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V. N. Efimenko[1], S. V. Efimenko[1], B. B. Teltayev[2], A. V. Sukhorukov[1]

[1]Tomsk State University of Architecture and Building, Tomsk, Russia;
[2]JSC "Kazakhstan Highway Research Institute", Almaty, Kazakhstan.
E-mail: svefimenko80@gmail.com, svefimenko_80@mail.ru,
bagdatbt@yahoo.com, av_suhar@mail.ru

ON THE NEED FOR DIFFERENTIATED ACCOUNT OF PROPERTIES OF THE GEOCOMPLEX OF TERRITORIES IN PAVEMENTS DESIGN

Abstract. The article presents the results of a comprehensive study of the relationships and regularities that affect the quality of the pavements design for roads of the West Siberian region. It is shown that the properties of clay soils of the subgrade in the area under study determine their composition, which is formed under the influence of the geographical complex characteristic for the region. The original approach to accounting peculiarities of natural and climatic conditions when zoning the territory is reflected in the taxonomic scheme «zone - subzone - road region». For the road areas identified in the II, III and IV road climatic zones the design characteristics of the subgrade soils of the roads and the study area are assigned. Recommended values of clay soil characteristics differ by up to 40% from those recommended by current standards, which indicates the importance and practical value of the results presented in the article.

Representativeness of samples of strength and deformation parameters in clay soils defined for road districts within West Siberia region is confirmed by the volume of tested soil samples (in the order of 1.2 thousand pieces), as well as by using the methods of probability theory and mathematical statistics when analyzing the test results.

A complex of simulation models is offered that accounts specifics of moisture accumulation in seasonally frost-susceptible road structures of West Siberian roads. The complex advances and adds forecast algorithms for spring and fall soil moisture values which were previously suggested by Prof. I.A. Zolotar. Considerably high consistency was found when comparing forecast and experimental values that characterize design soil moisture of capping layer of the subgrade within the locality of type 2 and 3. For the geocomplex of the II road climatic zone the value of linear correlation coefficient is $r \geq 0.82$, for the III road climatic zone it is $r \geq 0.82$. Within the IV road climatic zone the coefficient value for spring design moisture of silty loam is $r \geq 0.90$.

The outcomes of the study in question enabled to refine spread the boundaries of I-II, II-III and III-IV climatic zones; to define 112 road sections within 14 administrative territorial units of West Siberian region; as well as to substantiate design characteristics of the most widespread soil type. The presented recommendations are designed to increase the time between overhauls for the operating road network of West Siberia.

Key words: Road, geocomplex, climatic zoning, pavement, subgrade, clay soils, design values of the soil of the capping layer of the subgrade.

Introduction. Peculiarities of geocomplex zones features shall be accounted in road design to provide their reliable operation. Worldwide experience in the field of research on the account of the geographical complex features for road design purposes is integrated in standards, regulations and guidelines that are currently effective in the UK [1], PRC [2], the USA [3], FRG [4], Sweden [1], and other countries, including CIS countries (M.N. Guzinsky [5], B.B. Karimov [6], V.P. Koryukov, R.Z. Poritsky [7], B.B. Teltaev [8], and others).

Presently, the road pavement design theory has gained considerable development in studies performed by S.K. Iliopolov [9], V.A. Kulchitsky [10], V.P. Matua [11], A.E. Merzlikin [12], B.S. Radovsky [13], A.V. Smirnov [14], B.B. Teltaev [15], E.V. Uglovaya [16], etc. It shall be noted that the reliability of the design values of soil parameters used in the currently effective and developed design methods does not always comply with those required by science and practice.

The suggested research results are based on long-term study of water and thermal regime of road subgrade soils of the II, III and IV road climatic zones in the West Siberia region [17,18,19].

In 1963, Prof. N.A. Tsytovich noted that "physical and geographical environment has immense impact on the formation of soils composition and their properties" [20]. This conclusion is validated and advanced by the specialists of M. Lomonosov Moscow State University [21, 22]. The main law of soil science formulated by Prof. V.T. Trofimov [23] may be interpreted as follows: composition and properties of soils, their structure and condition to a considerable extent define their origin, formation history, manner of spatial location, as well as peculiarities of human-induced impact in the developed territories. Based on the above, one may conclude that consideration of specific features of natural and climatic conditions ensures quality of road structures design.

