RESEARCH PAPER / НАУЧНАЯ СТАТЬЯ
UDC 625.7/.8
DOI: 10.22227/2305-5502.2025.1.14

Design and construction of roads in difficult soil conditions: practical recommendations

Assel S. Tulebekova[1], Askar Zh. Zhussupbekov[1,2], Aizhan K. Zhankina[1], Dana G. Bakirova[1], Amina Ilyubaeva[1]
[1] L.N. Gumilyov Eurasian National University; Astana, Kazakhstan;
[2] Moscow State University of Civil Engineering (National Research University) (MGSU); Moscow, Russian Federation

ABSTRACT

Introduction. Designing and constructing highways in difficult soil conditions is a significant engineering objective that requires a comprehensive approach. Traditional design and construction methods may not be effective in unstable or heterogeneous soils, such as subsidence soils. This article discusses key aspects of highway design in complex soil conditions, including geotechnical analysis methods, material selection and application, and soil reinforcement techniques.
Materials and methods. Plate load tests and static pile tests of soils have provided a detailed assessment of soils' mechanical characteristics and bearing capacity in the project area. These tests provide accurate data on the resistance coefficient and deformation properties, facilitating the adjustment of design solutions and selecting optimal strengthening and stabilization methods.
Results. The test results showed that the soil-bearing capacity of the pile is sufficient to support the maximum indentation design load. The authors also discuss a modern stabilization method, such as the use of geosynthetics, which was applied in the study and improves the bearing capacity and durability of the roadway.
Conclusions. An analysis of successful case studies of projects in difficult soil conditions highlights effective strategies and methods that can be adapted for different geological conditions. The results of the study emphasize the importance of a multidisciplinary approach and the application of modern technologies to ensure the stability and reliability of roadways in difficult soil conditions.

KEYWORDS: road, pavement, design, strength, soil, test

FOR CITATION: Tulebekova A.S., Zhussupbekov A.Zh., Zhankina A.K., Bakirova D.G., Ilyubaeva A. Design and construction of roads in difficult soil conditions: practical recommendations. *Stroitel'stvo: nauka i obrazovanie* [Construction: Science and Education]. 2025; 15(1):14. URL: http://nso-journal.ru. DOI: 10.22227/2305-5502.2025.1.14

Corresponding author: Assel S. Tulebekova, krasavka5@mail.ru.

Проектирование и строительство дорог в сложных грунтовых условиях: практические рекомендации

Асель Сериковна Тулебекова[1], Аскар Жагпарович Жусупбеков[1,2], Айжан Курайышевна Жанкина[1], Дана Габдуалиевна Бакирова[1], Амина Илюбаева[1]
[1] Евразийский национальный университет имени Л.Н. Гумилева; г. Астана, Казахстан;
[2] Национальный исследовательский Московский государственный строительный университет (НИУ МГСУ); г. Москва, Россия

АННОТАЦИЯ

Введение. Проектирование и строительство автомобильных дорог в сложных грунтовых условиях — важная инженерная задача, требующая комплексного подхода. Традиционные методы проектирования и строительства могут оказаться неэффективными в условиях нестабильности или неоднородности грунтов, например при просадочных грунтах. Рассматриваются ключевые аспекты проектирования автомобильных дорог в сложных грунтовых условиях, включая методы геотехнического анализа, выбор и применение материалов, а также методы укрепления грунта.
Материалы и методы. Штамповые и статические свайные испытания грунтов позволили подробно оценить их механические характеристики и несущую способность в условиях стройплощадки. Такие испытания дают возможность получить точные данные о коэффициенте сопротивления и деформационных свойствах, что облегчает корректировку проектных решений и выбор оптимальных методов укрепления и стабилизации.
Результаты. Результаты испытаний показали, что несущая способность достаточна для восприятия максимальной расчетной нагрузки при вдавливании. Авторы также обсуждают такой современный метод стабилизации, как использование геосинтетических материалов, который применен в исследовании. Данный метод также повышает несущую способность и долговечность дорожного покрытия.

Выводы. Анализ успешных примеров реализации проектов в сложных грунтовых условиях позволяет выделить эффективные стратегии и методы, которые могут адаптироваться к различным геологическим условиям. Результаты исследования подчеркивают важность междисциплинарного подхода и применения современных технологий для обеспечения устойчивости и надежности автомобильных дорог в сложных грунтовых условиях.

