International Journal of GEOMATE, Aug. 2023, Vol. 25, Issue 108, pp.191-198
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.108.3849
Geotechnique, Construction Materials and Environment

A PRACTICAL SOLUTION FOR IMPROVING SOIL BASES IN PROBLEMATIC ENGINEERING CONDITIONS

*Assel Tulebekova[1], Aizhan Zhankina[1], Raikhan Imambayeva[2], Bekbolat Makhiyev[3], Alexandr Khapin[3], Darya Anop[3]

[1]Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Astana, Kazakhstan
[2]International Educational Corporation, Almaty, Kazakhstan
[3]D. Serikbayev East Kazakhstan Technical University, Ust-Kamenogorsk, Kazakhstan

*Corresponding Author, Received: 01 March 2023, Revised: 23 April 2023, Accepted: 28 May 2023

ABSTRACT: Improving the quality and efficiency of construction on problematic soil conditions largely depends on the correct assessment of their properties, the choice of foundations, and structural and technological solutions. This study presents a practical solution for improving soil bases using reinforcement as the chosen method of improvement. The effectiveness of the reinforcing element was established experimentally, which made it possible to identify the peculiarities of changing strength and deformation properties of ground bases reinforced with geosynthetic material, as well as the possibility of modeling destructive soils using a "quasi-soil" approach. Analysis of the influence of reinforcing geosynthetic material proved its positive effect on the properties of the ground. The calculation of the coefficient of relative collapse after reinforcing became 0.03. Geosynthetic material is not subject to rotting, or root penetration, the structure of the material provides good strength and filtering properties. Thus, the use of geosynthetic materials allows the improvement of the mechanical properties of soils in a targeted way.

Keywords: Road, Embankment, Soil Base, Pavement, Geosynthetics

1. INTRODUCTION

Road infrastructure, along with other infrastructure branches, is an important tool for achieving economic, political, social, and other goals, ensuring the improvement of the quality of human life [1]. Today the length of public roads in Kazakhstan is 96.000 km, of which the national network is 25.000 km, and the local network is 71.000 km [2].

To create an efficient and competitive transport infrastructure in Kazakhstan the State Program of Infrastructural Development "Nurly Zhol" for 2020-2025 was developed [3]. Its main objectives are to improve the technological, scientific, methodological, and resource provision of the infrastructure complex, and to facilitate the attraction of "Big Transit"[4].

It should also be highlighted that the territory of the Republic of Kazakhstan is characterized by one of the most problematic engineering and geological conditions [5]. And some areas of the territory of the republic are occupied by collapsible soils [4].

Being in a stressed state under the action of the weight of the construction and its own weight, these soils when soaking provide additional drawdown deformation caused by a radical change in the soil structure [1]. Therefore, when designing based on collapsible soils it is necessary to consider the possibility of their soaking and the occurrence of collapsible deformations [6-7]. The increase in their humidity may be due to explicit waterlogging owing to the soaking of soils from the external sources from the top and from the bottom at the rise of groundwater level, as well as implicit waterlogging due to the gradual accumulation of moisture in the soil due to surface water infiltration and screening of built-up areas surface [8].

Design and construction of highways on collapsible soils ensuring their strength and normal operation is one of the most important and complex problems of modern construction [9]. In this matter, it is necessary to ensure the driving safety and durability of the structure, one of the criteria of which is the bearing capacity of the soil [10].

The bearing capacity is largely influenced by the condition of the upper wetted zone of the ground [11]. The design of constructions on structurally unstable soils is regulated by the standard [12], which prescribes several necessary measures: to determine the type of collapsible soil (I, II types by making the experimental excavation); to study the characteristics of soils and take them into account when designing roads (during the geological survey); to monitor the road collapsible deformations [2].

Today, world practice uses different methods and ways to eliminate collapsible properties of soils, including compaction, consolidation, and the use of soil cushions [13]. Methods such as one-solution silicification [14], thermal firing [15], and fiber [16] can be used to consolidate collapsible soils. The construction of a ground cushion creates a layer of non-collapsible soil in the foundation base. Another method is the construction of fixed soil columns and piles in weak dusty-clayey soils, using combinations of jetting and boring methods or combining jetting technology with the immersion of pre-reinforced concrete elements, which also shows promise [17].

