International Journal of GEOMATE, July., 2021, Vol.21, Issue 83, pp.72-78
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2021.83.j2115
Geotechnique, Construction Materials and Environment

RELIABILITY CRITERION FOR CALCULATION OF THE OPTIMUM DRIVING SPEED ON ROAD IN WINTER

Dauren Yessentay[1], Akmaral Sagybekova[1], *Assel Tulebekova[2] and Tymarkul Muzdybayeva[3]

[1]L.B. Goncharov Kazakh Automobile and Road Institute, Almaty, Kazakhstan
[2]L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan
[3]Saken Seifullin Kazakh Agrotechnical University, Nur-Sultan, Kazakhstan

*Corresponding Author, Received: 14 Feb.2021, Revised: 01 Mar. 2021, Accepted: 28 Mar. 2021

ABSTRACT: The problem of eliminating winter slips on paved roads is a topical issue today. The paper analyzes the results of tests using traditional (chloride) and non-traditional chemical reagents and their influence on the strength properties of cement concrete. In general, the formation of slipperiness on the surface of cement concrete pavements does not differ from asphalt concrete, because cement concrete can have a high moisture capacity. The pores of cement concrete readily allow moisture to penetrate, and with decreasing air temperature significant ice formation can occur in the pavement. This kind of slipperiness is very dangerous. In appearance they look like a dry coating, in fact, they penetrate deeply into the body of the coatings. Not every chemical reagent can act positively to reduce moisture. And also this process in climatic zones with a sharply continental climate especially exacerbates the likelihood of peeling of cement stone, followed by crumbling of concrete (peeling) and loss of strength due to the low stability of this material.

Keywords: Road surface, Ice formation, Strength of concrete, Chemical reagent

1. INTRODUCTION

Currently, the construction of major highways with a hard surface type has significantly increased. In the process of operation of these highways, the requirements for maintenance and road safety increase.

Unfavorable conditions especially affect the movement of cars, which often occur during the winter, when traffic on the roads becomes more difficult with the appearance of various types of snow and ice formations. It is known that chemical reagents are widely used in almost all countries to eliminate such formations. For roads with asphalt concrete pavement, chemical reagents do not pose a significant danger, since bitumen-containing materials practically do not pass liquid chemical solutions into the body of the road surface. In contrast, the Portland cement-concrete coating is easily exposed to moisture absorption. Thus, chemical solutions easily penetrate into the body of the cement concrete and contribute to damage.

This process in climatic zones with a sharply continental climate especially exacerbates the likelihood of peeling of cement stone with subsequent painting of concrete (peeling) and loss of strength due to the low stability of this material [1-9].

The optimal concentration of chemical deicing solutions that do not affect the strength properties (peeling, painting) of cement concrete has been established by experimental methods [10-13]. The investigation was to determine the effect of deicing chemicals on the destruction of cement concrete and the selection of the chemical reagent and its optimal concentration for roads with cement concrete coating, depending on natural and climatic conditions. To study the above factors, the test was carried out in two stages: first, a visual assessment of the destruction of concrete (peeling, painting), second, determination of the strength loss of cement-concrete samples from exposure to chemical solutions at different concentrations.

2. RESEARCH SIGNIFICANCE

There are many ways to prevention winter slips on roads: thermal, friction, mechanical, chemical, and combined. Currently, the chemical method is considered to be the most effective. The study presented the composition of the proposed chemical reagent – technical urea which effectively reduces the adhesive forces between ice formations and cement concrete pavement. The effect of using a de-icing chemical reagent will improve the road performance of the pavement in winter, lead to economic, environmental, and safety benefits for road users.

3. INVESTIGATIONS

The process of performing tests was determination of the strength properties of cement concrete under the influence of various types of reagent when distributing them as deicing reagents and the choice of their optimal concentration.

Various types of reagents were used for the experiment, including non-hygroscopic ones, technical urea and ammonium acetate.