КЛЮЧЕВЫЕ СЛОВА: дорога, дорожное покрытие, проектирование, прочность, грунт, испытание

ДЛЯ ЦИТИРОВАНИЯ: *Тулебекова А.С., Жусупбеков А.Ж., Жанкина А.К., Бакирова Д.Г., Илюбаева А.* Проектирование и строительство дорог в сложных грунтовых условиях: практические рекомендации // Строительство: наука и образование. 2025. Т. 15. Вып. 1. Ст. 14. URL: http://nso-journal.ru. DOI: 10.22227/2305-5502.2025.1.14

Автор, ответственный за переписку: Асель Сериковна Тулебекова, krasavka5@mail.ru.

INTRODUCTION

The distribution of loess rocks occupies a considerable part of the land, in Kazakhstan, loess, and loess rocks are distributed mainly in the south and east of the country, which were formed under the influence of cryogenesis processes in the periglacial conditions of the mountain glaciations of the Tien Shan and Pamir [1]. A distinctive feature of collapsible soils is their ability when stressed by their weight or the foundation's external load, to give additional settlements, called collapses, when moisture increases — soaking [2]. Collapsible soils include loess, loess-like sand–clays, loams, and clays, some types of head loams and sand–clays, as well as, in some cases, fine and dusty sands with high structural strength, bulk clay soils, industrial wastes (grate dust, ash, ash deposits, etc.) [3]. Indirect methods [4] of determining collapsibility are used at the earliest stages of the investigation of loess soils in the territory under study to determine the propensity of soils to collapse. Based on their assessment of the choice of methods of further research of soils and justification of appointments of field and laboratory tests [5], the approximate evaluation of the volume of work unlike direct methods, doesn't allow for estimating the numerical collapsibility value of loess soils.

The indirect methods of investigation of collapsibility use the so-called "visual indicators" and indirect indicators. Visual indicators include the following already mentioned signs: climate and topography, thickness of loess rocks, and depth of occurrence of ground waters [6], loess rocks also have characteristic mineral and granulometric composition and appearance of rocks. The indirect indicators include calculated indicators [7]. The main ones are the coefficient of soil porosity, the dry density of the soil, water saturation ratio, and collapsing index, as well as the reduction coefficient of structural strength when wetting, macroporosity index, moisture deficit ratio, and collapsing index [8]. In difficult soil conditions before constructing structures, it is necessary to apply various methods to increase collapsible soil's bearing capacity and stability [9]. The bearing capacity of such soils is low, so before making foundations on them, applying different soil stabilization methods is necessary. Three groups of methods are used for the improvement of soil bases: constructive methods of base improvement; compaction of soil bases; and consolidation of soil bases [10].

Today the practice shows different methods and ways of eliminating subsidence properties of soils by their compaction or consolidation; the device of soil cushions is used. To consolidate the subsidence soils, use the methods of one-solution silicification or thermal firing [11–13]. The device of ground cushions creates a layer of non-subsidence soil in the foundation base. Another practice presented the construction of fixed soil columns and piles in weak dusty-clayey soils when combinations of jetting and boring methods or combination of jetting technology with the immersion of ready-reinforced concrete elements are also promising [14]. Also, one of the effective methods of designing structures on subsidence soils is the reinforcement of foundation soils. One of the basic concepts of soil reinforcement is reduced to the scheme when the weak soil mass is reinforced with high-strength elements and diaphragms placed in the ground [15]. In this case, both vertical and horizontal reinforcement is possible, which in each case has a different effect on the stress-strain state of foundation soils and the operation of foundations. The improvement of ground and soil base reinforcement is directly related to the materials used for reinforcement [16, 17].

MATERIALS AND METHODS

The projected section of the highway is in Almaty region [18]. The "Zero end of the survey" is located on the western side of Almaty city. The road is designed for traffic speeds up to 150 km/h [19]. Geomorphologically, the development site is located within a sloping plain in the foothills, extending northward from the foot of the Zailiyskiy Alatau. The climate of the district is sharply continental. The climate features of the district are determined by the latitude of orographic elements on its surface. The combination of climate-forming factors leads to the prevalence of hot, dry weather with sharp seasonal and daily fluctuations in air temperature. Summers are hot, winters are moderately cold and mild [20]. It rains in spring and summer.