Also, one of the effective methods of designing structures on collapsible soils is the reinforcement of foundation soils [18]. One of the basic concepts of soil reinforcement is related to a scheme in which weak soil masses are reinforced with high-strength elements and diaphragms that are placed in the ground [19]. In this case, both vertical and horizontal reinforcement is possible [20], which in each case has a different effect on the stress-strain state of foundation soils, as well as the operation of foundations. The improvement of ground and soil base reinforcement is directly related to the materials used for reinforcement [21].

Despite extensive research, many aspects of the problems mentioned are far from being solved, especially at the regional level with the development of specific recommendations for various methods of base preparation.

This is evidenced by the continuing difficulties with the operation of transportation structures. This study presented one of the structural and technological solutions adopted in the construction of roads in problematic engineering geological conditions.

2. RESEARCH SIGNIFICANCE

The study of methods to improve soil bases in problematical engineering conditions and the choice of solutions to improve the quality and efficiency of construction of structures, considering their properties is an important task. In this work, the improvement of soil base properties is carried out by reinforcing with geotextiles.

Laboratory tests have demonstrated that the use of geotextile reinforcement can increase the bearing capacity and improve the deformation properties of subsiding soils. The implementation of these structures can significantly reduce the cost of road base construction, as the soil's characteristics can be significantly improved through the introduction of reinforcing elements.

3. MATERIALS AND METHODS

The object is located in the Almaty region, Kazakhstan. Physical and mechanical properties, material composition, and salinity indicators of various engineering-geological elements (EGE) of soils were obtained by laboratory methods [4]:

- EGE-1. Topsoil layer;
- EGE-2. Asphalt-concrete (road pavement);
- EGE-3; 3a. Bulk soil;
- EGE-4. Lean clay brown loessal light very stiff subsiding. The initial collapsible pressure is 0.495 kg/cm².
  The coefficient of relative collapsible at a specific pressure of 0.5 kg/cm² is 0.008 to 0.011; at a specific pressure of 1.0 kg/cm² is 0.012 to 0.020; at a specific pressure of 2.0 kg/cm² is 0.017 to 0.028; at a specific pressure of 3.0 kg/cm² is 0.021 to 0.028. Engineering-geological conditions in terms of collapsible refer to type I (first).
- EGE-5. Lean clay brown loessal light very stiff non-subsiding;
- EGE-6. Lean clay brown loessal light soft non-subsiding.

3.1 Structural solutions of the considered pavement

When designing structures on collapsible soils, it is necessary to consider the possibility of increasing their moisture content. So, the design of pavement structures is a responsible stage [22]. The structural solutions of the considered pavement are shown in Fig.1.

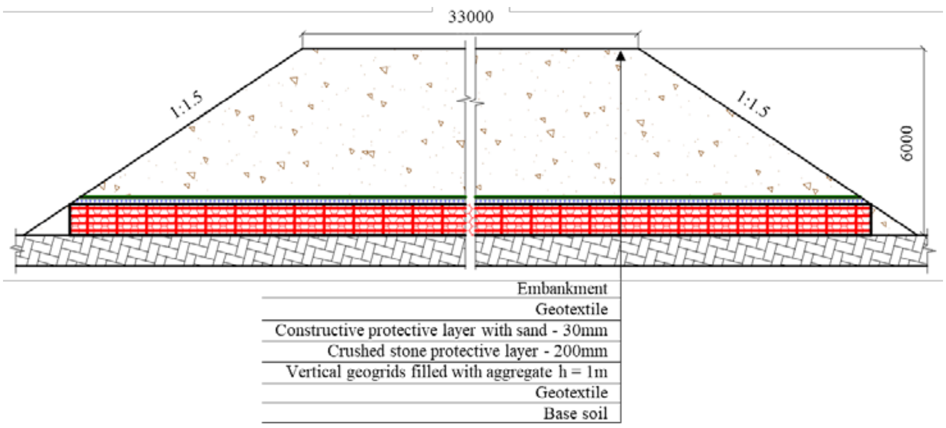


Fig.1 Type of pavement

Pavement design is carried out according to the requirements of the standard [12], considering regional conditions. The pavement structure of the road consists of polymer asphalt concrete, dense hot paving asphalt concrete (grade I), hot-laid porous asphalt concrete (grade II), a base layer, and a subbase layer. Considering this, it is necessary to provide a set of measures, including the elimination of collapsible properties, which include water protection and structural measures.

