Research on the Physical and Mechanical Characteristics of Stabilized Soil Subgrade of the Central Yakutia

G O Nikolæva

1Highways and Airfield Department, North-Eastern Federal University, 58, Belinsky St., Yakutsk, 677000, Russia.

E-mail: Gamiliya@mail.ru

Abstract. This work presents the results of research four soil samples were taken from the streets of the Gorny District, also tested for compressive strength before and after water saturation and swelling and estimation of physical and mechanical properties of soil stabilized by cement addition. The main aim of this paper was to estimate the optimal cement and water content in soil. The results of a study of the influence of the degree of compaction and temperature on the coefficient of moisture conductivity of thawed and frozen soils are presented. Plots of the dependence of the coefficient of moisture conductivity (KW) are constructed and the corresponding conclusions are drawn.

1. Introduction

Stabilization involves thoroughly grinding the local soil and mixing the soil with appropriate binders so that, after a good compaction and solidification, the soil becomes denser (stronger) and provides a stronger foundation for road pavement. One of the factors affecting the success of the work is that the pavement will become more resistant to weather and climate conditions.

Soil stabilization is the process of improving the engineering properties of the soil and thus making it more stable. It is required when the soil available for construction is not suitable for the intended purpose. However, the term stabilization is generally restricted to the processes that alter the soil material itself for improvement of its properties. A cementing material or a chemical is added to a natural soil for the purposes of stabilization.

Design of road pavement is connected with estimation of mechanical properties of each of the materials used for construction. The purpose of this research work is to recreate the optimal foundation design for roads in Berdigestyakh of the Mountain region.

In order to increase reliability, strength and durability, i.e. the service life of the road structure, the appropriateness of the use of soil stabilization (reinforcement) technologies. Ground stabilization is the process of preparing the ground to provide higher road stability under load, so that it can better withstand heavy traffic loads.

The development of methods for assessing and determining the bearing capacity of soil foundations during the construction of engineering structures involved many scientists such as P. Sherwood, N.N. Maslov, M.P. Klekovina, A. Taner, A. Muhammad and others [1 – 4].
2. Theoretical framework
Khemissa and Mahamedi [5] found that swell pressure decrease as the stabilizer content increased in cement treated samples. Unlike lime, hydration in cement occurs at a faster pace which allows for an immediate strength gain. Therefore, there is no need of a mellowing period when stabilizing with cement; compaction of soil–cement samples is typically conducted within 2 h of initial mixing. The strength gain achieved during compaction may be below the ultimate strength of a soil–cement sample [6]. However, the cement stabilized soil will continue to gain strength over the course of several days [7, 8].

To implement the research on the swelling and estimation of physical and mechanical properties of soil stabilized, laboratory studies were conducted at the Highway and Airport Department of the M. K. Ammosov North Eastern Federal University. The results of the studies of the physical properties of the soils are presented in Table 1.

Table 1. Physical properties of the studied soils.

| Sample Name of the soil | According to GOST 25100 soil refers to | Optimum moisture, % | Maximum density, kg/m³ | Moisture of soil, % | Density of soil, g/sm | Density of soil particles, g/sm | % content PiG in soil |
|------------------------|----------------------------------------|---------------------|------------------------|--------------------|-----------------------|-------------------------------|---------------------|
| №1 fine sand           | 12,46                                  | 2,05                | 1,40                   | 0,65               | 0,65                  | 12,42                         |                     |
| №2 fine sand           | 12,10                                  | 2,14                | 0,20                   | 0,645              | 0,645                 | 11,73                         |                     |
| №3 mixture of fine sand, crushed stone and crushed brick fine sand | 11,49                                  | 2,06                | 0,19                   | 0,61               | 0,61                  | 12,83                         |                     |
| №4 fine sand           | 12,66                                  | 2,35                | 0,80                   | 0,63               | 0,63                  | 13,59                         |                     |

Based on the results of these tests, the appropriate optimal composition was selected for the pavement foundation device in accordance with GOST 23558-94 [9].

The 20 samples of 71.4x71.4 mm were made for testing for compressive strength, 12 samples of 71.4x71.4 mm for water saturation, 12 samples of 71.4x71.4 mm for swelling. In accordance with GOST 23558-94, the samples gained strength within 28 days.

Figure 1. Photograph of the determination of compressive strength.
When selecting the composition, the required amount of binder is established, which ensures the production of processed materials and reinforced primers with specified grades for strength and frost resistance. The results of the studies of the tensile strength when stabilize the soil with the addition of 9% and 12% of cement in Table 2.

