Frost susceptibility of soil ground and its impact in Kazakhstan

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ABSTRACT

Construction in Kazakhstan is done on the soil ground which usually consist of loam and clay. Also the territory is totally seasonally frozen. However, there is not any permanent frozen layers on territory. The temperature is seasonally changing from negative to positive degree during calendar year. The temperature condition is harsh, therefore could reach -45 ºC in winter and +45 ºC in summer seasons. The soil types is different in territory of Kazakhstan because of the large size and different landscape (Shakhmov and Zhussupbekov 2015). The territory of Kazakhstan by type of landscape refers more to the flat type. Although in the East and South is a mountain type of landscape. Basically there are clay and loamy soils, which are quite susceptible to frost heaving. One of the main parameters for determining frost heaving is due to the physical-mechanical properties of soil bases. This article presents the indices of freezing, as well as the physical-mechanical properties of soil grounds of a construction object.

Keywords: frozen soil; soil ground; Kazakhstan, frost depth, frost heaving

1 INTRODUCTION

Improper laying of the base of the foundations can lead to loss of stability or to large uneven deformations of the latter. There are many examples in construction when it led to disappointing results in Kazakhstan, for example, such construction projects as: The Besoba residential complex in Karaganda, the Astana-Karaganda highway built and commissioned in 2017, and others. The above-mentioned construction sites had very large damage and some were completely in disrepair with subsequent collapse (Zhussupbekov et al.2017).

But there are so many other examples, where there were large deformations which did not entail an accident rate of the building objects themselves. Despite this, they created and creating problems related to the condition and operation of these construction projects. To determine the depth of the foundations bottom in Kazakhstan used depth of frost penetration and the groundwater level, after that designing of foundation depth. Further in this article we will consider such a parameter as the depth of frost penetration, which is one of the frost-hazardous properties of the soil ground.

Freezing process of soil ground one of the main source of damageable effects to foundations of buildings. So many research-scientific works was done related to freezing problems of soil on the last century. Pioneer of the research Beskow, Taber open and wrote that freezing of soil is accompanied by molar volume expansion with freezing of water depend of subzero temperature, with little contribution from migration of water inside of soil. His experiments furthermore illustrate development of ice lenses inside the soil column when it is frozen from upside to downside establishing a temperature gradient (Zhussupbekov et al.2017).

Another one of the main factor of frost susceptibility is the freezing force. This factor sometimes plays a very important role in designing of foundations on frost susceptible soil. Many research works illustrate that the freezing force could reach more than 400 kPa which is enough for uplifting light loading foundations. Freezing force influences to foundation sides by lateral and normal directions (Zhussupbekov et al.2018).

There are three levels of assessment of heaving soils, in accordance with the Technical Committee on frozen soils of the International Society for Soil Mechanics and Foundation Engineering (ISSMFE) (Shakhmov et al.2018).

I Level – a rough estimate of grain-size distribution which allows to allocate a known non heaving soils. Potentially heaving soils require more detailed analysis.

II Level – assessment of the average accuracy on several factors such as sieve analysis, plasticity index, height of the capillary rise and other. Soils are classified by degree of frost heaving.

III Level - exactly estimation by the results freezing specimens in special devices or according to stationary supervision in the field conditions.

2 FROST DEPTH DETERMINATION METHODS USED IN CONSTRUCTION

Freezing of soil bases is, as mentioned above, an important indicator in the design and determination of the depth of the foundations. In this regard, the ground base is divided into seasonally frozen and permafrost. Where, a positive average annual surface temperature is a condition for seasonally frozen soils, and a negative average annual temperature for the existence of permafrost soils. Properties of thermal conductivity of soils is a very important parameter in determining the frozen depth. The first who investigated the problem of thermal conductivity, taking into account the allocation of thermal phase transitions at the freezing point were made in 1831 by J. lame and P. Clayperon. Calculating the depth of freezing for the simplest case fulfilled L. Zealotry in 1862, an equation jointly developed by the Austrian mathematician, J. Stefan is called "the formula of Stephen". At the setting of thermophysical characteristics and temperature conditions on the surface has the following form Karlov V.D. (Karlov et al.2007):

$$d_{f(t)} = \sqrt{\frac{2\lambda_f |T_0| t}{Q_\phi}} \tag{1}$$

where, λ_f - coefficient of thermal conductivity of frozen soil, T_0 - temperature of soil on the surface, Q_ϕ - heat of phase transformations of water into ice.