The drainage layer is built based on the principle of volumetric absorption, in which water entering the layer can be stored in its pores at full volume without any discharge. These layers are placed only under the road pavement.

Water in the drainage layer with some reserve in its thickness for the height of capillary rise does not have a harmful effect on the road surface. The pavement design consisted of selecting the most suitable materials based on local resources, proper dimensioning of individual layers, and their paving to the required depth. All intersections of the designed roadway had an asphalt concrete surface with a gravel base. Asphalt concrete offers a smooth and durable riding surface that can withstand heavy traffic and provide adequate friction.

Moreover, asphalt concrete has excellent water resistance properties, which help prevent water infiltration into the underlying layers and reduce the risk of pavement damage due to freeze-thaw cycles. It also provides a skid-resistant surface, ensuring sufficient friction between the tires and the road, enhancing vehicle safety. Regular maintenance and periodic resurfacing are necessary to prolong the lifespan of the asphalt concrete pavement. This includes activities such as crack sealing, pothole repairs, and resurfacing to address surface distress and maintain the ride quality of the road.

3.2 Soil improvement

When sampling undisturbed collapsing soil structures, it is difficult to preserve their natural state. Therefore, errors occur during laboratory tests that can affect the reliability of the test results [20].

In this regard, an attempt was made to simulate artificial soil that would be similar in its properties to the collapsing soil - "quasi-collapsing soil" according to the method proposed by V. Mustakimov [20].

Therefore, a method of making quasi-collapsing soil using quicklime was proposed. It was supposed that after soaking, quenching, and complete drying of samples of quicklime and soil disturbed structure, pores, and structurally unstable bonds formed, which were destroyed under repeated soaking and loading, which subsequently led to large deformation of samples (collapsing). For improving the soil base a nonwoven geotextile was selected.

Geotextiles are widely used for the construction and strengthening of embankments with high steepness of loose materials, retaining walls, protecting areas from landslide phenomena, separating soil layers, and stabilizing weak soils (soil reinforcement). They are also extensively used to strengthen the bases of railways and roads due to their excellent performance characteristics. Placing a geotextile between these layers, prevents the mixing and migration of particles, maintaining the integrity and stability of each soil layer.

Road geotextiles are known for their elasticity, resistance to mechanical and chemical damage, ability to withstand temperature changes, and exceptional water-transmitting properties [23].

The methodology of the odometer experiments with standard shear rings is presented in Fig. 2. A mixture of disturbed loam and air binder-quicklime (CaO) was used to prepare quasi-collapsing soil. Prior to determining the physical characteristics of the soil using laboratory methods such as moisture content, upper limit of plasticity, and lower limit of plasticity, three mixtures were prepared with varying ratios of quicklime to soil: 60%-40% (sample 1), 50%-50% (sample 2), and 40%-60% (sample 3).

