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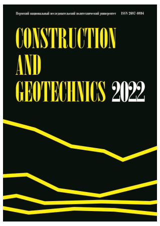

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ЭКСПЕРИМЕНТАЛЬНЫЕ ИССЛЕДОВАНИЯ ФИЗИКО-МЕХАНИЧЕСКИХ ПРОЦЕССОВ В СЕЗОННО-МЕРЗЛЫХ ГРУНТАХ КОНСТРУКЦИЙ АВТОМОБИЛЬНЫХ ДОРОГ

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АННОТАЦИЯ

Представлены результаты натурных исследований физико-механических процессов в глинистых пучинистых грунтах. Перед началом проведения экспериментов проанализированы поведение грунта при проявлении в нем процессов морозного пучения и возможные дефекты зданий, сооружений и, в частности, автомобильных дорог. Проблема оценки закономерности морозного пучения и теплообмена в слоях дорожной конструкции актуальна по причине недостаточной изученности и побуждает к изучению параметров данного процесса и определению зависимостей между изучаемыми характеристиками. Исследования включали в себя мелкомасштабные модельные участки дороги с глинистыми грунтами нарушенных (покровных) и ненарушенных (земляных) конструкций с использованием теплоизоляционного слоя в дорожном строительстве, что позволило получить качественную картину исследования. Для экспериментальных исследований были использованы две площадки по бокам автомобильной дороги в Свердловской области и Пермском крае. На площадках в ходе испытаний были измерены параметры промерзания грунта насыпи и земляных работ – влажности, температуры почвы и скорости промерзания грунта. Испытания моделей дорожных конструкций дороги на действие вертикальной нагрузки проводились в суглинках от полутвердой до жидкопластичной консистенции, охватывающих практически весь диапазон грунтовых условий, встречающихся при дорожном строительстве Уральского региона. Во время эксперимента регулярно отбирались пробы для определения влажности почвы и проводились измерения температуры. Представлены результаты изменения температуры в структуре дороги в зависимости от времени года и осадков с использованием тепловизионной инфракрасной камеры. Установлено, что амплитуда колебаний температуры нелинейно зависит от глубины.

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EXPERIMENTAL STUDIES OF PHYSICAL AND MECHANICAL PROCESSES IN SEASONALLY FROZEN SOILS OF CONSTRUCTIONS OF AUTOMOBILE ROADS

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ABSTRACT

heaving soils. Before the start of the experiments, the behavior of the soil during the manifestation of frost heaving processes in it and possible defects of buildings, structures and, in particular, highways were analyzed. The problem of assessing the regularity of frost heaving and heat transfer in the layers of the road structure is relevant due to insufficient knowledge and encourages the study of the parameters of this process and the determination of dependencies between the studied characteristics. The studies included small-scale model road sections with clay soils of disturbed (cover) and undisturbed (earthen) structures using a thermal insulation layer in road construction, which allowed us to obtain a qualitative picture of the study. For experimental studies, two sites were used on the sides of the highway in the Sverdlovsk Region and the Perm Region. During the tests, the parameters of the soil freezing of the embankment and earthworks were measured at the sites – humidity, soil temperature and the rate of soil freezing. Tests of models of road structures for the effect of vertical loading were carried out in loams from semi-solid to liquid-plastic consistency, covering almost the entire range of ground conditions encountered in road construction in the Ural region. During the experiment, samples were regularly taken to determine soil moisture and temperature measurements were carried out. The results of temperature changes in the road structure depending on the time of year and precipitation using a thermal infrared camera are presented. It is established that the amplitude of temperature fluctuations depends non-linearly on the depth.

Introduction

The road is a single engineering complex, all elements of which work in close relationship. The roadbed should serve as a reliable foundation for road pavement, ensure its strength and durability regardless of local soil, climatic, hydrological and other factors [1, 2]. The roadbed is erected on the soil layer changing in different seasons the properties from influence of natural factors and, first of all, from temperature of air and humidity of soil. It follows that the service life of the road structure depends mainly on the condition of the soil located at the base of the road, its type and humidity [3, 4].