The amount $|T_0|t = F_{f(t)}$ is named as sum of the frozen degree or freezing index, if its melting it is named as sum of heat degree or melting index $F_{th(t)}$. "The formula of Stephen" is got from point that $T_0 = const$, but it could be used if T_0 is not constant. Therefore, upper equation is changing to next modified version:

$$d_f = \sqrt{\frac{2\lambda_f F_{f(t)}}{Q_\phi}} \tag{2}$$

If there is a heat insulation layer with constant thermal resistance R_n and temperature on surface of heat insulation layer T_n and:

$$d_{f(t)} = \sqrt{\frac{2\lambda_f |T_n|}{Q_\phi} + S^2} - S \tag{3}$$

Where, $S = \lambda_f h_n / \lambda_n$- given thickness of the heat insulation layer, λ_f, h_n- heat conductivity and heat insulation thickness.

Scientist L. Leibenson create his own method for determination frost depth by next equation:

$$d_f = \alpha\sqrt{t} \tag{4}$$

Where, α - generalized characteristic of freezing rate, м/с$^{1/2}$; t - time during the period of freezing.

The main equation for calculating freezing depth regarding to Kazakhstan normative is next one:

$$d_{fn} = d_o\sqrt{M_t} \tag{5}$$

Where, λ_f- coefficient of thermal conductivity of frozen soil, T_0 - the temperature of the soil on the surface, Q_ϕ - heat of phase transformations of water into ice.

This type of equation is used usually in foundation design in construction. Further, this equation provided for calculation of frost depth (Shakhmov et al. 2016).

3 CLIMATIC DATA AND PARAMETERS FOR FROST DEPTH DETERMINATION

Frost susceptibility of soil ground one of the main group of parameters which is very important for determination and construction in the appropriate depth of the bottom of foundation. The most important thing for evaluate freezing process and its influence to soil ground of constructions is climatic data. So, therefore it is presented climatic data by the graph of climatic data from 2007 to 2017.

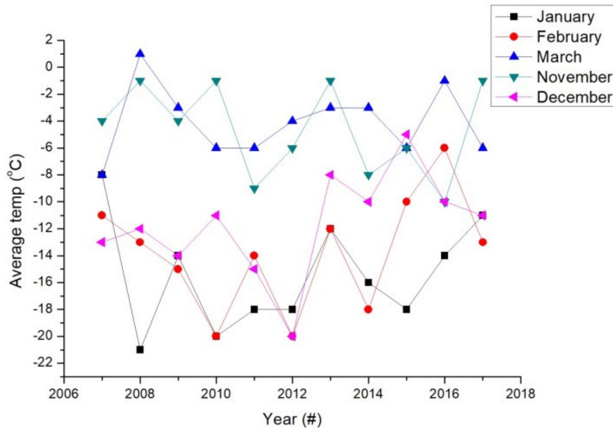

Fig. 1. Climatic data by average month temperature variations of Akmola region from 2007 to 2017

The graphs of the above shows that 2012 was the coldest year, while 2016 is the warmest year comparing to each other. It is visible that temperature in winter time is increasing generally especially last 4 years, although the trend is changing to increasing or decreasing each year.

Soil properties like grain size distribution is very important for frost susceptibility determination.

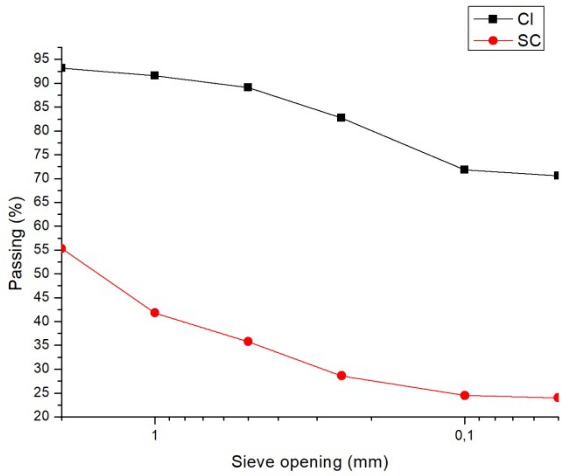

Fig. 2. Grain size distribution curve for soil ground in construction of highway in Akmola region

Table 1. Physical properties of soil samples

Location of soil sampling	Liquid limit,%	Plastic limit, %	Plastic index, %	Soil type by GOST 25100-95	Soil type by ASTM and ASHTO
19km	25,4	15	10,4	Silty light loam	A6(clayey soil), CL
76 km	34,8	18,7	16,1	Sandy heavy loam	A4(silty soil), SC

It is presented calculated frozen depth for different type of the soils, which is depend on sum of average negative temperatures of cold months.