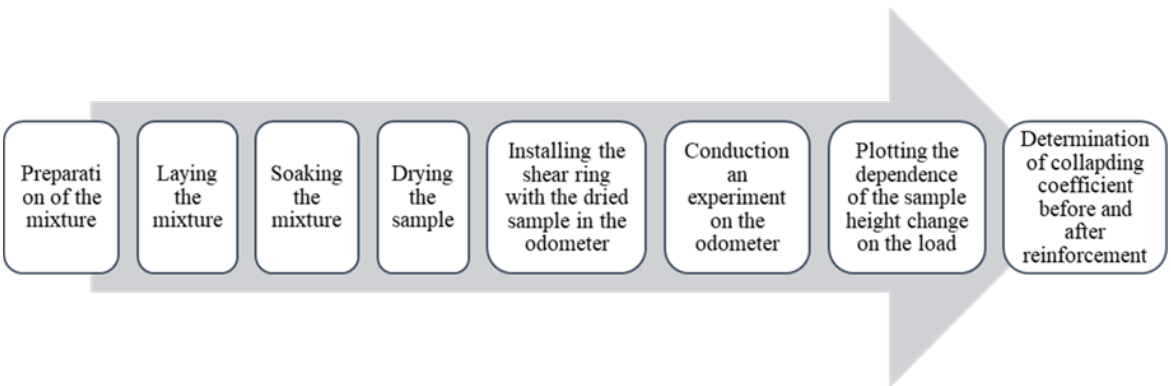


Fig.2 Methodology for experiments

Samples 1a, 2a, and 3a were prepared in the same ratio for reinforcement. The first part of the test aimed to determine the effect of the percentage of quicklime and disturbed soil on quasi-soil collapsing. The mixture of these components was placed in standard odometer shear rings with a diameter of 20 mm (Fig. 3) in a dry state.

Fig. 3 Samples before soaking

Soaking until complete water saturation was carried out, and lime was quenched with a significant increase in the sample volume in the ring.

The rise of the volume of artificially made samples at quenching of lime was within 70-90% due to the formation of macropores (Fig. 4).

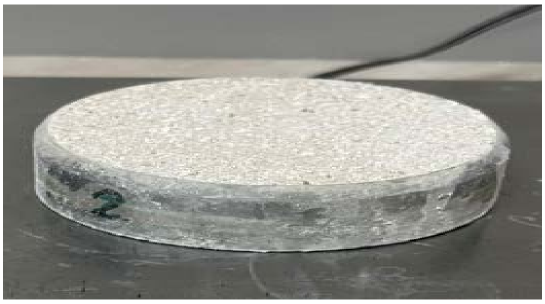
Fig.4 Samples after soaking

After complete quenching, the specimens were subjected to drying in heating furnaces. For this purpose, a nonwoven geotextile was selected. The physical and mechanical characteristics are given in Table 1**.**

Table 1 Values of physical and mechanical characteristics of non-woven geotextile

Name of indicators		Material Non-woven geotextile
Surface density g/m^2		530
Breaking load, kN/m	lengthways	13
	across	14
Relative elongation at break, %	lengthways	50
	across	60

Then the protruding part of the quasi-soil was removed, and a layer of geotextile was placed on it so that the total height of the tested soil with the geotextile was the same height as the shear ring (Fig.5). After these were conducted to determine the effect of quasi-soil reinforcement on collapsing.



a)

b)

Fig.5 Prepared samples: a) sample b) sample with reinforcement

Installing the shear ring with the dried sample in the odometer. Experiment with the odometer presented in Fig.6.

Fig.6 Testing of quasi-soil samples on the device of uniaxial compression

After installing the rings in the odometer, the samples were subjected to uniaxial compression. At that, loading was performed in stages, and each loading was withheld until the settlements stabilized (stabilization condition of 0.01 mm/min). The load was applied one kilogram at a time up to 5 kg. To obtain collapsing, the specimen was soaked at 3 kg during the experiment. After each loading, strain values were taken from watch-type indicators (WTIs). A coefficient of relative collapsing was used to describe the degree of quasi-soil collapsing.

$$\boldsymbol{\varepsilon_{st}} = \frac{\boldsymbol{h - h_{st}}}{\boldsymbol{h_0}} \quad (1)$$

where:

h – height of the sample of natural moisture at a given pressure;

$\boldsymbol{h_{st}}$ – the height of the sample after collapsible as a result of soaking;

$\boldsymbol{h_0}$ – the height of the soil sample with natural humidity at natural pressure at the sampling depth.

4. RESULTS AND DISCUSSIONS

Results of soil experiments in an odometer with soaking are presented in Table 2. Graphs of the sample height vs. load for different variations in the dosage of quicklime soil are presented in Fig. 7.

