OPTIMAL SELECTION OF SOILS AND AGGREGATES MIXTURES FOR A FROST BLANKET COURSE OF ROAD PAVEMENT STRUCTURE

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Abstract. Resistance to frost of road pavement structure is ensured by a functional frost blanket course from frost non-susceptible soils or aggregate mixtures. The material used and the thickness of frost blanket course must not only ensure the required resistance to frost of road pavement structure but also to increase bearing capacity of the structure, to distribute and reduce pressure to the subgrade surface. The article gives a summary of research on aggregates mixtures and soils used for a frost blanket course and taken from the currently operating quarries in Lithuania. The conclusion of research analysis gives the suggestions for the use of materials for a frost blanket course. Based on the data obtained it is recommended when laying a frost blanket course to take into consideration bulk density and Proctor density of the material used as well as transportation costs.

Keywords: frost blanket course, resistance to frost, frost non-susceptible materials, aggregates, Proctor density, bulk density, California Bearing Ratio (CBR).

1. Introduction

The main factors which determine the required resistance to frost of subgrade and road pavement structure are as follows (Aursand 2008; Bilodeau *et al.* 2008; 2011; Vaitkus 2010):

- the use of frost non-susceptible soils for the construction of the upper part of subgrade located in a freezing zone;
- assurance of the required elevation of road structure over the groundwater or surface water level;
- laying of a frost blanket course, the volume of the material of which does not change under the effect of frost and moisture, or the use of the thermal insulation materials which withhold frost penetration into the underneath layers and reduce the depth of frozen subgrade;
- installation of draining or insulating layers. A draining layer ensures the extremely rapid water discharge from the subgrade, whereas, the insulating layers (e.g. geomembrane) prevent water from getting into the subgrade.

A frost blanket course protects road pavement structure from the damaging effect of frost. The course is laid from the frost non-susceptible aggregate mixtures and/or soils (Hornych 2000). Konrad (2008) stated that a frost blanket course is obligatory when the layers of road pavement and road base are constructed from water permeable materials, and the subgrade is continuously or periodically moistened. Besides a protective function the purpose of a frost blanket course is to carry loads generated by traffic and by the pavement structural layers and to distribute them to the subgrade (Al-Qadi *et al.* 2011; Kavussi *et al.* 2010; Leng, Gabr 2002). Moreover, a frost blanket course drains pavement structure and evenly distributes loads on the subgrade surface, also protects pavement structure from the frost heaves. A frost blanket course is laid from coarse-grained materials (sand, gravel, sand and gravel mixtures, gravel and sand mixtures) the use of which represents the highest amounts in Lithuania (Skrinskas *et al.* 2010). However, when the subgrade is constructed from frost non-susceptible soils (class F1) a frost blanket course can be avoided.

The thickness of a frost blanket course and the materials used must serve four main functions:

- to ensure the required resistance to frost of road pavement structure, i.e. to ensure that the impact of frost heaves in the subgrade caused by frost and soil weakening during a spring flooding period was not damaging;

– to carry loads of road pavement structure, overlying a frost blanket course, as well as traffic loads and to distribute and reduce pressure to the subgrade surface;
– in the shortest possible time to discharge from the subgrade surface water which gets and condenses in pavement structure;
– to prevent pavement structure from water pumping from the subgrade to the upper pavement structural layers.

The reasons of pavement distresses due to the frozen ground, ice lenses and flooding are as follows (Kirschbaum 1994): frost; water and moisture; frost susceptible soils; traffic loads; insufficient load distribution within pavement structure. Freezing distresses in pavement structure show themselves under the effect of the first three reasons (frost, water and frost susceptible soils). For the formation of those distresses traffic loads are not necessary. Distresses related to thawing (flooding) are formed under the effect of all five reasons together. Theoretically, it is possible to avoid those distresses by eliminating at least one reason. Therefore, it is necessary to improve the conditions of hydrothermal mode and to ensure the sufficient thickness of pavement structure resistance to frost on frost susceptible soils (Kirschbaum 1994).

Each season has a different effect on road pavement structure (Motiejūnas *et al.* 2010). Based on the research by Aursand (2008) in autumn when moisture increases the load-bearing capacity decreases to almost 70% (Fig. 1). In winter there are no problems of the load-bearing capacity since pavement structure freezes in and its load-bearing capacity exceeds 100%. Spring is one of the most dangerous seasons. The weather getting warmer the freezing disappears. With a significant increase in the amount of precipitation the soils become soaked and plastic. Thus, in spring the load-bearing capacity decreases even to 30% depending on the type of soil. The more clayey and dusty soils the more water they absorb, the soils swell and become of fluid consistence, and this has a very negative impact on pavement structure and causes pavement distresses. With the decreased amount of precipitation in summer the soils dry out, become waterless and their load-bearing capacity is again 100%.