Table 2. Frozen depth by years

year	M_t, ºC	d_{fn}, m(clay and clay loam)	d_{fn}, m (loam, fine sand, silty sand)	d_{fn}, m (gravelly sand, coarse and middle sand)	d_{fn}, м (coarse fragmented soil)
2001	45,2	1,55	1,88	2,02	2,29
2002	32,2	1,31	1,59	1,70	1,93
2003	54,4	1,70	2,07	2,21	2,51
2004	46,1	1,56	1,90	2,04	2,31
2005	49,4	1,62	1,97	2,11	2,39
2006	45,5	1,55	1,89	2,02	2,29
2007	45,7	1,55	1,89	2,03	2,30
2008	47,4	1,58	1,93	2,07	2,34
2009	52,0	1,66	2,02	2,16	2,45
2010	58,7	1,76	2,15	2,30	2,60
2011	63,3	1,83	2,23	2,39	2,71
2012	61,5	1,80	2,20	2,35	2,67
2013	34,0	1,34	1,63	1,75	1,98
2014	37,0	1,40	1,70	1,82	2,07
2015	37,0	1,40	1,70	1,82	2,07
2016	38,5	1,43	1,74	1,86	2,11
2017	45,0	1,54	1,88	2,01	2,28

M_t- sum of the absolute values of the average monthly negative air temperature during the winter in the area under consideration.

Also, for a better visual assessment and analysis of the depth of freezing, a graph is presented in the form of a figure below.

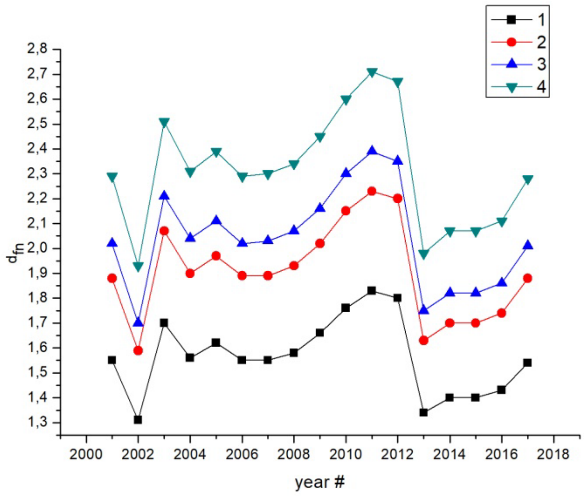

Fig. 3. Graphs on the depth of freezing, depending on the type of soil (1- clay loam and clay, 2-sandy loam, fine and silty sands, 3- gravelly sands, coarse and medium-sized, 4 - coarse fragmented soils)

There are found that freezing depth is 1,56m for CL soil and 1,90m for SC soil. This data is used during construction and design of highway project in Akmola region.

3 CONCLUSION

The obtained results on the depth of freezing and the analysis shows how the depth of freezing varies from year to year. Climatic data in the form of the average monthly temperature of the cold period, respectively, show a cyclic change in the course of ten years, and therefore the depth of freezing also varies. It is proposed to take into account the depth of foundations in heaving soils to avoid loss of stability.

REFERENCES

Shakhmov Zh, Zhussupbekov A. (2015). Frost susceptibility of soil and in-situ monitoring of frost depth in construction. The 15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering, Fukuoka, Japan, 558.

Zhussupbekov A, Shakhmov Zh., Tleulenova G. (2017). Geotechnical problems on freezing ground soil and experimental investigation in Kazakhstan. Sciences in Cold and Arid Regions, 9(3), 331-334.

Zhussupbekov A., Shakhmov Zh, Lukpanov R., Tleulenova G. (2017). Frost depth monitoring of pavement and evaluation of frost susceptibility at soil ground of Kazakhstan. 19th International Conference on Soil Mechanics and Geotechnical Engineering. Seoul, Republic of Korea, 1455-1458.

Zhussupbekov A., Shin E., Shakhmov Zh., Tleulenova G. (2018). Experimental study of model pile foundations in seasonally freezing soil ground. International Journal Of Geomate, 15(51), 85-90.

Shakhmov Zh., Lukpanov R., Tleulenova G., Mineev N., Tulebekova A. (2018). Comparison of experimental data of model piles in normal and seasonally freezing soil. Proc. of the 11th International Conference on Geosynthetics,

«Geosynthetics: Innovative Solutions for Sustainable Development», Seoul, Republic of Korea, PP-A-12

Karlov, V.D., (2007). Ground and foundations on seasonal-freezing heaving soil, SPbGASU, Saint-Petersburg, Russia.

Shakhmov, Z., Tleubayeva, A., Smagulova, E., Utepbergenova, L., Togabayev, Y., Bazarbayev, D. (2016). Analyzing of soil ground to frost heaving of structures. Proc. of the 8th Asian Young Geotechnical Engineers Conference, Astana, Kazakhstan, 47-50.