Table 2 Processed results after the quasi-collapsible soil test

Load, kg	Time, min	Indicator	$\boldsymbol{\Delta h \times 0.002 - h}$
Sample 1 - loam 60% - quicklime 40%			
1	15	40	19.92
2	15	146	19.71
3	15	280	19.44
3 (sat)	45	582	18.84
4	15	703	18.59
5	15	790	18.42
Sample 1a - loam 60% - quicklime 40% reinforced by geotextile			
1	15	193	19.61
2	15	375	19.25
3	15	511	18.98
3 (sat)	45	721	18.56
4	15	846	18.31
5	15	993	18.01
Sample 2 - loam 50% - quicklime 50%			
1	15	8.5	19.98
2	15	44	19.91
3	15	122	19.76
3 (sat)	45	478	19.04
4	15	675	18.65
5	15	895	18.21
Sample 2a - loam 50% - quicklime 50% reinforced by geotextile			
1	15	5	19.99
2	15	70	19.86
3	15	162	19.68
3 (sat)	45	462	19.08
4	15	620	18.76
5	15	808	18.38
Sample 3 - loam 40% - quicklime 60%			
1	15	21	19.96
2	15	187	19.63
3	15	286	19.43
3 (sat)	45	666	18.67
4	15	833	18.33
5	15	966	18.07
Sample 3a - loam 40% - quicklime 60% reinforced by geotextile			
1	15	30	19.94
2	15	140	19.72
3	15	265	19.55
3 (sat)	45	540	18.92
4	15	713	18.57
5	15	925	18.15