Unfortunately, the road pavement design regulations currently effective in Russia (ODN 218.046-01 and PNST 265-2018) recommend generalized design values of shear properties and elastic moduli of subgrade soil subtypes, and in most cases they are irrespective of the zone location of the designed object.

With the account of the above, studies on composition and properties of clay soils of road subgrades are characterized by scientific novelty, relevance and have practical value.

Methods. A network of about 100 road sections for intermittent long-term observations was assigned for the purpose of studying the features of water-heat processes in the road structures of the West Siberia region.Prior to selection of the sections in the territory under study, the stages of design documents analysis, pre-design inspection and technical condition assessment of the object were performed.

Decisions on assigning the basic road sections located in representative natural and climatic conditions for the administrative unit were made on the alternative basis. The selection criteria were compliance of structural and technological solution of the object with the requirements stated in the regulatory documents, access to the operating hydrometeorological station, and vehicle access for visual and instrumental observations irrespective of the season.

When sampling soil monoliths from the base layer on the road section under study, vertical trial holes were made in the roadpavement grooves. Monolith and soil samples were taken from the depth of 0.1…0.2 m from the pavement bottom. Laboratory research include definition of grain size composition, natural, relative and optimum moisture content and maximum density, moisture conductivity coefficient, as well as strength parameters of subgrade soil. General elastic modulus, the value of elastic moduli of pavement layers and subgrade were found as a result of plate bearing tests. Standardized methods and equipment were used while testing.

When planning field and laboratory research, preliminary calculations of minimum required amount of samples were made depending on the accuracy factor Δ, mean squared deviation σ and confidence coefficient P. In total, around 900 subgrade soil samples were tested in the laboratory.

Results. Laboratory research of grain size composition of clay soil samples taken from the West Siberian road subgrades revealed that silt fractions (0.05-0.005 mm) are contained in the amount up to 82.3%in sandy clay, and in the amount up to 81.6% in loamy clay. Clay fraction content (<0.005 mm) for sandy clays does not exceed 20.3%, and for loamy clays it is no more than 32.3%.

The given values are close to our recently obtained research results for clay soil samples (silt loam) taken from the right bank of the Tom river nearby Loskutovo village. The studied soil has non-homogeneous structure (saturation level = 11.4), it contains 17.9% of sand fraction, 62.6% of silt fraction and 19.5% of clay fraction.

The results of mineralogical composition studies showed that it is quartz (crystalline silica) that prevails in clay soil in the amount of 60.7%, the content of plagioclase is 15.4% and of montmorillonite – 14.5%. The total content of calcium, chlorite, illite and potash feldspar taken together is 3%.

X-ray study of the samples indicated that the dominating clay minerals have mixed-layer non-homogeneous structure with regard to ratio of alternating textures.

In the samples' chemical composition the most dominant are silicon oxides (SiO_2) with 62.8%, aluminum oxides (Al_2O_3) with 13.5% and iron oxides (Fe_2O_3) with 5.5%. The samples have neutral pH = 7-8. In the light fractions of the samples the dominant positions are taken by quartz (around 70%) and feldspars (20-25%).

The studies of Prof. V.I. Korobkin [13] performed for European Russia showed that the content of silt and clay fractions in the samples is higher than 25 and 50% respectively, which makes a considerable difference from clay soils of West Siberia region. Assessment of mineralogical composition of clay soils indicates that the light fractions are rich in quartz with its percentage higher than 70%, carbonates (calcite) in the amount up to 11.3%, and feldspars (orthoclase) between 7.2 and 10.2%.

The amount of calcedony and rock fragments content in the samples is between 6.4 and 11%. Heavy fractions are rich in ilmenite, magnetite, limonite, leucoxene, etc. Hydrous micas, like illite, are dominating in the mineral composition of clay fraction.

Comparison of the given outcomes of clay soils composition studies performed for West Siberia and south of European Russia districts confirms the validity of previous suggestions [20,22,23] that diverse genesis and age of surface deposits and selective weathering processes in mantle rock formation define the features of composition, condition, structure, and texture of surface soil layer material.

Considering the fact that soils composition significantly defines their properties, when designing road structures one should account the diversity of natural and climatic conditions that also affect road subgrade soil composition and characteristics [20].

For that reason, to provide high quality design and ensure the required service life of roads it is necessary to use the complex of design values for soils of subgrade capping layer determined for their location with individual geographical complex, rather than generalized values taken from regulatory documents, which are developed for vast territories.