Measurements with the Falling Weight Deflectometer (FWD), carried out according to the COURAGE (*Construction with Unbound Road Aggregates in Europe*) program, showed that with the increased moisture in road pavement structure the pavement deflections increase. Research by Bjarnason *et al.* (1999) showed that moisture in pavement structure varies from 6.1% (4.7% lower than the optimal) in late autumn to 14.1% (3.3% higher than the optimal) in spring during a flooding period. It was determined by the research that when the ground is frozen from February to mid-March there is large moisture variation, and from mid-March to May the increase in moisture is observed. Research by Laaksonen *et al.* (1999) and Suni and Kujala (1999) indicated that the moisture in road pavement structure decreases from mid-December
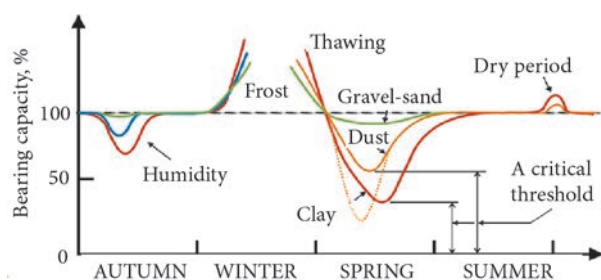

Fig. 1. Relationship between the load-bearing capacity of road pavement structure and the season (Aursand 2008)

to April during a freezing period. Latvian investigations of sand used for laying a frost blanket course concluded that the quality of local sand did not meet the requirements: a low filtration coefficient was determined, as well as a large amount of fines and pollution (Akimovs 2009).

2. Determination of the need for pavement structure resistance to frost and of the required thickness

In Russia, the following method is applied: knowing the local soil and hydrological conditions the thickness of pavement structure resistance to frost H_{frost} is determined in order to avoid in pavement structure the frost heaves of unallowable dimensions. The calculated frost heave of subgrade soil H_{calc} is determined in a way of calculations. When it is obtained that H_{calc} is higher than the allowable H_{allow}, then, it is assumed that there is no need to lay a frost blanket course. In inverse situation when $H_{calc} \geq H_{allow}$ a frost blanket course is obligatory. In this case the problem is solved in inverse order, i.e. the calculated heave $l_{heave, av}$ is determined for the soil of the corresponding pavement type. Having determined the calculated (design) heave $l_{heave, av}$ and knowing the largest frozen ground depth the thickness of pavement structure resistance to frost is defined.

In Sweden, according Swedish *General Technical Construction Specifications for Roads,* roads are designed in such a manner as to ensure their 40-year technical service life. Pavement structures are designed in way that during the whole winter the depth of frozen ground would not exceed the allowable limit values depending on road evenness class, where for pavements of class 1 the allowable depth of frozen ground is 160 mm, of class 2 – 120 mm, of class 3 – 80 mm, of class 4 – 50 mm, of class 5 – 20 mm. The thickness of pavement structure resistance to frost is determined according to the climatic zone, pavement evenness class, frost susceptibility class of soils and traffic class.

In Germany, the type of road pavement structure and the thickness of layers are selected according to the requirements of the document *RStO 01 Richtlinien fur die Standardisierung des Oberbaues von Verkehrsflachen* [Guidelines for the Standardization of the Pavement of Traffic Areas]. Based on this document the *KPT SDK 07 Automobilių kelių standartizuotų dangų konstrukcijų projektavimo taisyklės* [Design Rules of Road Pavement Structure] have been prepared and currently used in Lithuania. According to the frost index Germany is divided into

3 frost zones (I, II, III). Such a zoning of Germany into frost zones is used to determine the thickness of pavement structure resistance to frost. Pavement thickness is corrected (increased or decreased) by the quantity which is equal to the algebraic sum (A + B + C + D) of four criteria: A, B, C and D (A – frost impact, B – height of pavement top, C – water impact, D – zone at the pavement (margin lanes, cycle and pedestrian paths)).