The soils of the upper layers of the earth's crust during the annual period are in three states: thawed, frozen and thawing [5, 6]. It is established that during freezing there can be such conditions when the increase in the volume of soil due to the migration of moisture to the front of freezing.

Frost heaving of soils refers to physical and mechanical processes, as a result of which the freezing soil acquires a stress-strain state under the influence of thermodynamic changes [7–9]. The stresses arising from soil heaving are so significant that they can cause: deformation of industrial buildings and structures, displacement of bridge supports and power lines, destruction of road surfaces, airfields, etc [10–12].

Currently, the parameters of moisture migration and patterns of frost heaving, heat transfer in the layers of the road structure under the influence of dynamic load and climatic conditions remain insufficiently investigated. The problem of quantitative and qualitative assessment of these processes is inextricably linked with the dynamics of frost cracking of the road structure, the need to study which is determined by the practice of using seasonally frozen soils as the basis of road pavement [13].

The aim of the work was to obtain high-quality data of physical and mechanical processes in seasonally freezing soils of road structures.

Materials and methods

When carrying out laboratory experiments and literature analysis, it can be concluded that it is very difficult to conduct experimental studies on modeling the formation of frost cracks in laboratory conditions with heaving soil, since it is difficult to create a theory of similarity of the interaction of the road structure taking into account the terrain and the sides of the light in a specially created tray using a freezer approximately gives a quantitative assessment of the influence of humidity on the appearance of deformations [14, 15]. The studies included small-scale model sections of the road with clay soils of disturbed (mound) and undisturbed (excavation) structures with the use of a heat-insulating layer in the road structure, which allowed obtaining a qualitative picture of the research.

Tests of models of road structures of the road on the action of the vertical load were carried out in the loam with a yield index of IL from 0.2 to 0.8, i.e. from semi-solid to fluid-plastic consistency, covering almost the entire range of soil conditions encountered in the road construction of the Urals. For experimental studies were laid two areas on the sides of the road structure in the area of gravity of the highway in the Sverdlovsk region (mining Area).

First platform. To remove the indicators from the experimental sites used coal moisture sensors AM-11. At the same time before the measurements they were calibrated at a temperature of 15 °C. The depth of the sensors was from 1.5 to 2 meters, with the indentation from the edge of the pavement-0.5 m. when fixing the resistance indicators from the sensors, at the same time the temperature of the ground base was measured from the depth of the sensors. The testimony of the resistances of the experimental plots were subsequently brought to the temperature to 15 °C:

$$R_{15} = R_{izm} (1 + \hbar t), \tag{1}$$

R_{izm} – the value of the ohmic resistance; $\hbar$ – factor changes in temperature regimes (0,03 temperature for 1 OS); t – temperature reading in the sensor installation area (OS).

Then, graphs were built to determine the soil moisture base using the weight method. For this purpose, at the site of installation of humidity sensors, one control well was drilled about once a month, from which samples were taken to determine the natural moisture content of the soil [16–18]. Control wells were drilled at a distance of 10.0 to 20.0 cm from the sensor installation site. After sampling, the wells were filled with tightly compacted drainage material and materials extracted from the well during drilling. In determining the natural moisture content observed threefold repetition. So, on October 7, the soil moisture in the well drilled in the soil of natural composition in the excavation was at a depth of 0.9 m 21.5 %, at a depth of 1.5 m – 20.7 %. According to the results of the experiment, the amplitude of changes in the humidity of natural soil for the warm period of the year was at a depth of 0.9 m – 3.2 %, at a depth of 1.5 m-less than 1 %. At the place of mating of the embankment with the excavation, soil samples were regularly taken to determine the humidity (W) and temperature measurements were made [19–21]. To determine the freezing rate on the side of the road was dug a pit the size 1,5×2,0 m and a depth of 2.5 m. the walls of the pit are isolated with 20 cm layer of expanded polystyrene brand "PENOPLEX". During the tests, measurements of soil freezing of the embankment and excavation were carried out.

Second platform. Timber road Perm-Polazna-Chusovaya. The topography of the area is the Northern slope of the hill leading down to the river Polazna. According to the results of engineering-geological studies in the right of way to a depth of 9 m slope is composed of loam. Humidity soil hard and semi-hard with the flow rate IL < 0,25 [22].