To increase time between overhauls and life cycle of roads with enhanced heavy-duty road surfacing one requires detailed zoning of the territory obtained in the previous studies on road climatic zones with specification of their boundaries, and a database that includes design values of soils parameters peculiar for the region. Such developments can be exemplified by the effective regulatory documents of Germany, the USA, China, etc.

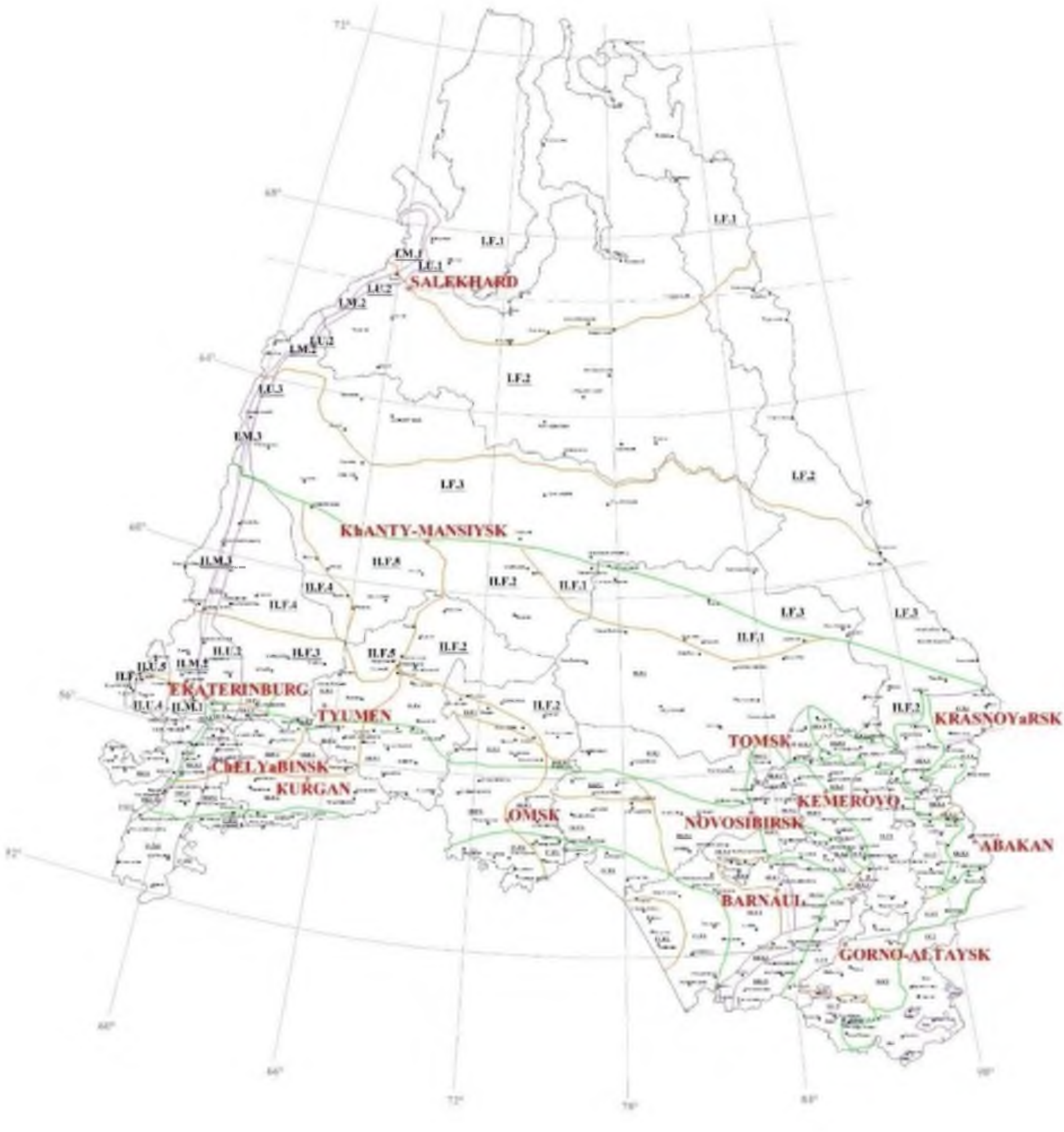
The map of road climatic zones of West Siberia (figure) region is based on the common ideology described in [17–19], as well as on the studies by Prof. A.I. Yarmolinsky and Prof. V.A. Yarmolinsky [24]. It consists in distinguishing uniform territories with respect to the geocomplex within the administrative boundaries of regions and districts. The suggested approach to the technology of road climatic zoning is substantiated by the argument that the main network of roads located within an administrative unit is represented by a network of roads of regional or district importance.