The Tien-Shan region is a complex mountainous country formed because of repeated changes in the tectonic regime. The oldest geosynclinal period of tectonic development extended from the Archean to the Ordovician. From the orographic point of view, the region is represented by a complex system of ridges and depressions. The Tien Shan region is formed by the structure of Precambrian and Caledonian folds. The Alpine folding began in the Upper Cretaceous and continues to this day with interruptions.

The relief was formed because of the active activity of debris flows and river waters and represents a weak hilly plain with river valleys, where remnants of floodplain terraces I and II are observed. There is a general northward slope of the relief.

Hydrographically, the study area is located between the Kaskelen and Talgar rivers, through which the project route passes.

The project road directly crosses a network of watercourses. Because the route of the projected road passes through these watercourses, they will have a direct impact on the formation of engineering and geological conditions of the projected object.

The geological structure of the area involves friable Quaternary sediments overlying the basic rocks of the Paleozoic era. Local deposits are represented by granitoid, granodiorite, and porphyry intrusions in the river basins crossing the Zailiyskiy Alatau ridge. These rocks do not have a determining influence on the engineering-geological conditions of construction, so a detailed description of the bedrock is not given. Loose sediments of the middle and modern Quaternary periods form a complex of alluvial-pluvial rocks.

For detailed determination of the geological and lithological cross-section along the route axis 51 exploration boreholes with a depth of up to 6.0 m, totaling 1.0 m, were drilled. Absolute marks of the boreholes are 631.59–680.70 m. The section of the route is represented by a soil and vegetation layer from the surface of the Earth, with a thickness of 0.2 m. Below lie loams with a thickness of up to 6.0 m, uncovered from hard-liquid consistency, as well as hard sandy loam with a thickness of up to 1.5 m. Below are layers of medium-coarse and coarse sand with a thickness of 0.6 m.

Embankment occurs on existing highways where soil has been cross-cut. It is represented by a semi-hard loam containing crushed stone. The maximum exposed thickness is 3.2 meters. During the study period, groundwater was opened at a depth of 1.0–7.8 m. Physical and mechanical properties of soil are given in Table 1, 2.

Calculated values of soil characteristics are given considering the soil reliability coefficient. According to the degree of frost hazard, the soils are hard loam, semi-hard and hard sandy loam — not granular, medium coarse sand, coarse sand — slightly granular, dense plastic loam — moderately granular, soft plastic and liquid plastic loam — strongly granular. During search wells up to 6.0 m, groundwater was uncovered at a depth of 1.0–7.8 m seasonal amplitude of age fluctuations +1.0–1.5 m. Groundwater-fresh water to slightly brackish, bicarbonate, sodium-calcium. The degree of sulfate-aggressive impact of groundwater on concrete according to the permeability of Portland cement W4 is non-aggressive and very aggressive. The degree of aggressive impact of groundwater on the reinforcement of reinforced concrete structures (by chloride content) under periodic wetting is slightly aggressive.

Investigation of the bearing capacity of the foundation soil under the overpass was carried out at 3 points of plate loading tests [21]. Tests were carried out at air temperature +8 °C. Values of Eu, U, and Ks are defined because of the cameral processing of sizes of loadings and deposits corresponding to them received during static plate tests. Plate-bearing tests are the most reliable method of the deformation module definition, module of elasticity, coefficient of soil bed, natural bases, and constructive layers of pavement surfacing [18]. The plate installation with the rotary console operating by the balance beam principle was used for tests.

To determine the bearing capacity and deforming capacity of piles in the ground with the establishment of the pile

Table 1. Physical and mechanical properties of soil [18]

Табл. 1. Физико-механические свойства почвы [18]

Parameter name	EGE-2a	EGE-2b	EGE-2v	EGE-2d	EGE-3a	EGE-4v	EGE-4g
Liquid limit, %	26.9	26.3	27.1	27.3	20.7	–	–
Plastic limit, %	18.8	18.7	18.9	19.0	16.9	–	–
Plasticity index, %	8.1	7.6	8.2	8.3	3.8	–	–
Index of liquidity, %	<0	0.38	0.62	0.94	<0	–	–
Natural humidity, %	12.2	21.6	24.0	26.7	4.6	–	–
Soil particles density, g/sm^3	2.71	2.70	2.71	2.71	2.69	–	–
Soil density, g/sm^3	1.61	1.91	1.94	1.84	1.61	1.62	1.88
Dry soil density, g/sm^3	1.45	1.57	1.57	1.45	1.54	–	–
Void ratio	0.86	0.72	0.73	0.87	0.74	–	–
Degree of humidity	–	–	–	0.97	–	–	–
Coefficient of permeability, m/d	–	–	–	–	–	7.4	–
The natural angle of slope in the dry state, deg.	–	–	–	–	–	35	38
Soil resistance, kPa	318.0	145	98	98	294	400	500