Groundwater well is not opened. Physical characteristics and granulometric composition of soils are given in table 1. At the test site were dug two pits and subsequently filled with the same soil with varying degrees of compaction:

– pit No. 1 – filled with soil sealed it with hand rammer with a mass of 15 kg in layers of thickness of 40 cm with fixed number of strokes (250) on each layer on the cross-sectional area of the hole is 2 m^2;

– pit № 2 – filled with soil with compaction layers of 10 cm with the same number of strokes on each layer.

The physical characteristics of the pits soils on the experimental site are presented in table 2.

For subsequent measurements of soil moisture in the backfill of the experimental pits were laid coal sensors AM-11 at depths: 0.5; 1.0; 1.5 and 2.0 m. to register the temperature of the soil in each of the pits installed garlands of resistance thermometers at intervals of depth 20 cm.

Table 1

Physical properties of soils

Index	Depth, m			
	0,5	1,0	1,5	2,0
Natural humidity, %	25,4	28,2	30,0	25,0
Density, g/cm^3	1,94	1,8	1,88	1,85
Density of soil particles, g/cm^3	2,79	2,78	2,78	2,79
Dry soil density, g/cm^3	1,55	1,46	1,47	1,42
Porosity, %	44,7	48,0	47,2	49,1
Porosity ratio	0,82	0,92	0,89	0,96
Degree of humidity	0,86	0,85	0,87	0,87
Liquid limit, %	42,8	42,2	44,1	47,2
Plastic limit, %	26,3	25,6	27,8	29,1
Plasticity index, %	16,6	16,6	16,3	18,1
Liquidity index	0	0,17	0	0,05
Type of soil	Loam	Loam	Loam	Clay

Table 2

Physical properties of pits' soils

Number of pit	Depth, m	Natural humidity, %	Density, g/cm^3	Density of soil particles, g/cm^3	Dry soil density, g/cm^3	Porosity, %	Porosity ratio	Total moisture capacity, %	Degree of humidity
1	0,5	24,0	1,91	2,79	1,54	44,8	0,81	29,1	0,83
	1,0	25,3	1,91	2,78	1,52	45,4	0,83	29,9	0,85
	1,5	26,1	1,88	2,78	1,49	46,5	0,87	31,3	0,3
	2,0	27,2	1,85	2,78	1,45	47,9	0,92	33,1	0,82
2	0,5	21,3	1,88	2,79	1,55	44,5	0,8	28,7	0,74
	1,0	25,2	1,93	2,8	1,54	44,6	0,81	29,2	0,86
	1,5	27,	1,89	2,76	1,48	46,4	0,87	31,5	0,88
	2,0	28,1	1,87	2,76	1,46	47,2	0,89	32,3	0,87

Subsequently, at this site were determined temperature changes in the road structure, depending on season and precipitation, using thermal imagers.

Interpretation and discussion of results

High categories of roads are carried out along the cutting line to reduce the amount of excavation and compliance with regulatory requirements. As a result, on the road there are areas with embankment and excavation. As a result of experimental and theoretical studies it was found that the distribution of thermal energy in these areas is different [23].

In the first year of operation of highways on sites of interface of a bulk – dredging frosty cross cracks [24, 25] are formed.

The field studies conducted using the FLIR P620 thermal infrared camera for industrial use confirmed that the change in the thermal properties of the road surface in the area of the mating of the embankment occurs by a different mechanism. The ambient temperature at the time of measurement was 9.2 °C, on the surface of the embankment the temperature of the road edge near the roadside – 9.4 °C, on the site of excavation – 8.9 °C (Fig. 1–3).