Road pavement structures in Lithuania are selected following the *KPT SDK 07* in consideration of traffic safety, traffic composition, road category, climatic and soil-geological conditions, also the use of local construction materials. A frost blanket course is not laid in case when the road pavement structure has been constructed on soils of the frost susceptibility class *F1* which lie over the soils of classes *F2* and *F3*. The min thickness of pavement structure resistance to frost is determined based on the class of frost susceptibility of soils. The min thickness of pavement structure resistance to frost is once again corrected depending on the height of pavement top, water impact and the zone at the pavement (margin lanes, cycle and pedestrian paths). Juknevičiūtė-Žilinskienė (2010) suggested correcting the thickness of pavement structure resistance to frost by taking into consideration the frost impact in the certain locality. The territory of Lithuania was divided into zones according to the frost index *F1*. In this way, it is possible to correct the thickness of a frost blanket course taking into consideration the locality according to the respective zone.

3. Experimental research

3.1. The object and methodology of research

The deposits of soil, sand and gravel, used for road building in Lithuania, have been formed in alluvium period, whereas, the practical value have only those which occur not deep and are easily accessible for using. Therefore, in Lithuania all the materials, used for laying frost blanket course, are excavated in quarries. For the purpose of research on aggregates mixtures and soils 15 specimens were chosen in 6 quarries. Because of confidentiality the quarries were numbered as: quarry No. 1; quarry No. 2; quarry No. 3; quarry No 4; quarry No. 5; quarry No. 6.

The following materials were chosen in the quarries to implement the research:
- in quarry No. 1 – washed sand of fr. 0/4, sand of fr. 0/4, sand and gravel mix of fr. 0/11;
- in quarry No. 2 – washed sand of fr. 0/5, sand of fr. 0/5;
- in quarry No. 3 – sand and gravel mix of fr. 0/11, sand and gravel mix of fr. 0/32;
- in quarry No. 4 – natural sand No. 1, natural sand No. 2, natural sand No. 3, sand of fr. 0/2, sand of fr. 0/4;
- in quarry No. 5 – gravel of fr. 0/22;
- in quarry No. 6 – sand of fr. 0/2, sand and gravel mix of fr. 0/32.

According to the *TRA SBR 07 Automobilių kelių mineralinių medžiagų mišinių, naudojamų sluoksniams be rišiklių, techninių reikalavimų aprašas* [Road Technical Requirements for Layers without Binders] a frost blanket course shall be laid from soils and unbound mineral material mixtures ranging from fine of fr. 0/2 to coarse of fr. 0/63. For the evaluation and analysis of materials used for laying a frost blanket course the following tests were carried out:
- particle size distribution – sieving method, *LST EN 933-1:2002 Užpildų geometrinių savybių nustatymo metodai. 1 dalis. Granuliometrinės sudėties nustatymas. Sijojimo metodas* [Tests for Geometrical Properties of Aggregates – Part 1: Determination of Particle Size Distribution – Sieving Method];
- filtration coefficient, *R 34-01 Automobilių kelių pagrindai* [Road Base Layers], annex B;
- permeability by constant head, *LST CEN ISO/TS 17892-11:2005 Geotechniniai tyrinėjimai ir bandymai. Laboratoriniai grunto bandymai. 11 dalis. Pralaidumo vandeniui nustatymas esant pastoviam ir kintančiam spūdžiui* [Geotechnical Investigation and Testing – Laboratory Testing of Soil – Part 11: Determination of Permeability by Constant and Falling Head];
- bulk density and voids, *LST EN 1097-3:2002 Užpildų mechaninių ir fizikinių savybių nustatymo metodai. 3 dalis. Piltinio tankio ir tuštymėtumo nustatymas* [Tests for Mechanical and Physical Properties of Aggregates – Part 3: Determination of Loose Bulk Density and Voids];
- laboratory reference density and water content – Proctor compaction, *LST EN 13286-2:2010 Nesurištieji ir hidrauliškai surišti mišiniai. 2 dalis. Laboratoriniai bandymo metodai nustatyti kontrolinį tankį ir vandens kiekį. Proktoro tankinimas* [Unbound and Hydraulically Bound Mixtures – Part 2: Test Methods for Laboratory Reference Density and Water Content – Proctor Compaction], using 2.5 kg hammer;
- California Bearing Ratio, *LST EN 13286-47:2004 Nesurištieji ir hidrauliškai surišti mišiniai. 47 dalis. Laikomosios gebos Kalifornijos rodiklio, tiesioginės laikomosios gebos rodiklio ir linijinio išbrinkimo nustatymo metodas* [Unbound and Hydraulically Bound Mixtures – Part 47: Test Method for the Determination of California Bearing Ratio, Immediate Bearing Index and Linear Swelling].