Unlike the effective standardized zoning in Russia provided by the Code of Regulations (SP 34.13330.2012), the suggested territorial division of West Siberia presents in considerable detail natural and climatic conditions for such taxons as zone, subzone, road district. Each of the zones distinguished in the territory of the Russian Federation occupies a significant area and represents a single geographical unit that includes various enclaves with diverse combination of geographical components. Zoning of the Russian Federation fixed in the regulatory documents does not correspond to the results of long-term studies and fails to provide high quality of road design.

The outcomes of laboratory tests of soil samples taken from the subgrades of West Siberian roads that occupy the II climatic zone revealed that the upper layer of subgrade primarily consists of silt loams (69% of samples taken during field research), with plasticity index I_p = 0.02…0.07. Variation of the natural moisture content observed in silt loams is W_e = 0.14…031, and in sandy silt loams it is W_e = 0.09…0.16. It is peculiar that the range of relative humidity variation $W_{REL}$for loamy clays is 0.42…0.69 and for sandy clays it is W_{REL} = 0.40…0.69. With respect to the value of liquidity index I_L the studied soils are divided into loamy clays, from solid to semi-solid, and solid sandy clays.The variation range of porosity ratio for silt loams is e_0 = 0.401…0.870, and for sandy clays – e_0 = 0.370…0.737.

In the West Siberian territory located in the III road climatic zone, man-made soils of the subgrade body are represented by silt loams with plasticity index I_p = 0.09…0.17 and by sandy silt loams with

I_p = 0.04…0.07. The observed values of natural moisture content belong to the following range: W_e = 0.11…0.31 – for loamy clays and W_e = 0.07…0.22 for sandy clays. The variation range for relative humidity values are W_{REL} = 0.41…0.75 for loamy clays and W_{REL}= 0.31…0.55 for sandy clays. Based on the liquidity index I_L the following classed are distinguished: loamy clays – solid, semi-solid and of low plasticity, and solid sandy clays. Porosity variation observed for loamy clays is e_0 = 0.117…0.957 and for sandy clays – e_0 = 0.323…0.707.



Base map of road climatic zoning of the territory of Western Siberia:
I, II, III, IV – road-climatic zones based on the results of TSUAB research;
F, U, M – the subzone by the type of relief (flat, undulated, or mountainous);
1–5 – numbers of the road districts.

In the West Siberian territories that belong to the IV road climatic zone the most spread subgrade soils are silt loams with plasticity index of I_p = 0.07…0.17 and sandy silt loams with plasticity index of I_p = 0.06. Values of natural moisture content W_e varied in loamy clays between0.14 and 0.24, and in sandy clays it was W_e = 0.22. The following values of relative humidity were observed: W_{REL} = 0.44…0.58 for loamy clays and W_{REL} = 0.62 for sandy clays. With respect to the liquidity parameter I_L the following types of soil are distinguished: solid and semi-solid loamy clays and solid sandy clays. The value of porosity ratio e_0 for loamy clays varied between 0.441 and 0.698 and for sandy clays – between 0.338 and 0.411.

Grain size composition of clay soil samples showed that the content of silt fraction in clay subgrade soils of the roads of the II climatic zone does not exceed 81.6% for sandy clay and 82.3% for loamy clay. The content of clay fractions in sandy clays is no higher than 10.7% and 28.6% in loamy clays. Subgrades of road sections that belong to the III climatic zone are mainly represented by clay soils and are characterized by high content of silt fractions – up to 80.8% for sandy clays and up to 80.6% for loamy clays. The percentage of clay fractions reaches 12.2% in sandy clays and 29.7% in loamy clays.

The studied road sections located in the IV road climatic zone with upper layer of subgrade consisting of clay soils are characterized by a decrease in content of silt fractions to 64% for sandy clays and to 77.5% for loamy clays. The amount of clay fractions grew up to 20.3% for sandy clays and up to 32.3% for loamy clays.

