Mapping of frost penetration depth for highways in Kazakhstan

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ABSTRACT

Paper shows short information regarding meteorological stations for weather observation in Kazakhstan. Data are represented regarding minimum values of air temperature for the period from 2006 to 2011, obtained by data processing of 40 meteorological stations of Kazakhstan. The results are represented in the form of climatic map of the Republic for minimum air temperature values for the specific period of time. Adjusted map is represented regarding soil frosting depth throughout Kazakhstan, constructed on the basis of frosting depth data, determined by calculation according to empiric formula.

Keywords: climatic map; frosting depth; empirical dependencies; minimum air temperature

1 INTRODUCTION

One of the important characteristics, which is required to consider as closely as possible for provision of long-term normal operation of highways in the regions with cold winter climate, is a depth of frost penetration. The first separate map for depth of frost penetration of highways in Kazakhstan was developed by B.B. Teltayev and D.K. Sakanov in 2004 (R RK 2004), which further was included into the main state standards for designing of pavement structures (CN RK 2005; CN RK 2007). This map was developed on the basis of limited data regarding actual depths of frost penetration for highways and air temperatures and temperatures in points of pavements and subgrade.

For the purpose long-term monitoring for temperature and moisture variations in points of pavement and subgrade of highways, in different climatic conditions in 2010, 3 special measurement sets, equipped by temperature and moisture sensors, were installed near Astana city (on highway sections with asphalt concrete and cement concrete pavements). Then in 2013 the similar sets were installed near Oskemen, Almaty, Shymkent, Atyrau cities (Teltayev et al. 2015; Teltaev and Suppes 2017a; Teltaev and Suppes 2017b; Teltaev and Suppes 2017c; Teltayev and Aitbayev 2015).

As distinct from meteorological stations where only air temperature and precipitation amount are measured, the measurement sets determine data regarding air temperature, temperature and moisture in points of pavement structure, which is very important for approbation of the developed mathematical model.

However, equipping and maintaining of measurement sets, organizing of recording for the measured data will require investment of significant material and time expenses, which does not allow covering of the whole territory of the Republic of Kazakhstan with them. Due to the above mathematical modeling method is used for determination of non-stationary temperature field in pavement structures, the awareness about which is very important for a highway designing.

Mathematical modeling method is used all over the world for determination of non-stationary field in pavement and subgrade of highways, and at present there are different variants for it (Kovalev 1966). All of them as the main source information use data regarding air temperature variations. Then the authors act individually for determination of temperature for pavement surface, which is very important for identifying of boundary conditions. Mainly, all of them first determine regularities for solar radiation level variation for a day and during the season, which obviously depend on geographical latitude of the area. Then in one case the average wind speed is considered on the territory in a specific season, and in another case empiric regularity of convective heat exchange on the pavement surface is used and so on.

In this paper the data are shown regarding maximum and minimum air temperature values for the period from 2006 to 2011, obtained by processing of data from 40 meteorological stations of Kazakhstan. The results will be represented in the form of climatic maps of the Republic for temperature extremes for the specific time period. Adjusted map is shown for the depth of frost penetration into soil throughout Kazakhstan, constructed on the basis of data regarding frost penetration depth, obtained by calculation under empiric formula, found in Kazakhstan Highway Research Institute.

2 FOREIGN EXPERIENCE FOR MAPPING OF A CLIMATE

Many countries analyze the information regarding weather and weather forecast during designing, construction and maintenance of highways.

There are different principles for climate classification (Chen D and Chen H 2013; Peel et al. 2007). Climatically the regions are identified not only by individual meteorological data, but also by their combinations. Each country has specific climate, which is characteristic only for this specific country, for example, the most actual data for Great Britain are air temperature, precipitation and wind. Sweden (Eriksson and Lindqvist 2002) pays a great attention to the information regarding peculiarities of climatic conditions in winter, road surface temperature below or equal to 0°C. Road organizations of many countries use the maps, prepared by meteorological agencies, based on multiyear data of World Meteorological Organization (https://www.wmo.int/pages/prog/lsp/meteoterm_wmo_ru.html).