The selection of reagents was carried out in accordance with [14,15]. In the theoretical justification was considered two cases: the first, the interaction of particles of a solute with a solvent, the process of solvation; the second, with water. Here, the process is considered as hydration between water and snow-ice formation. The dissolution of solid sodium chloride (or other chemical materials) in water can be divided into the following stages: the destruction of the ice crystal from the action of chloride solutions, sodium chloride can be divided into the following free ions:

$NaCl \rightarrow Na^+ + Cl^-$

a) hydration of these ions (Eq. (1,2)):

$$Na^+ + pH_2O \rightarrow Na^+(H_2O)_p \text{ (solution)}; \quad (1)$$

$$Cl^- + qH_2O \rightarrow Cl^-(H_2O)_q \text{ (solution)} \quad (2)$$

b) the resulting expression (Eq. (3)):

$$NaCl \text{ (sol.)} + (p+q)\, H_2O \rightarrow Na^+(H_2O)_p \text{ (solution)} + Cl^-(H_2O)_q \text{ (solution)} \quad (3)$$

The deicing solution has a freezing point of below 0° C. Moreover, its minimum value depends on heat transfer upon the entry of chemicals with snow-ice formations and its concentration. Ice melting is a complex physical and mechanical process. The chemical formula of water and ice H_2O can be represented as follows:

H — O — H.

Here, a dash means a bond between atoms. The formula of water shows that in its molecule both hydrogen atoms are bonded to an oxygen atom, but not bonded to one another.

The oxygen atom is not enough to complete the outer layer of two electrons. It has the following structure: that is, six electrons in the outer orbit, and for the stability of the valence shell there must be eight electrons, so it needs two electrons, which in the oxygen water molecule generalize their outer orbit with two hydrogen atoms (each hydrogen atom has one electron), covalent bond.

As a result of the formation of covalent bonds, each pair e^- ions (one from oxygen and one from hydrogen) now belong to both hydrogen and oxygen.

Covalent bonding is the bonding of atoms through electron pairs, and this bonding is very strong. Not only identical atoms but also equal atoms, such as in water, can bind by covalent bonds. These bonds that bind molecules do not break even during the “vapor – water – ice” phase transitions. In particular, the water molecule has a “corner” shape, hydrogen atoms are attached to the oxygen atom at an angle of 105 °.

One of the main tasks of practical use of chemical solutions in the fight against slipperiness is to reduce the freezing force of the snow-ice formation, changing its molecular structure (weakening of the hardness, reducing the density, etc.).

This is due to the duration of the reagent’s entry with snow (t_p), distribution density (q), solution concentration (Cp), normal shear stress by grader blade (σ), the coefficient of internal friction (tg), the adhesion of the material (C).

In addition, the value of the freezing power of ice (or snow) may also depend on the temperature and humidity of the air.

The freezing power of ice when shifting the grader blade can be represented in the form of a diagram (Fig. 1). In the theory of using chemical reagents, that as the salt affects the ice, the freezing forces weaken (τ) between its crystals and the ice crust softens [11].

High-quality snow removal can be achieved only if the snow does not lose its bulk properties (C). In this case, the state of the loose body and, consequently, the newly fallen snow, is characterized by the Eq. (4):

$$\boldsymbol{\tau = \sigma tg\varphi + C} \quad (4)$$

The following devices and equipment were used for conducting experimental studies: a set of hydrometers for determining the density of the solution, high-precision electronic scales, a freezer, and a hydraulic press for testing a sample of cement concrete for strength after holding samples in chemical solutions.

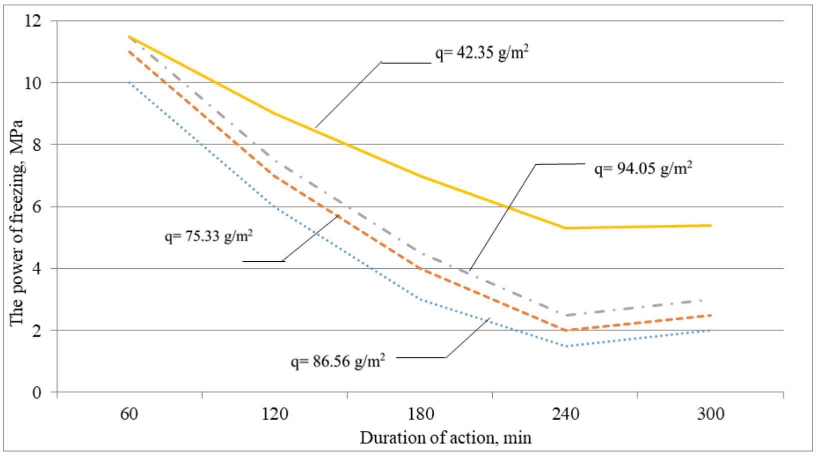
In the first stage, in laboratory conditions in accordance with [16], cement-concrete samples of the B30 and B35 brands used for highways with a cement-concrete coating were prepared.