Fig. 1. The intersection of mound – excavation

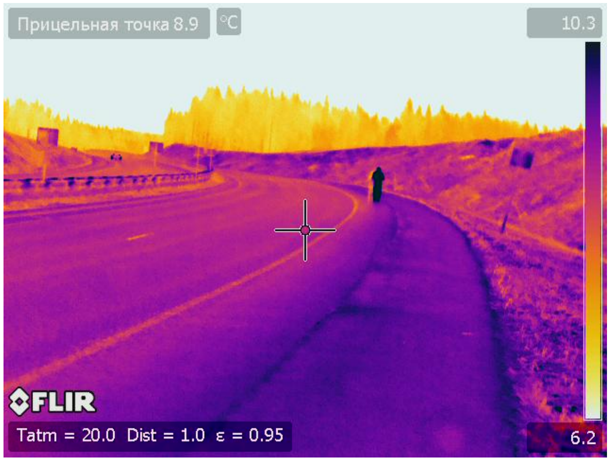

Fig. 2. Surface temperature
(a stretch of road in the excavation)

Fig. 3. Place the interface on the site is a mound – excavation

Figure 4 shows the appearance and the thermal balance of the crack at the junction of the mound – notch. It was determined that the temperature in the crack is higher than on the surface by 1.8 °C and amounted to 11.2 °C. This phenomenon indicates an intense heat and moisture exchange within the road structure [23]. Therefore, in the spring there is a maximum opening of the crack. In the cold time of day (at night) brought through a crack in the day in the layers of the road structure heat is spent on evaporation of water and heating of the surrounding space.

Fig. 4. View and theprogramme cracks in the plot mound – excavation

When compiling the heat diagram of the road surface from the point of junction of the embankment to the point of completion of the excavation, the following was established:

The temperature at the inlet in the recess, and the output is about the same (compared to 10.2 °C on the roadway at a distance of 1 meter from the curb);

At the site of the excavation temperature changed linearly with the inflection point. The lowest temperature was recorded in the middle of the recess and was 8.3 °C.

In this area with the lowest temperature, a transverse frost crack was formed (Fig. 5).

Fig. 5. A transverse frost crack in the middle of excavation

Conclusion

Thus, it is possible to note the pattern of formation of frost transverse cracks at the junction of the notch-mound, as well as in the middle of the notch.

The presence of cracks in the areas of transition from the embankment to the recess, a transverse crack in the middle of the recess is mostly due to changes in the thermal conductivity of materials in the road structure itself under the influence of ambient temperature and the impact of dynamic load from the pneumatic wheels of the car.

Финансирование. *Исследование не имело спонсорской поддержки.*
Конфликт интересов. *Авторы заявляют об отсутствии конфликта интересов.*
Вклад авторов. *Все авторы сделали равный вклад в подготовку публикации.*

Библиографический список

1. Абелев М. Слабые водонасыщенные глинистые грунты как основа сооружения. – М.: Стройиздат, 1973. – 290 с.
2. Ильин Б.А. Теория проектирования лесных дорог: учеб. пособие. – Л., 1963. – Ч. 1. – 180 с.
3. Агейкин В.Н. Несущая способность насыщенных глинистых грунтов при строительстве основания дороги // Тюмень. Государственный архитектор.-строит. Университет Иллинойса. – Тюмень, 2007. – 10 с.
4. Mechanisms of frost heave and salt expansion of soils / X. Xu, J. Wang, L. Zhang, Y. Deng // Beijing. – N.Y.: Science press, 1999. – 167 p.
5. Иноземцев А.А. Упруговязкое сопротивление материалов. – Л.: Стройиздат, 1966. – 168 с.
6. Dafalias Y.F. Corotational rates for kinematic hardening at large plastic deformations // Trans. ASMFE J. of Appl. Mech. – 1983. – No. 3. – P. 561–565.
7. Николаева Г.О., Соловьев Д.Б. Особенности процессов морозного пучения грунтов земляного полотна автомобильных дорог в Центральной Якутии // По британскому летнему времени: бюллетень строительной техники. – 2019. – № 11. – С. 56–59.
8. Saarelainen S. Modelling frost heaving and frost penetration in soil at some observation sites in Finland. The SSR model. – Espoo, VVT, VVV Publication 95, 1992. – 120 p.
9. Тютюнов И.А. Пучение грунтов и количественная оценка этого процесса. – М.: Изд-во НИИОСП, 1981. – Т. 76. – С. 143.
10. Фурман Б.В., Ярмолинский А.И. Причины и методы борьбы с морозным пучением на автомобильных дорогах // Материалы 57-й студенческой научно-технической конференции Инженерно-строительного института ТОГУ. – Хабаровск, 2017. – С. 323–329.
11. Губаева Е.Р. Анализ мероприятий по устранению морозного пучения грунтов дорожного полотна // Сибирская академическая книга. – Казань, 2020. – С. 6–10.
12. Kelm M., Grabe J. FE-simulation of soil compaction // Proc. XIIIth European Conf. on Soil Mechanics and Geotechnical Engineering. – Prague, 2003. – Vol. 1. – P. 739–742.
13. Корнева И.А., Локощенко М.А. Многолетние изменения температуры грунта на разных глубинах в Москве // Состав атмосферы. Атмосферное электричество. Климатические эффекты: материалы XVI Междунар. конф. молодых ученых, Звенигород, 28 мая – 1 июня 2012 г. – ИФА им. А.М. Обухова РАН, 2012. – С. 93.
14. Ратинов В.Б. Химия в строительстве. – М.: Стройиздат, 1960. – 200 с.
15. Устройство дорожных и аэродромных покрытий из щебеночно-асфальтобетонных смесей. – М.: Информавтодор, 2003. – 95 с.