Some countries (Great Britain, Scandinavian countries) created websites, where the climatic collections of maps are given in accordance with the submitted enquiry (https://www.weather-gb.com/ru). Enquiries can show the preferred period (month, quarter, year, etc.) or preferred climatic factor (air temperature, precipitation and wind). This material is available in Internet for everybody.

The most attention is paid to winter season, when there are especially severe weather conditions. For this purpose the territory of Canada is additionally divided into 6 regions according to the average maximum snow depth (1979-1997, https://open.canada.ca/data/en/dataset/d90ddf8f-8893-11e0-bc5e-6cf049291510)).

Climatic conditions are modeled in many countries by different methods and they are used for the forecast of weather conditions; however, historical data, collected for many years, provide more chances for preparing of climatic collections of maps, designed specifically for road construction (https://mesonet.agron.iastate.edu/request/rwis/fe.phtml).

3 THE EXISTING METHOD FOR DETERMINATION OF FROST PENETRATION DEPTH IN KAZAKHSTAN

It is clear that it is advisable to have a map of frost penetration depth for highways, constructed on the basis of multiyear experimental observations, covering all the variety of climatic peculiarities of the regions in the republic.

Performing of experimental works in such volume requires a lot of material and time inputs. Due to the above only the results of available experimental data, obtained by temperature sensors, installed on "Astana-Burabai", "Almaty-Bishkek", "Aktobe-Atyrau-Astrakhan" and "Pavlodar-Sharbakty" highways were used for construction of maps for frost penetration depth in Kazakhstan. Measurement periods, characteristics of cold season and frost penetration depth values for the above mentioned highways are shown in Table 1.

Correlation relationship between the amount of negative temperatures and depth of maximum frost penetration of a highway during winter season, constructed with the use of data from Table 1, is represented in Figure 1. As it is seen, there is a close correlation relationship between the amount of negative temperatures and frost penetration depth, about which a high value of validity coefficient R2 = 0.9157 certifies.

Such dependence is described in the following power function:

$$h_{fr} = 2.647 \cdot \theta^{0.6} \quad (1)$$

where h_{fr} is maximum frost penetration depth of a highway, cm;

Θ is the amount of negative air temperatures during the whole winter season, degrees · day.

Table 1. Characteristics of winter season and frosting depth.

Highway	Frosting period, years	Number of days with negative temperature, day	Amount of negative tempera-tures Θ, degrees ·days	Maxi-mum fros-ting depth, cm
Almaty-Bishkek	2004-2005	71	555.8	105
	2013-2014	93	903.3	150
Aktobe-Atyrau-Astrakhan	2013-2014	84	620	147
Astana-Burabai	2010-2011	133	1669.2	232
Pavlodar-Sharbakty	2004-2005	144	1844.1	239

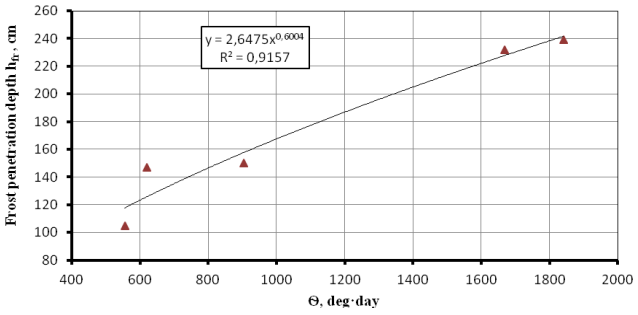

Fig. 1. Correlation relationship between amount of negative temperatures and maximum frosting depth

In 2012 Kazakhstan Highway Research Institute received information regarding air temperature for data of 40 meteorological stations for 20 years with the assistance of the former Ministry of Transport and

Communications and its Committee of Roads. Processing of these data allowed obtaining of values for frost penetration of highways, calculated under formula (1).