3.2. Analysis and evaluation of research results

Testing of materials, chosen in the quarries, was carried out in the *Road Research Laboratory of Road Research Institute of Faculty of Environmental Engineering of Vilnius Gediminas Technical University*. The tests showed that the grading of specimens of sand, gravel and their mixtures most often meet the requirements to the passing particles

through the corresponding sieves according to the particle distribution of the material.

The Proctor tests showed a potential tendency that with the wider particle distribution of specimen the Proctor density increases (Fig. 2). The values of bulk density of the specimens are given in Fig. 2. It was determined by the calculations that the amount of voids in bulk soil varies from 28.8% to 63.3%, and in the compacted soil - from 18.2% to 35.7%. The largest variation in the amount of voids was found in natural sand No. 3 taken from the quarry No. 4.

Up to the year 2007 materials used for a frost blanket course had to meet the requirements to filtration coefficient depending on road category: for AM and category I roads > 3.0 m/day, for category II–III roads > 2.0 m/day, and for category IV–V roads > 1.0 m/day. Since 2007, when the rules of *TRA SBR 07* came into force, instead of soil filtration coefficient another index has been used – water permeability index. It is required that on AM–I category roads when laying a frost blanket course the soils with water permeability index > 2.0×10^{-5} m/s shall be used, on category II–III roads > 1.5×10^{-5} m/s and on category IV–V roads > 1.0×10^{-5} m/s. Testing results showed that the properties of water permeability in almost all specimens meet the requirements of permeability index > 2.0×10^{-5} m/s. Water permeability index and filtration coefficient of natural sand No. 1 from the quarry No. 4 were lower than permeability index 2.0×10^{-5} m/s, however, this soil is suitable for laying a frost blanket course on the roads of category II–III (> 1.5×10^{-5} m/s). Water permeability index of sand and gravel mix of fr. 0/32 was the lowest of all suitable specimens.

Having determined water permeability index (x) and filtration coefficient (y) the relationship between those two characteristics was established (1). Correlation coefficient was determined $R = 0.96$. The equation of relationship is:

$$y = \frac{-0.68 + 449249.43x}{1 + 45543.95x - 78295914x^2}.$$

Based on the CBR results obtained (Fig. 3) it was determined that natural sand No. 1 from the quarry No. 4 belongs to the gravel group – the material gravel. This was determined from the grading since the coarse materials larger than 2 mm were found, whereas, the specimens of natural sand No. 2 and No. 3 from the quarry No. 4, the specimens of sand fr. 0/2 from the quarries No. 4 and No. 6, the specimens of washed sand and sand fr. 0/4 from the quarry No. 1 should be treated as weak sand since according to the load-bearing capacity of sand the CBR value should vary from 9% to 14%.

4. Economic comparison of road pavement structures with different thicknesses and materials of a frost blanket course

When laying a frost blanket course the most commonly used are the materials from the quarry situated in the nearest proximity to the construction site, however, sometimes
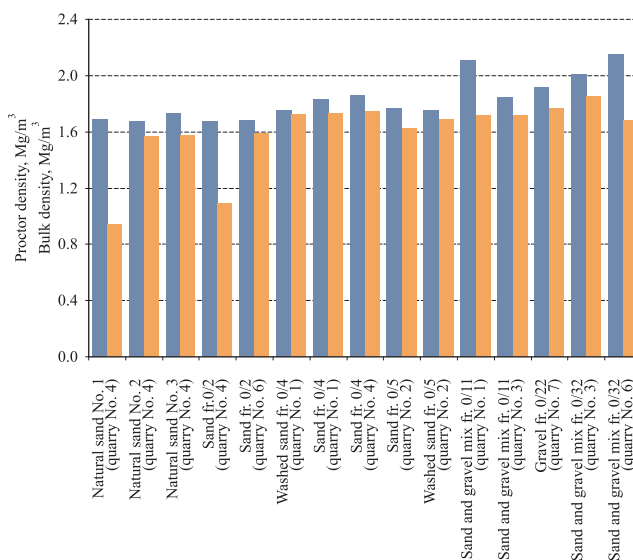