Representativeness of samples of clay soils parameters determined for uniform features of territories occupied by the zones of West Siberia is confirmed by the amount of tested soil samples, as well as by the use of probability theory and mathematical statistics methods while analyzing the test results.

Conclusion. Based on the performed research a set of recommendations were developed for administrative units of West Siberia region. They contain a complex of design values of the most spread parameters in the region of clay subgrade soils (for example table 1, 2) with the account of new data on regularities and connections that define features of water-heat processes in structures of roads with uniform geocomplex characteristics located within the studied administrative unit.

Table 1 – Estimated values of the characteristics of clay soils of the subgrade of road sections with deep occurrence of the groundwater level (type 1 of area by nature and degree of moisture allocated in the territory of Kemerovo region)

Road districts	Type of road surface	Calculated relative moisture of soil, W_v (u.f.)	Elasticity modulus, E_{ss} (MPa)	Angle of internal friction, φ_{ss} (°)	Specific cohesion, C_{ss} (MPa)
II.U.1	A B	0.82 0.79	15.6 18.4	9 10	0.041 0.043
II.U.2	A B	0.80 0.79	22.5 23.0	13 13	0.049 0.049
II.U.3	A B	0.86 0.82	22.0 25.0	11 12	0.009 0.011
II.M.2	A B	0.90 0.86	19.5 22.0	11 11	0.007 0.009
II.F.2	A B	0.77 0.76	22.0 22.5	16 17	0.019 0.020
III.F.1	A B	0.76 0.71	30.0 37.0	14 16	0.016 0.022
III.F.3	A B	0.76 0.71	30.0 37.0	14 16	0.016 0.022
III.U.1	A B	0.75 0.70	32.0 38.5	14 16	0.017 0.023
Note: A – advanced coatings of capital type; B – advanced lightweight coatings					

Table 2 – Values of the calculated characteristics of the clay soil (silty loam)
for the road district III.U.2 allocated in the territory of Novosibirsk region

Hydraulic conductivity coefficient, K_l (cm²/h)	The level of ground or surface water from the top of the subgrade, H_w (m)	Calculated values of soil indicators			
		Calculated relative moisture of soil, W_s(u.f.)	Elasticity modulus, E_{ss}(MPa)	Angle of internal friction, φ_{ss} (°)	Specific cohesion, C_{ss} (MPa)
1.0	0.5	0.76	24	14.2	0.051
	1.0	0.69	28	17.0	0.055
	1.5	0.61	33	21.2	0.061
	2.0	0.58	37	24.0	0.065
	2.5	0.56	38	25.2	0.068
1.5	0.5	0.77	24	13.7	0.050
	1.0	0.70	27	16.6	0.054
	1.5	0.62	33	21.0	0.060
	2.0	0.58	37	23.9	0.065
	2.5	0.56	38	25.2	0.068
2.0	0.5	0.79	23	13.3	0.050
	1.0	0.71	27	16.3	0.054
	1.5	0.62	32	20.8	0.060
	2.0	0.58	36	23.8	0.065
	2.5	0.56	38	25.1	0.067

Continuation of the table 2

Hydraulic conductivity coefficient, K_l (cm²/h)	The level of ground or surface water from the top of the subgrade, H_w (m)	Calculated values of soil indicators			
		Calculated relative moisture of soil, W_s(u.f.)	Elasticity modulus, E_{ss}(MPa)	Angle of internal friction, φ_{ss} (°)	Specific cohesion, C_{ss} (MPa)
2.0	0.5	0.79	23	13.3	0.050
	1.0	0.71	27	16.3	0.054
	1.5	0.62	32	20.8	0.060
	2.0	0.58	36	23.8	0.065
	2.5	0.56	38	25.1	0.067
2.5	0.5	0.80	23	13.0	0.049
	1.0	0.71	26	16.0	0.053
	1.5	0.62	32	20.6	0.060
	2.0	0.58	36	23.7	0.065
	2.5	0.56	38	25.1	0.067
3.0	0.5	0.81	22	12.7	0.049
	1.0	0.72	26	15.7	0.053
	1.5	0.63	32	20.5	0.060
	2.0	0.58	36	23.6	0.065
	2.5	0.56	38	25.1	0.067

Considerable differences were found in comparison of the values recommended by the regulatory documents ODN 218.046-01 and PNST 265-2018 with the substantiated standardized design values of clay subgrade soils parameters for road districts under study. For instance, the value of elastic modulus for silt loam given in the regulatory documents is higher than the actual one by 25-40% depending on the

relative moisture of the soil. At the same time, the values of angle of internal friction are lower than those experimentally obtained by 5-30%, and the value of specific cohesion is lower by 10-45%. The given research results indicate the ability to increase time between overhauls for road structures.