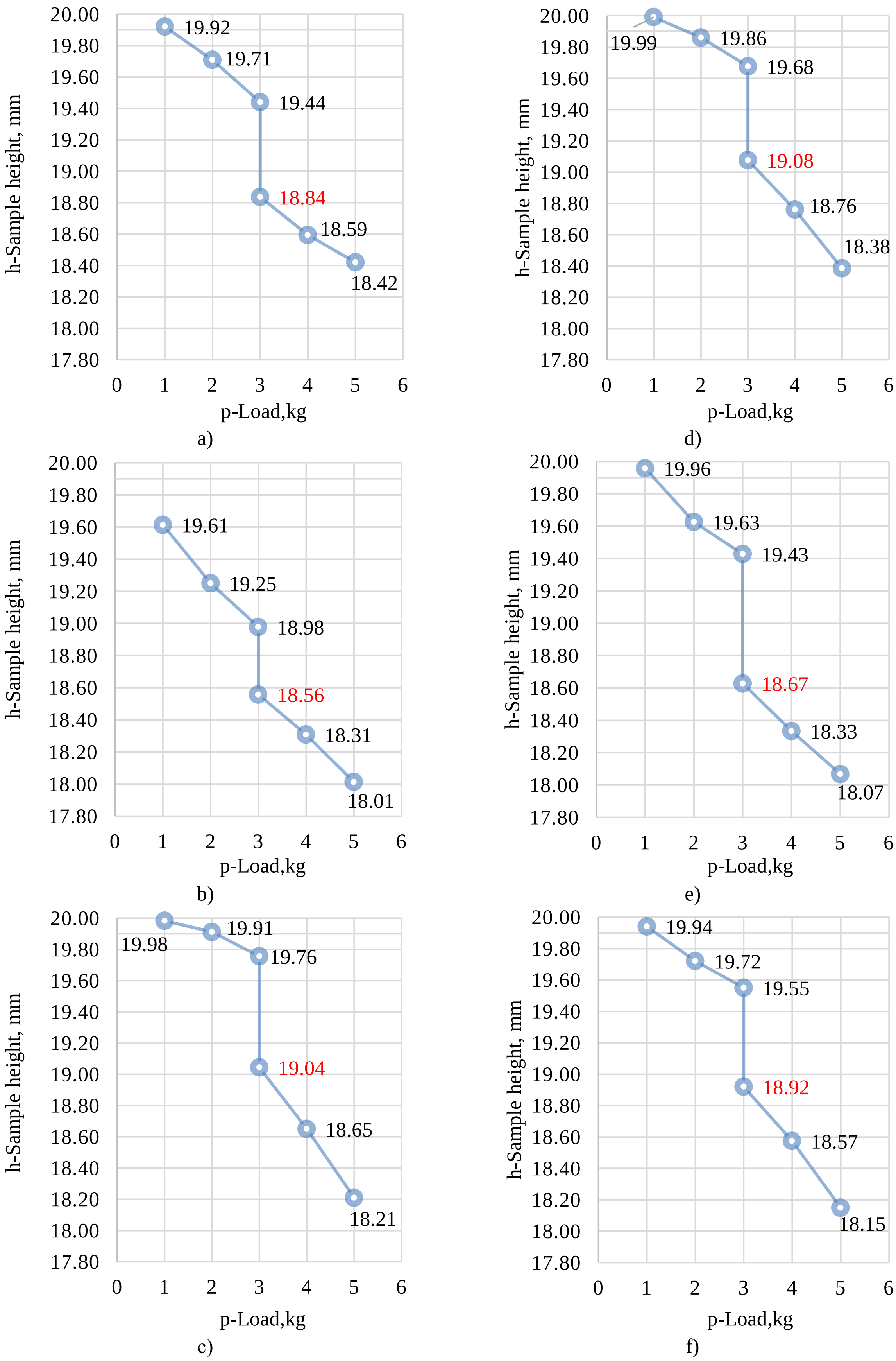


Fig.7 Dependence of change in sample height h on load P with soaking at 3 kg for soil ratio a) Sample 1 b) Sample 1a c) Sample 2 d) Sample 2a e) Sample 3 f) Sample 3a

The graphs presented show that geotextile-reinforced quasi-collapsing soil exhibits less collapse during soaking compared to quasi-soil without geotextile.

Therefore, reinforcing quasi-collapsing soil with geotextile improves its bearing capacity and deformation properties (Table 3).

Table 3 Changing relative collapse of quasi-soil

Sample	Relative collapse without geotextile reinforcement	Relative collapse with geotextile reinforcement
1	$\boldsymbol{\varepsilon_{st} = 0.03 > 0.01}$	$\boldsymbol{\varepsilon_{st} = 0.02 > 0.01}$
2	$\boldsymbol{\varepsilon_{st} = 0.04 > 0.01}$	$\boldsymbol{\varepsilon_{st} = 0.03 > 0.01}$
3	$\boldsymbol{\varepsilon_{st} = 0.04 > 0.01}$	$\boldsymbol{\varepsilon_{st} = 0.03 > 0.01}$

5 CONCLUSIONS

The peculiarities of designing structures in difficult soil conditions were explored in this study. When designing road structures in difficult soil conditions, it is necessary to:

- Consider the possibility of increasing soil moisture content due to soaking the soil from external sources (rainwater, meltwater) from above.
- Provide measures to prevent the penetration of surface and anthropogenic water into the foundations.
- Provide runoff and channel-regulating structures and measures to prevent flooding adjacent to unregulated medium and small rivers and protect crossings under highways.

The model of soil showing collapsible properties (quasi-collapsible soil) is obtained. reinforcement of the collapsible soil with geomaterials, namely geotextile, allows for increasing the bearing capacity of the soil and improves its deformative properties.

6 ACKNOWLEDGMENTS

The authors are grateful to Gulzhanat Tanyrbergenova, a Senior Lecturer in the Department of Civil Engineering and ENU-Lab of L.N.Gumilyov Eurasian National University for support in conducting the laboratory tests.

7 REFERENCES

[1] Paikun, Irawan A., Suminar E., Bahri S., Rozandi A., Road Infrastructure Completeness Factors on Road Section Performance, 2021 IEEE 7th International Conference on Computing, Engineering and Design (ICCED), 2021, p. 1–6.

[2] Development Roads Committee of the Ministry of Industry and Innovative. Automobile Roads; Available online: https://www.gov.kz/memleket/entities/roads/activities/252?lang=ru.

[3] Government of the Republic of Kazakhstan. State Program Infrastructural Development Republic of Kazakhstan "Nurly Zhol for 2020 – 2025; Available online: https://primeminister.kz/ru/gosprogrammy (accessed on 9 December 2020).

[4] Zhussupbekov A.Zh., Zhankina A.K., Tulebekova A., Yessentayev A., Zhumadilov I., Features of the bearing capacity estimation of the collapsing soil bases, International Journal of GEOMATE, Vol.22, Issue 92, 2022, pp.32-40.

[5] Tulebekova A.S., Alibekova N.T., Zhumadilov I.T., Alipbayeva G.R. Advantages of the piles testing methods according to the USA standards, Challenges and Innovations in Geotechnics - Proceedings of the 8th Asian Young Geotechnical Engineers Conference, 8AYGEC, 2016, p. 51 – 56.

[6] Hamdy D.B., A sustainable approach for improving the behavior of collapsible soil using marble dust, Innovative Infrastructure Solutions, Vol.7, Issue 4, 2022, P. 260.