**Table 2.** Determination of tensile strength when stabilize the soil with the addition of 9%, 12%, 16% of cement.

| Sample name of the soil | Age    | Addition of cement, % | Compressive strength, MPa | Medium strength, MPa | Demanding strength, MPa |
|------------------------|--------|-----------------------|---------------------------|----------------------|-------------------------|
| №1                     | 28 days| 9                     | 2,10                      |                      |                         |
|                        |        | 12                    | 3,14                      |                      |                         |
|                        |        | 16                    | 6,59                      |                      |                         |
| №2                     |        | 9                     | 2,84                      |                      |                         |
|                        |        | 12                    | 3,78                      |                      |                         |
|                        |        | 16                    | 7,84                      |                      |                         |
| №3                     |        | 28 days               | 2,10                      |                      | 2,0                     |
|                        |        | 9                     | 2,10                      |                      |                         |
|                        |        | 12                    | 3,05                      |                      |                         |
|                        |        | 16                    | 6,10                      |                      |                         |
| №4                     |        | 9                     | 2,04                      |                      |                         |
|                        |        | 12                    | 3,13                      |                      |                         |
|                        |        | 16                    | 5,53                      |                      |                         |

Series results are plotted in the graph of the dependency of the on the content of cement in the soil (Figure 1.).

![Graph of the dependency of the on the content of cement in the soil](image)

**Figure 2.** Graph of the dependency of the on the content of cement in the soil

The compressive strength of samples in all mixtures naturally increases with increasing cement content. In this case, soil No. 1, containing cement in the soil of 16%, had the greatest strength. The soil No. 4 had somewhat lower strength, as one would expect.

3. Materials and methods
There are many factors contributing to the length of curing time required for strength gain in soil–cement samples. These include ambient air temperature, relative humidity, type of cement used, and concentration of cement used.
The given method provides for the calculation of the value of the coefficient of hydraulic conductivity, through measuring the initial values of the soil moisture and density, and the time required to achieve dampening of the front upper surface of the sample when moistened from below [12, 13].

During the tests, the following boundary conditions apply:

- the initial moisture content and density are uniform throughout the volume of the soil sample [14];
- the soil sample, to be moisturized through the bottom surface, has a stable initial moisture content of the upper surface; with the arrival of the moisture to that surface the experiment is completed;
- moistening of the soil sample occurs in an unpressurized mode at a constant rate [15].

![Figure 3. Determination of moisture conductivity coefficients of stabilized soils with the PKVG-F device.](image)

Moisture permeability - the property of non-saturated soil to pass through its pores a non-continuous stream of water under the influence of moisture gradients, which provide gradients of absorption force. These forces arise due to the interaction of water with the surface of mineral particles and air [11].

4. Results and discussion
Two series of tests were conducted. During all two series of tests graphs of dependence of coefficient of moisture conductivity (KW) are constructed and corresponding conclusions are drawn. When establishing experimental regularities, statistical data of experiments performed with 5-fold repetition were analyzed.
Table 3. The results of the study of the dependence of the moisture conductivity coefficient on the degree of compaction of stabilized soils. Moisture coefficient at different values of the coefficient of compaction with an initial humidity of 10%.

| No | Sample name of the soil | initial moisture content, % | compaction ratio | content of cement, % | Full moisture capacity | Time of humidification, hours | Specific gravity of soil particles, g/cm³ | Skeleton density of soil, g/cm³ | Amount of absorbed water, g. | Moisture conductivity coefficient (cm²/s) |
|----|-------------------------|-----------------------------|------------------|---------------------|-----------------------|----------------------------|--------------------------------|-----------------------------------|-----------------|-------------------------------|
| 1  | №1                     | 1,90                        | 0,95             | 9                   | 3,13                  | 0,52                      | 2,65                                | 2,65                              | 0,64            | 6,41                          | 0,20 |
|    |                         |                             | 1,00             | 9                   | 3,18                  | 0,65                      | 2,65                                | 2,65                              | 0,64            | 5,21                          | 0,11 |
| 2  | №2                     | 1,30                        | 0,95             | 9                   | 2,66                  | 0,48                      | 2,65                                | 2,65                              | 0,64            | 7,1                           | 0,17 |
|    |                         |                             | 1,00             | 9                   | 2,68                  | 0,52                      | 2,65                                | 2,65                              | 0,64            | 5,56                          | 0,12 |
| 3  | №3                     | 0,59                        | 0,95             | 9                   | 1,78                  | 0,54                      | 2,65                                | 2,65                              | 0,61            | 6,2                           | 0,22 |
|    |                         |                             | 1,00             | 9                   | 1,79                  | 0,89                      | 2,65                                | 2,65                              | 0,63            | 4,89                          | 0,43 |
| 4  | №4                     | 0,70                        | 0,95             | 9                   | 2,01                  | 0,58                      | 2,65                                | 2,65                              | 0,63            | 6,8                           | 0,41 |
|    |                         |                             | 1,00             | 9                   | 2,03                  | 0,68                      | 2,65                                | 2,65                              | 0,63            | 2,56                          | 0,35 |
|    |                         |                             | 1,05             | 9                   | 2,04                  | 0,89                      | 2,65                                | 2,65                              | 0,63            | 2,06                          | 0,29 |

Figure 4. Graph of the dependency of the coefficient of hydraulic conductivity (KW) on the degree of compaction (Kcom) of stabilized soils.