Adjusted map for Kazakhstan, constructed with the use of frost penetration depth values, obtained by such method, is shown in Figure 2. As it is seen, isolines of frost penetration depths are of sub-parallel nature and they have smooth form. Minimum frost penetration depth in the south of the country is equal to 40 cm approximately, and maximum one in the north is about 280 cm. Growth rate for frost penetration depth gradually decreases from south-western part to northern-eastern one.

It turned out that there are also reliable correlation dependences between frost penetration depth and multiyear average temperature, frost penetration depth and the number of days with negative temperature. Relevant correlation dependences and validity coefficients are represented below:

$$h_{fr} = -8.45 \cdot T_{\min} - 121.7, \quad R^2 = 0.868 \qquad (2)$$

$$h_{fr} = 1.755 \cdot t_{\theta} - 17.01, \quad R^2 = 0.973 \qquad (3)$$

where T_{min} is multiyear average minimum air temperature, ºC

t_{θ} is number of days with negative temperature, day.

The required data for calculations under formula (2) can be derived from climatic map, constructed on the basis of data from 40 meteorological stations by software SURFER. Figure 3 shows a map of statistically average values of minimum air temperatures for 2006-2011.

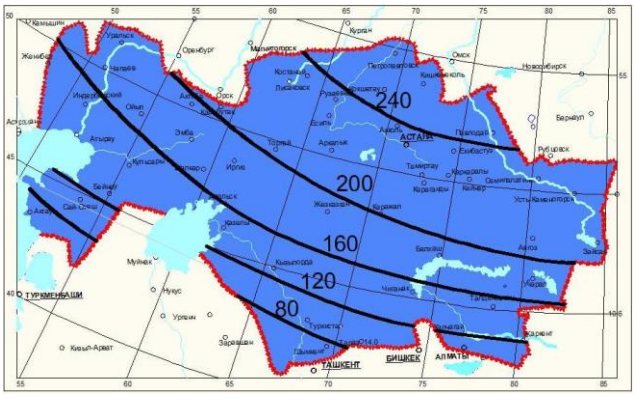

Fig. 2. Adjusted map for frosting depth of highway of Kazakhstan

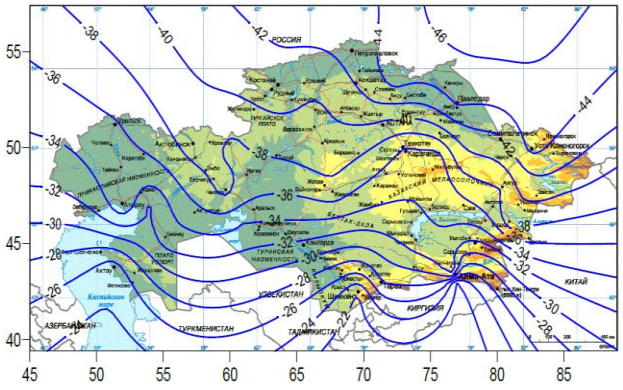

Fig. 3. Map for minimum air temperatures

4 CONCLUSION

The performed brief review of works for preparing of maps on frost penetration allows drawing the following conclusions:

- available experimental data regarding temperature and moisture variations of road structure in time cover only minor part of the territory of the republic. Stationary experimental points, located in the southernmost (Turkestan), in the south-east (Almaty), in the east (Ust-Kamenogorsk), in the west (Atyrau) of the republic and in central Kazakhstan (Astana), cannot cover all the variety of climatic peculiarities for all the regions of the republic;

- empiric relations, based on data regarding air temperature variations, can be used during preparing of maps for frost penetration depths of the subgrade of a highway.

From all has been said it follows that together with the expected increase for the number of experimental points for the research of temperature and moisture variations of road structure in time it is required to develop widely the works for the research of processes of non-stationary temperature field and moisture regime variations in road structure by mathematical modeling methods.

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