Fig. 2. Results of the Proctor test (Proctor density) and the bulk density test of sand, gravel and their mix
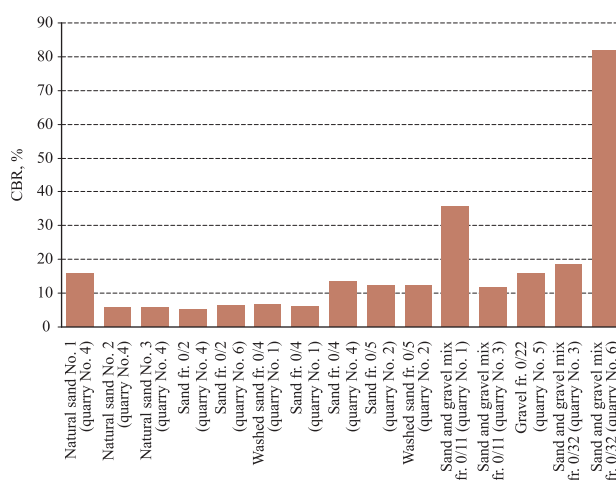

Fig. 3. The values of California Bearing Ratio (load-bearing capacity) of sand, gravel and their mix

the quality of those materials does not meet the requirements to physical and mechanical properties of a frost blanket course, and material transportation costs highly increase the price of laying a frost blanket course. Economic comparison was carried out using the physical and mechanical properties of materials tested in the laboratory in order to evaluate the effect of material properties on the price of laying a frost blanket course. The costs of the quantity of materials used for laying a frost blanket course were calculated during the research for the following road parameters: category III road (*KTR 1.01:2008 Kelių techninis reglamentas "Automobilių keliai"* [Road Technical Regulations "Automobile roads"]); class III pavement structure (*KPT SDK 07*); road section length – 1 km; thickness of a frost blanket course – 42 cm.

Under different physical and mechanical properties of materials the following conditions were assumed: the action of mechanisms used was not considered (due to the

different compaction properties of materials); 100% compaction of a frost blanket course is achieved; material prices were assumed based on official pricelists of the quarries of 1 August 2009.
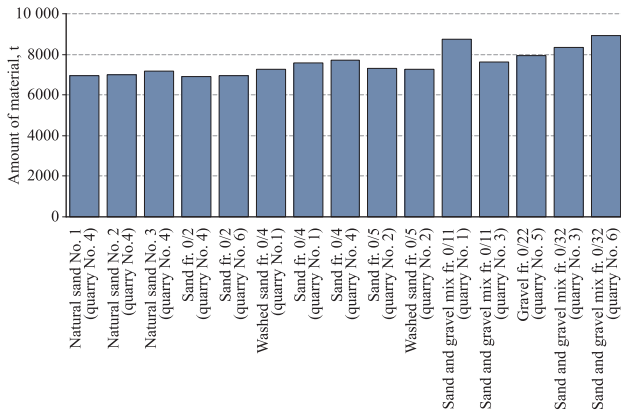

Fig. 4. The need for different materials to lay a 1 km long, 42 cm thick frost blanket course on the road of category III
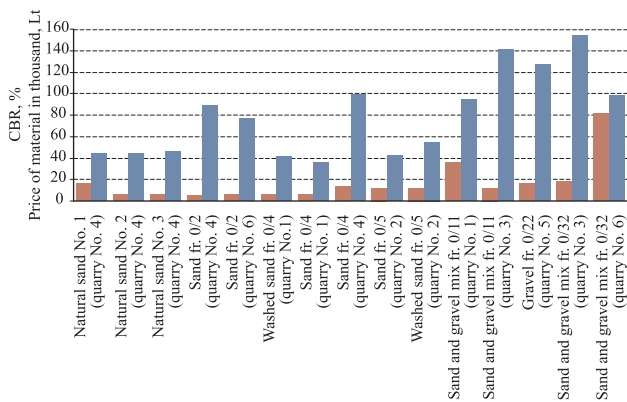

Fig. 5. Relationship between the costs of laying a 1 km long, 42 cm thick frost blanket course and CBR on the road of category III and the type (price) of material
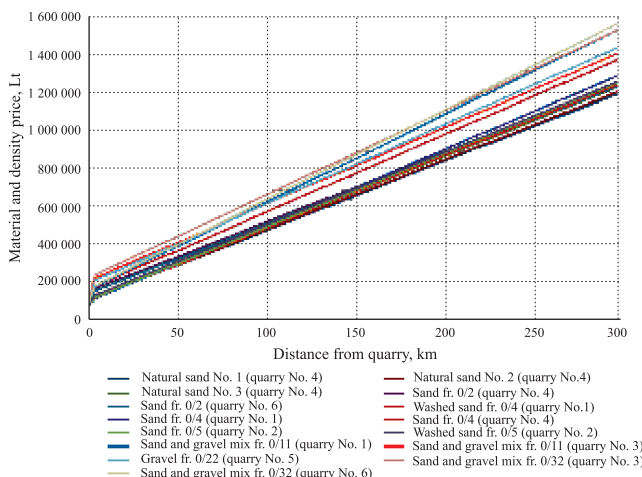