The method involves the following boundary and initial conditions:
From the first series of studies of the dependence of the coefficient of moisture conductivity on the degree of compaction of thawed soil, it follows that the type of soil and the degree of compaction are of
great importance for the capillary rise of moisture. Studies show that the coefficient of moisture permeability (Kw) of the soil depends on the degree of compaction. Therefore, increasing the degree of compaction of the soil of the subgrade is one of the most effective measures to stabilize the water-thermal regime of the road structure [16, 17].

![Graph of the dependency of the coefficient of hydraulic conductivity (Kw) on the temperature of the frozen stabilized soil.](image)

**Figure 5.** Graph of the dependency of the coefficient of hydraulic conductivity (Kw) on the temperature of the frozen stabilized soil.

From the second series of studies of the dependence of the moisture conductivity coefficient on the temperature of frozen soil it is clear that moisture freezes in the middle pores, whose share in the total porosity of the heaving soils is very high. This leads to a sharp drop in the content of the liquid phase in the soil and, as a consequence, a drop in the conductivity of the soil water. The conductivity of the soil of water gradually decreases at a temperature in the region of -2.5 to -4°C [19-21].

5. **Conclusions**

When solving the tasks, the following results were obtained:

- a series of experiments was carried out to determine the compressive strength before and after water saturation and swelling;
- the results of a study of the influence of the degree of compaction and temperature on the coefficient of moisture conductivity of thawed and frozen soils are revealed.

Thus, we can conclude that as a result of the work, a linear nature of the change in the strength of the soil fortified from the cement content was revealed. The greatest increase in the strength of the material at 28 days of age is achieved with an increase in the dosage of cement.

6. **References**

[1] Sherwood P 1993 Soil stabilization with cement and lime Transport Research Laboratory (College Park)

[2] Taner A 2005 Recent Experiences with Cement and Lime – Stabilization of Local Typical Poor Cohesive Soil pp 448–453

[3] Chen L, Lin D-F 2009 162 Stabilization treatment of soft subgrade soil by sewage sludge ash and cement J. Hazard. Mater. pp 321–327
[4] Muhammad A 2019 Performance Evaluation of Sustainable Soil Stabilization Process Using Waste Materials

[5] Khemissa M, Mahamedi A 2014 Cement and lime mixture stabilization of an expansive over consolidated clay Appl Clay Sci 95 pp 104–110

[6] Little D N, Nair S 2009 Recommended practice for stabilization of subgrade soils and base materials National cooperative highway research program Transportation research board of the national academies

[7] Chittoori BCS 2008 Clay mineralogy effects on long-term performance of chemically treated expansive clays, Doctoral dissertation, The University of Texas at Arlington

[8] Pedarla A, Chittoori S, Puppala A 2011 Influence of mineralogy and plasticity index on the stabilization effectiveness of expansive clays Transp Res Rec J Transp Res Board 2212 91–99

[9] GOST 23558-94 Mixtures of crushed stone-gravel-sand and soils treated with inorganic binders for road and airfield construction

[10] Nikolaeva G O 2018 Research on the hydraulic conductivity properties of the materials of the soil subgrade of the highways of Central Yakutiya Transport business of Russia 6 pp 347-351

[11] Li J, Cameron D A, Ren G 2014 “Case study and back analysis of a residential building damaged by expansive soils” Computers and Geotechnics vol 56 pp 89–99

[12] Emelyanova T Ya, Kramarenko V V 2009 Workshop on merzlitovedeniya Art (Tomsk. Izd-on TPU)

[13] Zolotar I A, Puzakov N A, Sidenko V M 1971 Water-thermal regime of the roadbed and road clothes Transport (Moscow) p 413

[14] Roman L T, Ershov E D, Volokhov S S 1995 Methods for determining the mechanical properties of frozen soils Publishing house of Moscow state University (Moscow) 160 p

[15] Roman L T 2002 Mechanics of frozen soils (M: MAIK.“Nauka/Interperiodica,”) 426 p

[16] Ershov E D 2002 General Geocryology: a Textbook MSU Publishing house (Moscow) 682 p

[17] Ershov E D, Danilov I D, Cheverev V G 1987 Petrography of frozen rocks. Textbook MSU Publishing house (Moscow) 311 p

[18] Bittelli M M, Flury M A 2003 Thermodielectric analyzer to measure the freezing and moisture characteristic of porous media Water resources research Vol 39 2 p 10

[19] Puzakov N A 1960 Water-thermal regime of the roadbed Avtotransizdat (Moscow) 128 p

[20] Tsarapov M N 2018 Manual to determine the physicomechanical properties of freezing frozen and thawing dispersed soils University book (Moscow) 188 p

[21] Mokeev M A, Urkhanova L A, Khagleev A N, Solovev D B 2020 The Impact Evaluation of Factors on the Adhesion of Modified Polytetrafluoroethylene Films in a Glow Discharge Non-Thermal Plasma Materials Science Forum 992 658-662. [Online]. Available: https://doi.org/10.4028/www.scientific.net/MSF.992.658