16. Технический отчет по инженерно-строительным изысканиям на объекте «Полигон твердых бытовых и промышленных отходов в Березниках». Ч. I. Маршрут внеплощадочных коммуникаций. – Березники, 1997.

17. Wang Y., Wang B. Study on autocorrelation model and reduction function of variance of soil random field // Proc. of the 1st International Symposium on Geotechnical Safety and Risk (ISGSR2007). – Shanghai, 2007. – P. 265–272.

18. Колесников Г.Н., Гаврилов Т.А., Хорошилов К.В. Сдвиг и растяжение в верхнем слое лесовозной дороги при сезонном промерзании: численное моделирование // Эколого-биологические основы повышения продуктивности и устойчивости естественных и искусственно обновляемых лесных экосистем: материалы междунар. науч.-практ. конф., посвящ. 100-летию высшего лесного образования в Воронеже и Центральном парке России. – 2018. – С. 179–186.

19. Тютюнов И.А. Природа миграции воды в грунтах при промерзании и основы физико-химических методов борьбы с набуханием. – М.: Академия наук СССР, 1963. – 104 с.

20. Тяжелов В.П. Землеройные подрядчики зимой. – М.: Госстройиздат, 1958. – 177 с.

21. Федоров В.И. Процессы влагонакопления и морозоопасности грунтов в строительстве. – Владивосток: Дальниис, 1993. – 178 с.

22. Бургонутдинов А.М. Обоснование способов строительства и ремонта лесных дорог, препятствующих образованию трещин (на примере Пермского края): дис. … канд. техн. наук. – Йошкар-Ола, 2012. – 225 с.

23. Бургонутдинов А.М., Клевеко В.И. Образование морозных трещин на дорогах // Современные проблемы и пути их решения в науке, транспорте, производстве и образовании: материалы междунар. науч.-практ. конф. – Одесса: Черноморское побережье, 2011. – Т. 3, 4. – С. 32–39.

24. Наземный транспорт / Д. Попов [и др.]. – М., 1963. – 863 с.

25. Елоев Т.В., Гудиева И.Н. Деформации конструкций при морозном пучении грунтов // Инновации в науке и практике: сб. ст. по материалам XII Междунар. науч.-практ. конф. – Владикавказ, 2018. – С. 93–96.

References

1. Abelev M. Weak water-saturated clay soils as the base of the structure. Moscow, Stroyizdat, 1973, 290 p.

2. Il'in B.A. Theory of designing forest roads. Part 1. Leningrad, 1963, 180 p.

3. Ageikin V.N. The bearing capacity of saturated clay soils in the road base construction. *Tyumen. state architect.-builds. Univ. of Illinois.* Tyumen, 2007, 10 p.

4. Xu X., Wang J., Zhang L., Deng Y. Mechanisms of frost heave and salt expansion of soils. Beijing. New York, Science press, 1999, 167 p.

5. Inozemtsev, A.A. elastico viscous Resistance of materials. Leningrad, Stroyizdat, 1966, 168 p.

6. Dafalias Y.F. Corotational Rates for Kinematic Hardening at Large Plastic Deformations. *Trans. ASMFE J. of Appl. Mech.*, 1983, no. 3, pp. 561-565.

