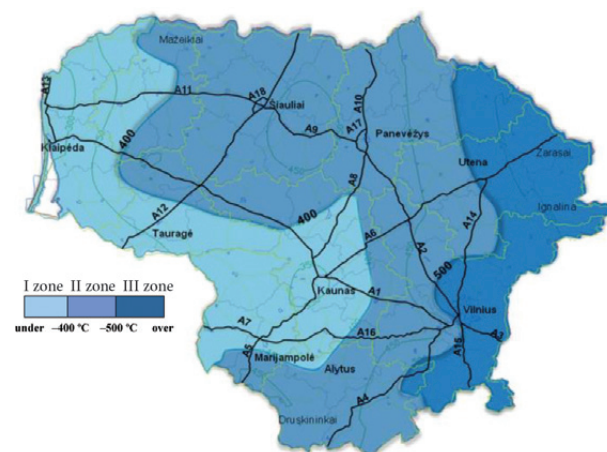


Fig. 7. Map of frost impact

Table. Correction of the thickness of road pavement structure

Certain (local) condition	Zone	Thickness
Frost impact	I	±0 cm
	II	+5 cm
	III	+10 cm

5. Conclusions and recommendations

1. Having made a review of territorial dividing methods, it could be stated that dividing, dividing methods of other countries have their own particularity due to specific climatic features of each country and different conditions of weather regime. Road organizations and services of many countries, when solving road construction tasks, refer to the maps compiled by meteorological services from the multi-year data, and data recorded by Road Weather Information System is modelled in various ways and used for weather forecasts. However, historical data collected for many years gives large possibilities for compiling climatic maps intended namely for the road construction.

2. According to the currently valid Lithuanian standards for the determination of minimum thickness of frost-resistant road pavement structure, it is recommended to take into consideration the vertical alignment of road, road pavement gradients, zone of shoulders, road pavement structure service life, and frost impact. The problem is that the standards do not suggest methods to determine the frost impact therefore it was necessary to compile the map of frost impact distribution.

3. The compiled map of frost impact gives three frost impact zones based on which thickness of the frost blanket course is corrected. In the frost impact zone I to increase thickness of the frost blanket course by 0 cm, in the frost impact zone II – by 5 cm, in the frost impact zone III – by 10 cm.

4. Since the depth of frozen ground is also important factor for the design and reconstruction of road pavement structure, the map of the distribution of the depth of frozen ground was compiled. If the map of frozen ground is compared to the map of frost impact, a similar distribution of zones is evident: in areas with a longer period of the negative air temperature the frozen ground is respectively deeper. Therefore, both of the maps enable to correct the thickness of frost blanket course in road pavement structure.

5. A topical issue for road construction is still related to the effect of global warming on the distribution of negative temperature and the depth of frozen ground. In the nearest future it would be advisable to compile the same maps every five years, to compare them and to predict how the global warming affects the change of climatic regions.

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