В. Н. Ефименко[1], С. В. Ефименко[1], Б. Б. Телтаев[2], А. В. Сухоруков[1]

[1]Томск мемлекеттік сәулет-құрылыс университетінің, Томск, Ресей;
[2]«Қазақстан жол ғылыми-зерттеу институты» АҚ, Алматы, Қазақстан

ЖОЛ ТӨСЕМЕЛЕРІН ЖОБАЛАУ КЕЗІНДЕ САЗДЫ ТОПЫРАҚТАРДЫҢ ҚАСИЕТТЕРІН САРАЛАП ЕСЕПКЕ АЛУ ҚАЖЕТТІЛІГІ ТУРАЛЫ

Аннотация. Мақалада Батыс Сібір аймагындагы автомобиль жолдарының жол төсемесін жобалау сапасына ықпал ететін байланыстар мен заңдылықтарды кешенді зерттеу нәтижелері келтірілді. Зерттеу аумағындағы жер төсемінің сазды топырақтарының қасиеттері аймаққа тән географиялық кешен белгілерінің әсерінен қалыптасатын құрамын анықтайды. «Аймақ - кіші аймақ - жол ауданы» таксономиялық схемасында аумақты аудандастыру кезіндегі табиги-климаттық жағдайлардың ерекшеліктерін есепке алудың ерекше тәсілі көрсетілген. II, III және IV жол-климаттық аймақтарда бөлінген жол аудандары үшін автомобиль жолдарының жер төсемі топырақтарының, зерттеу аумағының есептік сипаттамалары тағайындалды. Сазды топырақ сипаттамаларының ұсынылатын мәндері 40% дейін ұсынылган қолданыстағы нормалардан ерекшеленеді, бұл мақалада ұсынылган нәтижелердің маңыздылыгы мен тәжірибелі құндылыгын көрсетеді.

Батыс-Сібір аймагындагы аймақтар шегіндегі жол аудандарының аумақтары үшін белгіленген сазды топырақтардың беріктік және деформациялық сипаттамаларының мәндерін іріктеудің репрезентативтілігі сынақ нәтижелерін өңдеу кезінде ықтималдықтар теориясы мен математикалық статистика әдістерін қолдану арқылы сыналған топырақ сынамаларының көлемімен (шамамен 1.2 мың) расталган.

Бұган дейін профессор И. А. Золотарь ұсынган топырақтың күзгі және көктемгі ылгалдылыгының шамаларын болжау алгоритмдерін дамытатын және толықтыратын Батыс-Сібір өңірінің автомобиль жолдарының маусымдық қатып қалган жол құрылымдарында жинақталу ерекшеліктерін ескеретін имитациялық модельдер кешені ұсынылды. Жергілікті жердің 2 және 3 типтері жагдайында жер төсемесінің жұмыс қабаты топырағының есептік ылғалдылыгын сипаттайтын болжамды және эксперименталдық белгіленген шамаларды салыстыру нәтижелері сәйкестіктің жеткілікті жогары дәрежесін куәландырады. II геокешен үшін жол-климаттық аймақтар (ЖКА) үшін $r \geq 0.82$ корреляция сызықтық коэффициентінің мәні, III ЖКА үшін $r \geq 0.82$. IV ЖКА жағдайында көктемгі есептік ылгалдылыққа арналған шаңды саздақ $r \geq 0.90$.

Қарастырылып отырган зерттеулердің нәтижелері I-II, II-III және III-IV жол-климаттық аймақтардың кең таралу шекараларын нақтылауга, Батыс-Сібір аймагының 14 әкімшілік-аумақтық құрылымы шегінде 112 жол ауданын бөлуге мүмкіндік берді. Ұсынылган ұсыныстар Батыс-Сібірде пайдаланылатын автомобиль жолдары желісінің жөндеуаралық мерзімдерін арттыруга бағытталган.

Түйін сөздер: автомобиль жолы, геокешен, жол-климаттық аудандастыру, жол төсемесі, жер төсемесі, сазды топырақ, жер төсемесінің жұмыс қабаты топырағының есептік мәні.