[7] Reznik Y.M., Influence of Physical Properties on Deformation Characteristics of Collapsible Soils, Eng. Geol., Vol.92, 2007, pp.27–37.

[8] Opukumo A.W., Davie C.T., Glendinning S., Oborie E., A review of the identification methods and types of collapsible soils, Journal of Engineering and Applied Science, Vol. 69, 2022, p. 17-1-17-2.

[9] Zarei C., Wang F., Qiu P., Laboratory Investigations on Geotechnical Characteristics of Albumen Treated Loess Soil, KSCE Journal of Civil Engineering, Vol.26, 2022, p. 539-549.

[10] Trofimov V.T., On the Results of Engineering Geological Research of Loess-Soil Massifs of Northern Eurasia, MoPow Univ. Geol. Bull, Vol.71, 2016, pp.457–461.

[11] Zhussupbekov A., Tulebekova A., Jumabayev A., Zhumadilov I., Assessment of soils deformability under vertical load. International Journal of GEOMATE, Vol. 18, Issue 70, 2020, pp.221-228.

[12] Interstate Council for Standardization. Public Highways. Rules for Design of Highways in Difficult Conditions; GOST 33149-2014; Office of Technical Regulation and Rationing of the Construction Committee, Housing and Communal Services and Management Land Resources of the Ministry of National Economy of the Republic of Kazakhstan:

Astana, Kazakhstan, 2017. Available online: https://online.zakon.kz/Document/?doc_id=34246856 (accessed on 1 January 2017).

[13] Niu L., Ren W., Zhang A., Wang Y., Liang Z., Han J., Experimental Study on the Influence of Soluble Salt Content on Unsaturated Mechanical Characteristics of Undisturbed Ili Loess, Bull Eng. Geol. Environ, Vol.80, 2021, pp. 6689–6704.

[14] Lv Q., Wang S., Wang D., Wu Z., Water Stability Mechanism of Silicification Grouted Loess, Bull. Eng. Geol. Environ., Vol.73, 2014, pp.1025–1035.

[15] Bellil S., Abbeche K., Bahloul O., Treatment of a Collapsible Soil Using a Bentonite–Cement Mixture, Stud. Geotech. Mech, Vol.40, 2018, 40,pp. 233–243.

[16] Ayeldeen M., Azzam W., Arab M.G., The Use of Fiber to Improve the Characteristics of Collapsible Soil Stabilized with Cement, Geotech. Geol. Eng., Vol.40, 2022, pp.1873–1885.

[17] Hameedi M.K., Field Study on Soft Soil Improvement Using Continuous Flight Auger (CFA) Piles, Int. J. GEOMATE, Vol.21, 2021, doi:10.21660/2021.86.j2329.

[18] Copetti Callai S., Tataranni P., Sangiorgi C., Preliminary Evaluation of Geopolymer Mix Design Applying the Design of Experiments Method, Infrastructures, Vol.6, 2021, p.6030035.

[19] Muzdybayeva, T.K., Zhussupbekov, A.Zh., Toleubayeva, Sh.B., Muzdybayev, Ye,. Analysis of Interaction of Geosynthetics and Collapsible Soils on the Examples of the Use in Kazakhstan. In Proceedings of the 11th International Conference on Geosynthetics 2018, p.50.

[20] Mustakimov V. Study of Collapsing Soils Reinforced by Vertical Elements, 2016, p.105.

[21] Neeraj Singh Parihar, Rajesh Prasad Shukla and Ashok Kumar Gupta, Effect of Reinforcement on Soil, Int. J. Appl. Eng. Res., Vol.10, 2015, pp.4147–4151, doi:10(55):4147-4151.

[22] Jordaan G.J., Steyn W.J., Practical Application of Nanotechnology Solutions in Pavement Engineering: Construction Practices Successfully Implemented on Roads (Highways to Local Access Roads) Using Marginal Granular Materials Stabilised with New-Age (Nano) Modified Emulsions (NME), Appl. Pi., Vol.12, 2022, p.1332.

[23] Maschenko A.V., Ponomarev A.B., Analysis of changes in strength and deformation properties of geosynthetically reinforced soil at different degrees of water saturation, Bulletin of the Perm National Technical Institute, Vol.4, 2014. pp. 265-274.