At the second stage, the selection of deicing chemicals was carried out and solutions in polyethylene baths with a concentration of 8% (minimum) and 25% (maximum) were prepared in laboratory conditions.

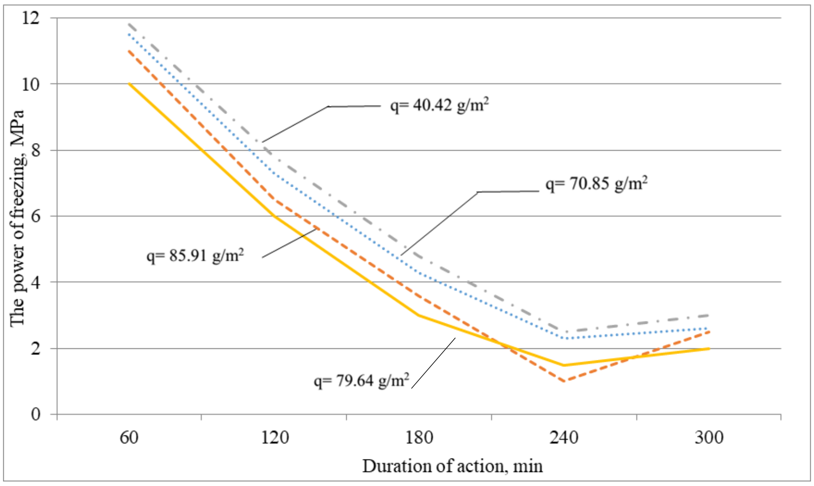
Here, as anti-ice materials the following were used: a) traditional chloride materials, such as sodium chloride (NaCl) [17] and 6-water magnesium chloride (bischofite) ($MgCl_2 \cdot 6H_2O$) [18]; b) non-hygroscopic materials, such as ammonium acetate (CH_3COONH_4) [19] and technical urea (urea) ($(NH_2)_2 \cdot CO$) [20].

In the third stage, pre-prepared samples were immersed in polyethylene baths with appropriate concentrations and types of solution [21-24].

Then, from the moment the samples were immersed in the solution, time tracking began [25-26]. Fig. 2a shows the results of the visual assessment. As can be seen, not all samples were destroyed. For example, the top 4 samples and the bottom 2 right samples were virtually unbroken, while the bottom 2 left samples showed structural failure. At the fourth stage, cement concrete samples after aging (in 3 days, a week, 15 days, a month) were tested by a hydraulic press for compressive strength.



(a)



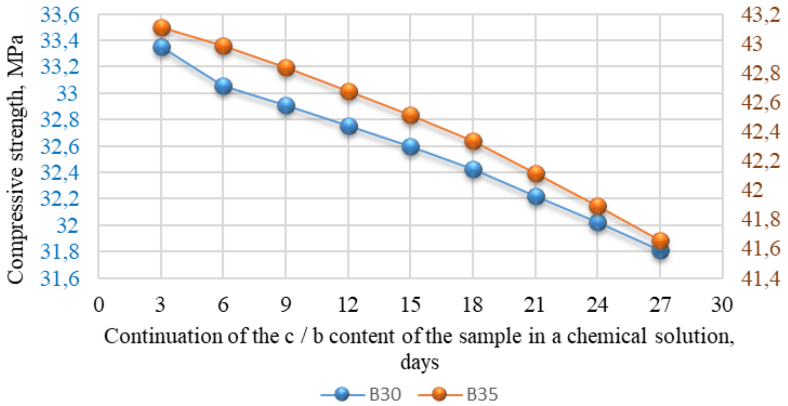
(b)

Fig. 1 Dependence of the freezing force of snow and ice formations from exposure to various types of salty solutions with the shift of the grader blade: (a) sodium chloride solution and (b) magnesium chloride