В. Н. Ефименко[1], С. В. Ефименко[1], Б. Б. Телтаев[2], А. В. Сухоруков[1]

[1]Федеральное государственное бюджетное образовательное учреждение высшего образования «Томский государственный архитектурно-строительный университет», Томск, Россия;
[2]АО «Казахстанский дорожный научно-исследовательский институт», Алматы, Казахстан

О НЕОБХОДИМОСТИ ДИФФЕРЕНЦИРОВАННОГО УЧЁТА СВОЙСТВ ГЛИНИСТЫХ ГРУНТОВ ПРИ ПРОЕКТИРОВАНИИ ДОРОЖНЫХ ОДЕЖД

Аннотация. В статье приведены результаты комплексного изучения связей и закономерностей, влияющих на качество проектирования дорожных одежд автомобильных дорог Западно-Сибирского региона. Показано, что свойства глинистых грунтов земляного полотна на территории исследования определяет их состав, формирующийся под влиянием признаков географического комплекса, характерных для региона. Отражён оригинальный подход к учёту особенностей природно-климатических условий при районировании территории в таксономической схеме «зона – подзона – дорожный район». Для дорожных районов, выделенных во II, III и IV дорожно-климатических зонах, назначены расчётные характеристики грунтов земляного полотна автомобильных дорог, территории исследования. Рекомендуемые значения характеристик глинистых грунтов до 40% отличаются от рекомендованных действующими нормами, что свидетельствует о важности и практической ценности представленных в статье результатов.

Репрезентативность выборок значений прочностных и деформационных характеристик глинистых грунтов, установленных для территорий дорожных районов в пределах зон в Западно-Сибирском регионе, подтверждена объёмом испытанных проб грунта (около 1.2 тыс.), применением при обработке результатов испытаний методов теории вероятностей и математической статистики.

Предложен комплекс имитационных моделей, учитывающих особенности накопления в сезонно промерзающих дорожных конструкциях автомобильных дорог Западно-Сибирского региона, развивающий и дополняющий алгоритмы прогнозирования величин осенней и весенней влажности грунтов, ранее предложенные профессором И.А. Золотарём. Результаты сопоставления прогнозных и экспериментального установленных величин, характеризующих расчётную влажность грунта рабочего слоя земляного полотна в условиях 2 и 3 типов местности, свидетельствует о достаточно высокой степени совпадения. Для геокомплекса II дорожно-климатические зоны (ДКЗ) значение линейного коэффициента корреляции $r \geq 0.82$, для III ДКЗ $r \geq 0.82$. В условиях IV ДКЗ для весенней расчётной влажности суглинка пылеватого $r \geq 0.90$.

Результаты рассматриваемых исследований позволили уточнить распространение (было распространённых) границ I-II, II-III и III-IV дорожно-климатических зон, выделить 112 дорожных районов в пределах 14 административно-территориальных образований Западно-Сибирского региона, обосновать расчётные характеристики наиболее распространённого грунта. Представленные рекомендации направлены на увеличение межремонтных сроков сети эксплуатируемых в Западной Сибири автомобильных дорог.

Ключевые слова: автомобильная дорога, геокомплекс, дорожно-климатическое районирование, дорожная одежда, земляное полотно, глинистые грунты, расчётные значения грунтов рабочего слоя земляного полотна.

Information about authors:

Efimenko V.N., Doctor of Technical Sciences, Professor of Automobile Roads Department, Tomsk State University of Architecture and Building, Tomsk, Russia; svefimenko80@gmail.com; https://orcid.org/0000-0001-6080-5482

Efimenko S.V., Doctor of Technical Sciences, Dean of Road Construction Faculty, Head of Automobile Roads Department, Tomsk State University of Architecture and Building, Tomsk, Russia; svefimenko_80@mail.ru; https://orcid.org/0000-0001-7064-1418

Teltayev B.B., Doctor of Technical Sciences, Professor, Academician of NEA RK, President of JSC "Kazakhstan Highway Research Institute", JSC "Kazakhstan Highway Research Institute", Almaty, Kazakhstan; bagdatbt@yahoo.com; https://orcid.org/0000-0002-8463-9965

Sukhorukov A.V., Candidate of Technical Sciences, Associated Professor of Automobile Roads Department, Tomsk, Russia; av_suhar@mail.ru; https://orcid.org/0000-0001-8778-5418

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