7. Nikolaeva G.O., Soloviev D.B. Characteristics of the processes of frost heaving of soils of the roadbed of the highways of Central Yakutia. *BST: bulletin of construction machinery*, 2019, no. 11, pp. 56-59.

8. Saarelainen S. Modelling frost heaving and frost penetration in soil at some observation sites in Finland. *The SSR model*. Espoo, VVT, VVV Publication 95, 1992, 120 p.

9. Tyutyunov I.A. Heaving of soils and quantitative estimation of this process. *Proc. of NIIOSP.* Moscow, 1981, vol. 76, pp. 143.

10. Furman B.V., Yarmolinsky A.I. The causes and methods of combating frost heaving on highways. *Materials of the 57th student scientific and technical conference of the Engineering and Construction Institute of TOGU*. Khabarovsk, 2017, pp. 323-329.

11. Gubaeva E.R. Analysis of measures for the elimination of frost heaving of soils of the roadbed. *Siberian Academic Book.* Kazan, 2020, pp. 6-10.

12. Kelm M., Grabe J. FE-simulation of soil compaction. *Proc. XIIIth European Conf. on Soil Mechanics and Geotechnical Engineering*. Prague, 2003, vol. 1, pp. 739–742.

13. Korneva I.A., Lokoshchenko M.A. long-term changes of ground temperature at different depths in Moscow. *Atmospheric Composition. Atmospheric electricity. Climatic effects: proc. of the XVI international salekonferencyjne young scientists*, Zvenigorod, 28 May – 1 June 2012. *ELISA behalf of the A.M. Obukhov RAS*, 2012, pp. 93.

14. Ratinov V.B. Chemistry in construction. Moscow, Stroyizdat, 1960, 200 p.

15. Construction of road and airfield pavements from crushed-stone asphalt concrete mixtures. Moscow, Informavtodor, 2003, 95 p.

16. Technical report on engineering and construction surveys at the site "Landfill of solid domestic and industrial waste in Berezniki". Part I. The route off-site communications. Berezniki, 1997.

17. Wang Y., Wang B. Study on autocorrelation model and reduction function of variance of soil random. *Proc. of the 1st International Symposium on Geotechnical Safety and Risk* (ISGSR2007). Shanghai, 2007, pp. 265–272.

18. Kolesnikov G.N., Gavrilov T.A., Khoroshilov K.V. Shear and stretching in the upper layer of a logging road during seasonal freezing: numerical modeling// Ecological and biological bases of increasing productivity and sustainability of natural and artificially renewed forest ecosystems, Materials of the international scientific and practical conference dedicated to the 100th anniversary of higher forest education in Voronezh and the Central Park of Russia – 2018. – pp. 179-186.

19. Tyutyunov I.A. Nature of water migration in soils during freezing and the basis of physico-chemical methods of combating swelling. Moscow: USSR Academy of Sciences, 1963, 104 p.

20. Tyazhelov V.P. Excavation contractors in winter. Moscow, Gosstroiizdat, 1958, 177 p.

21. Burgonutdinov A.M. Substantiation of methods of construction and repair of forest roads that prevent the formation of cracks (the example of the Perm region). Ph. D. thesis. Yoshkar-Ola, 2012, 225 p.

22. Burgonutdinov A.M., Kleveko V.I. The Formation of frost cracks in the roads. *Modern problems and ways of their solution in science, transport, production and education*. *Proc. of the international. scientific.- prakt. conf.* Odessa, Black Sea Coast, 2011, vol. 3, vol. 4, pp. 32-39.

23. Popov D. [et al.]. Land transport. Moscow, 1963, 863 p.

24. Eloev T.V., Gudieva I.N. Deformations of structures during frost heaving of soils. *Innovations in science and practice, collection of articles based on the materials of the XII International Scientific and Practical Conference*. Vladikavkaz, 2018, pp. 93-96.

25. Fedorov V.I. Processes of moisture accumulation and frost hazard of soils in construction. Vladivostok, Dalniis, 1993, 178 p.