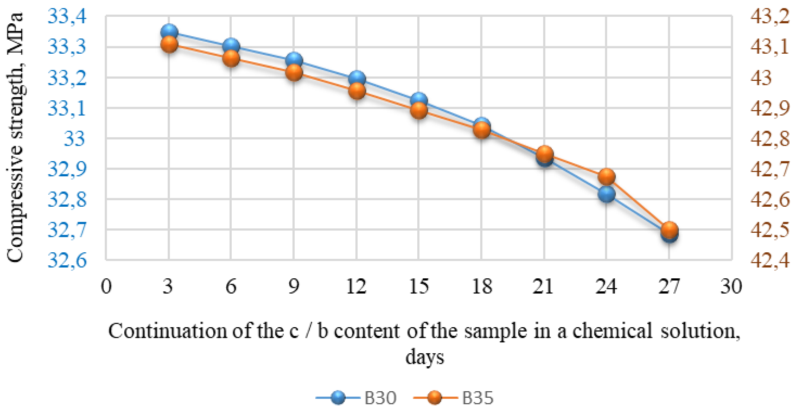
(a) (b)

Fig. 2 Visual view of cement concrete samples: (a) after exposure and (b) testing on hydraulic press

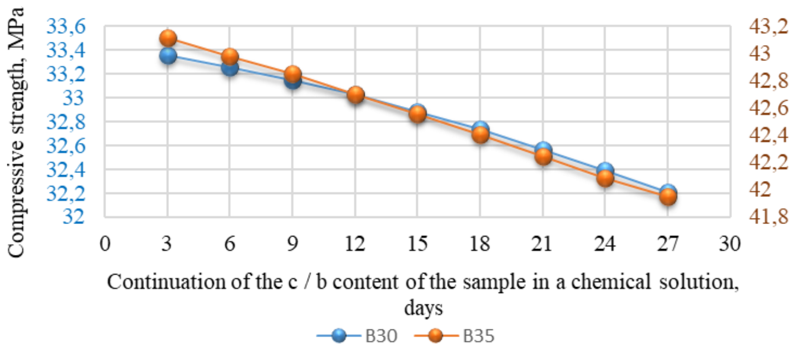
The test results are shown in Fig. 2b. The results of laboratory studies were carried out on the highway “Western Europe – Western China” (km 70-74) and “Almaty–Ust-Kamenogorsk” (km 27-32) of Kazakhstan, especially on the newly constructed sections; a relationship between the content of cement concrete samples of the B30 and B35 grades in a chemical solution and its strength was established [21-23]. As can be seen in Fig. 3, with a maximum monthly exposure of 25% ammonium acetate, the strength loss of concrete grade B30 is 4.46 % (Fig. 3 a), and grade B35 is 3.37 %, technical urea solution loss of strength of concrete grade B30 is 2.01%, and grade B35 is 1.42 % (Fig. 3 b), sodium chloride solution loss of strength of concrete grade B30 is 3.44 %, and grade B35 is 2.69 % (Fig. 3 c), solution of 6-water magnesium chloride loss of strength of concrete grade B30 is 3.06%, and grade B35 is 2.14 % (Fig. 3 d).



(a)

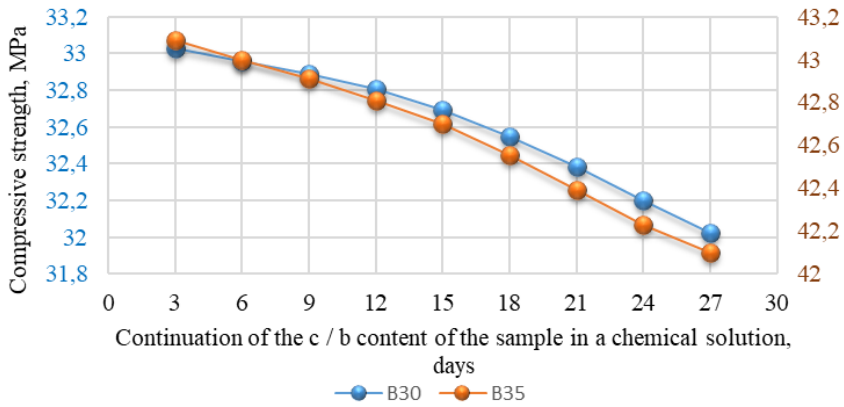


(b)



(c)

Fig.3 Loss of strength of cement concrete samples in deicing chemical solution: (a) 25% ammonium acetate, (b) technical urea, (c) sodium chloride solution



(d)

Fig.3 Loss of strength of cement concrete samples in deicing chemical solution: (d) 6-water magnesium chloride