Fig. 6. Relationship between the costs of laying a frost blanket course, the materials and their transportation distance up to 300 km (1 Lt = 3.4528 EUR)

The amount of material resistant to frost necessary for laying a frost blanket course is directly proportional to the Proctor density of the material (Fig. 4). The final price of the amount of necessary material consists of the necessary material amount and the price of a unit of mineral material. Fig. 5 shows that when laying a frost blanket course and using the sand and gravel mix of fr. 0/11 from the quarry No. 1 it is possible to save up to 33% of funds compared to the material of the same type taken from the quarry No. 3. Besides, the CBR of sand and gravel mix of fr. 0/11 from the quarry No. 1 was 199% higher than of the mixture from the quarry No. 3.

It was determined by the research and calculations that the sand and gravel mix of fr. 0/32 from the quarry No. 6 had the best mechanical properties and the costs of material necessary for laying a frost blanket course were lower compared to the sand and gravel mix of fr. 0/11 and fr. 0/22. From the whole tested unbound mineral material mix and soils a natural sand No. 3 from the quarry No. 4 was distinguished since the costs of this material were one of the lowest and the determined mechanical properties were better than those of fractionated mixtures.

Transportation distance (it is assumed that the price of 1 tkm is 0.50 Lt). It was determined that for transportation distances up to 50 km the costs for laying a frost blanket course increase from 2 to 6 times compared to the transportation distance up to 10 km. However, if the materials have to be transported from the distance larger than 10–15 km the transportation costs become a very important factor determining the final price of the layer. Calculation results showed that transportation costs are directly proportional to the Proctor density of mineral material or such the density of mineral material which is obtained having compacted material to the required compaction degree. Relationship between the costs of laying a frost blanket course, the materials and their transportation distance up to 300 km is given in Fig. 6.

When transporting mineral materials from longer distances (100–300 km) the transportation costs increase more than 10 times (Fig. 6). Therefore, it can be stated that when laying a frost blanket course it is worth using as much local (available close to the building site) materials as possible the physical and mechanical properties of which are not of the highest quality. However, if there are no local materials available or they do not meet the current requirements it is recommended to take into consideration the transportation costs depending on the bulk density or the Proctor density of the material.

5. Conclusions and recommendations

1. In many countries when selecting the thickness of pavement structure resistant to frost the frost impact is taken into consideration (frost impact zone, the depth of frozen ground, etc.) depending on the country's region and specific local conditions. Based on those conditions the design thickness of pavement structure resistant to frost is increased or decreased.

2. The grading of tested specimens from sand, gravel and their mixtures taken from various Lithuanian quarries only partly met the requirements to passing particles through the sieves of corresponding size of meshes. However, the amount of particles smaller than 0.063 mm in the mixtures of all tested materials did not exceed the allowable 5% limit value according to the *TRA SBR 07*. This shows that in most cases sand, gravel and their mixtures excavated in the quarries of Lithuania are not polluted with fine particles.

3. The research showed that the Proctor density of specimens increases with the wider particle distribution of material. The void content of bulk soil varies from 28.8 to 63.3%, the amount of air voids in 100% compacted soil varies from 18.2 to 35.7%.

4. The research showed that the results of filtration coefficient and water permeability index meet the requirements to the roads of category AM–I ($> 2.0 \times 10^{-5}$ m/s). Having determined water permeability index and filtration coefficient a strong interdependence of those two characteristics was found, correlation coefficient $R = 0.96$.

5. The costs of laying a frost blanket course do not depend on material physical and mechanical properties. Using the material of better mechanical properties the lower laying costs are possible than using the material of worse characteristics. When calculating the costs of material demand and consumption the density of material is important under which the required compaction is achieved.

6. In locations where there are no materials suitable for a frost blanket course, when calculating costs of a frost blanket course the transportation costs become an important indicator. When choosing the site from which the material will be transported the amount of the required material is a decisive factor which directly depends on the density under which the required compaction is achieved.

7. When selecting material for a frost blanket course, especially where transportation distances are large (> 50 km), it is recommended to take into consideration the Proctor density of the material. Selection of the material with a lower Proctor density enables to reduce the costs of laying a frost blanket course up to 30%.

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