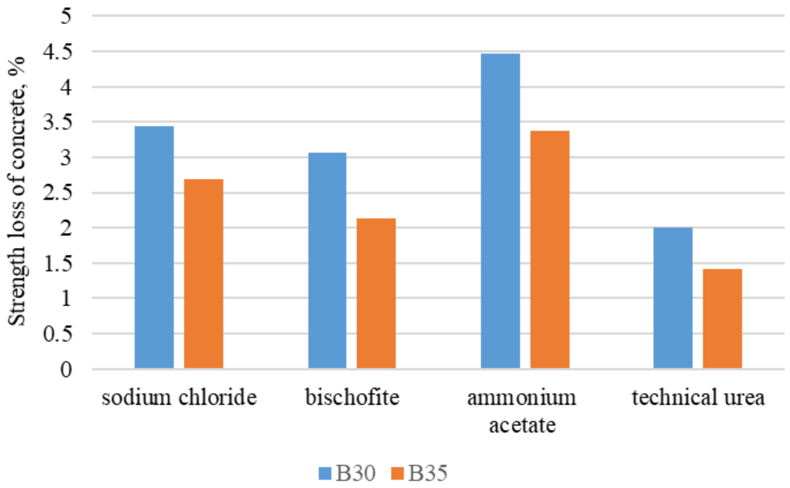


Fig.4 Comparison analyses of anti-ice materials

4. RESULTS

The use of chemical reagents to combat road surfaces in winter is based on the fact that when they interact with ice, chemicals, destroy the crystal structure of the ice, as a result of which it melts and forms a solution with a freezing point of more than lower than water.

The chemical reagents very effectively reduce the adhesion forces between the snow-ice formations and the concrete pavement as compared to the “clean” ice: at a distribution density of q=50 g/m2, chlorides are 10-15 times, and at q = 100 g/m2 by 20-30 times.

Liquid deicing chemicals (brines), in turn, are divided into the following: weak – 50-150, strong – 150-320, very strong – 320-500, and extremely saturated is more than 500 g/l. The test results showed that with an increase in the strength of concrete, their resistance to the effects of chemical solutions increases. According to the results, the most effective material for combating slipperiness on cement-concrete coatings was urea, since the loss of strength is lower than other anti-ice materials. The comparison analyses showed (Fig.4) that exposure to ammonium acetate, to the greatest extent increases the aggressive effect on concrete in the cyclic freeze-thaw compared with other de-icing agents. The magnesium chloride dissolves differently than sodium chloride. In contact with ice, these salts actively release heat. The ice layer melts, leaving in return a solution that does not freeze. However, often when these salts dry out, an oily film remains on the road, which reduces the coefficient of traction of the wheels with the road.

Technical urea is an organic compound that can decompose into carbon dioxide and water when exposed to sunlight. Therefore, it is the safest to use. Urea is also characterized by low corrosiveness.

5. CONCLUSION

This study presents examples of using chemical deicing solutions. Based on investigations, the following recommendations are given: after laboratory tests to study the effect of diluted de-icers on the durability of the concrete pavement structure. Based on freeze or thaw observations of samples at the same time after laboratory freeze or thaw testing, deionized water, solid de-icer, technical urea, and bischofite mixture were found to be favourable for the durability of the concrete structure.

Chlorides were found to be the most harmful to concrete. In addition to exacerbating physical problems, each investigated chemical entered into a chemical reaction with some cement hydrates and formed new products in pores and cracks, the composition of which can be determined by the thermodynamics of chemical reactions. Several new reaction products have been identified as oxychloride crystals, which, according to previous studies, can be large. This work provides sights into the interaction between deicing agent and concrete and highlights the need to bridge the gap between laboratory data and practical experience. The physicochemical changes in the cement paste caused by anti-icers pose various risks to the strength of the concrete, the level of which depends on the kinetics of chemical reactions.

6. ACKNOWLEDGMENTS

This research has been funded by the Ministry of Education and Science of the Republic of Kazakhstan (Grant “The Best Teacher-2020”).

7. REFERENCES

[1] Borisyuk N. V., Winter maintenance of urban roads, 2006, 115 p.

[2] Ormanbekova A., Bek A., Nurpeissova T., Sagybekova A., Deformations of Engineering Structures with the Help of Modern High-Precision Geodetic Devices, Biosc. Biotech. Res. Comm Special, Vol 12, No (5), 2019, pp. 184-195.

[3] MacInnis C. and Nathawad Y., The Effects of a Deicing Agent on the Absorption and Permeability of Various Concretes, in Durability of Building Materials and Components, ed. P. Sereda and G. Litvan 1980, pp.485-496,https://doi.org/10.1520/STP36083S.

[4] Nurakov, S., Awwad, T. & Kaliyev A. and Tulebekova A., The Determination of Soil Cutting Force Applied with Bucketless Bottom Rotor with Account of Speed and Runout. In: Petriaev A., Konon A. (eds) Transportation Soil Engineering in Cold Regions, Volume 1. Lecture Notes in Civil Engineering, vol 49, 2020, Springer, pp 479-486.

[5] Ghani A. N. A., Roslan N. I., Hamid A.H., Road submergence during flooding and its effect on subgrade strength. International Journal of GEOMATE, Vol. 10, Issue 21, 2016, pp.1848-1853.

[6] Silyanov V.V., Domke E.R., Transport and operational qualities of highways and city streets, Academy, 2007, 348 p.

[7] Bekmagambetov M.M., Problems of the development of road and urban transport in the Republic of Kazakhstan, 2009,520 p.

[8] Klungboonkrong P., Faiboun N., Luathep P., Road safety analysis in Thailand and other Asian countries: urgent actions for Thailand. International Journal of GEOMATE, Vol.14, Issue 45, 2018, pp.177-183.

[9] Kurakina E.V., On the deviation of the normative characteristics of the indicators of the motor road (on the example of accident-prone sections of roads in the Leningrad region). // Modern problems of science and education, 2014, pp. 12-16.

[10] Zhussupbekov A., Tulebekova A., Awwad T., Mussabayev T., Tleubayeva A., Geotechnical specification of American and Kazakhstan standards in Pile testing. International Journal of GEOMATE, Vol. 17, Issue 63, 2019, pp.157-163.

[11] Ogar P.M., Loginov O.M., Alekseev I.N., Influence of the roughness of the road surface on the value of the coefficient of adhesion of automobile tires. - Bratsk: works of BSTU, 2006, 2, pp. 292-297

[12] Nagel K., Wagner R., Woesler R., Approaches to traffic flow and traffic jam modeling, 2003.

[13] Peben M.R. Scurfield D., Mohan D., Huder F., Jarawan E. and Mathers C., World Report on Road Traffic Injury Prevention. – Geneva: WHO, 20,2004.

[14] Kiyalbaev A.K., Kiyalbay S.N., The maintenance of roads. Textbook. /under the editorship of prof. Kulbaeva A. K 2017, 343 p.

[15] PR RK 218-64-2007 instructions for combating winter slipperiness on public roads. - Astana: Ministry of transport of Kazakhstan, 2008, 96 p.

[16] GOST 7473-2010-concrete Mixes. General requirements for test methods, 2011, 9 p.
[17] GOST 4233-77-Reagents. Sodium chloride. Technical conditions, 2019, 8 p.
[18] GOST 7759-73. Reagents. Technical magnesium chloride. Technical conditions, 2017, 11 p.
[19] GOST 3117-78 Reagents. Ammonium acetic acid. Technical conditions, 2019, 8 p.
[20] GOST 2081-2010. Carbamide. Technical conditions, 2010, 9 p.
[21] Zhussupbekov A.Z., Tulebekova A.S., Lukpanov R., Zhumadilov I.T., Comparison analysis of features in Eurocode and Kazakhstan norms requirements. Challenges and Innovations in Geotechnics - Proceedings of the 8th Asian Young Geotechnical Engineers Conference, 8AYGEC, 2016, pp. 251–255.
[22] Goryachkin V.P., Collected works, T.1 and 2.M.: Selkhozgiz, 1965, p. 97.
[23] Vetrov Yu.A., Ground cutting by digging machines. M.: Mechanical engineering, 1971, p. 357.
[24] Vladimirov V.M., Shenderov A.I., Kalashnikov Yu.T., Open cut bucket wheel excavator. Kiev: Tekhnika, 1968, p. 282.
[25] Alekseeva T.V. Road vehicle. Part 1. Earthmoving machine. M.: Mechanical engineering, 1972, p.504.
[26] Zhusupbekov A. Zh., Yenkebaev S. B., Lukpanov R. Ye., and Tulebekova A. S., Analysis of the settlement of pile foundations under soil conditions of Astana. Soil Mech. Found. Eng. 49(3), 2012, pp. 99–104.