Table 2. Normative and calculated values of soil characteristics

Табл. 2. Нормативные и расчетные значения характеристик почвы

EGE	Unit weight of soil, kN/m^3			Intercept cohesion, kPa			Angle of internal friction, deg.			Modulus of deformation, MPa
	norm	PII	PI	norm	CII	CI	norm	γII	γI	
1	2	3	4	5	6	7	8	9	10	11
2a	1.61	1.61	1.58	22.0 16.0*	22.0 16.0*	15.0 11.0*	22.0 16.0*	22.0 16.0*	19.0 14.0*	13.7 7.8*
2b	1.91	1.91	1.87	25.0	25.0	17.0	21.0	21.0	18.0	15.5* 13.5*
2v	1.94	1.94	1.90	21.0	21.0	14.0	18.0	18.0	16.0	13.0* 12.2*
2d	20.3	20.3	20.1	13.0	13.0	8.7	5.0	5.0	4.3	7.7
3a	1.61	1.61	1.58	13.0 11.0*	13.0 11.0*	9.0 7.0*	24.0 21.0*	24.0 21.0*	21.0 18.0*	10.6 7.0*
4v	1.62	1.62	1.59	1.0	1.0	0.7	35.0	35.0	32.0	30.0
4g	1.88	1.88	1.84	1.0	1.0	0.7	38.0	38.0	34.0	30.0

Note: * — the denominator shows the characteristics of soils in the water-saturated state.

Fig. 1. Hydraulic pump with pressure gauge for pressure monitoring

Рис. 1. Гидравлический насос с манометром для контроля давления

Fig. 2. System of experimental and anchor piles

Рис. 2. Система экспериментальных и анкерных свай motion dependence in the ground, static tests [22] were carried out with a backward load of the bored pile No. 3 of the support No. 3 of the track bridge (Fig. 1, 2). Loading device and measuring instruments consist of a power stand, jack DG200P250, hydraulic pump, deflection meters 6PAO-0.01, tape measure, WIKA monometer.

At each stage of pile loading calculations were obtained on all devices with an interval of the first hour 15 min, with a further interval of 30 min until the weakening of displacement (shrinkage) of the pile, which is called conditional stabilization. For conditional stabilization of the pile by the pile design, the rate of displacement (shrinkage) of the pile in the soil, according to GOST 5686–2012 [23, 24], not more than 0.1 mm for the last 60-minute observations at this stage of loading was adopted. The zero readout was obtained from the instruments before loading the pile. The first readout was taken immediately after the load was applied. The dwell time for each stage, from the first to the eighth stage, was 120 minutes for each pressurized stage. In the ninth stage, time amounted to 270 minutes.

RESULTS OF THE RESEARCH

The results of the plate-bearing tests are shown in Table 3 and Fig. 3.

The following conclusions can be drawn based on the results of tests carried out on km P 1 on the study of the bearing capacity of the artificial soil of the base under the pipe:

- the average modulus of deformation of the structure at 3 test points makes the following: E_d = 16.43 MPa;
- the average modulus of elasticity of the structure at all 3 test points is: E_e = 60.68 MPa;

Table 3. Plate-bearing test results

Табл. 3. Результаты штамповых испытаний

Location	Soil	Deformation modulus E_{def}, MPa	Elastic modulus E_{elas}, MPa	Coefficient of compaction K
P 1	Point 1	11.4	57.0	≈ 0.88
	Point 2	16.5	65.4	≈ 0.92
	Point 3	21.4	59.64	≈ 0.96
P 2	Point 1	27.54	58.50	~ 0.98
	Point 2	22.85	70,76	~ 0.95
	Point 3	11.70	–	<0.9
P 3	Point 1	30.4	116.65	0.94–0.98
	Point 2	18.34	84.77	<0.94
	Point 3	20.38	85.35	0.945–0.95

Note: * — characteristics are given for soil at a water-saturated state.

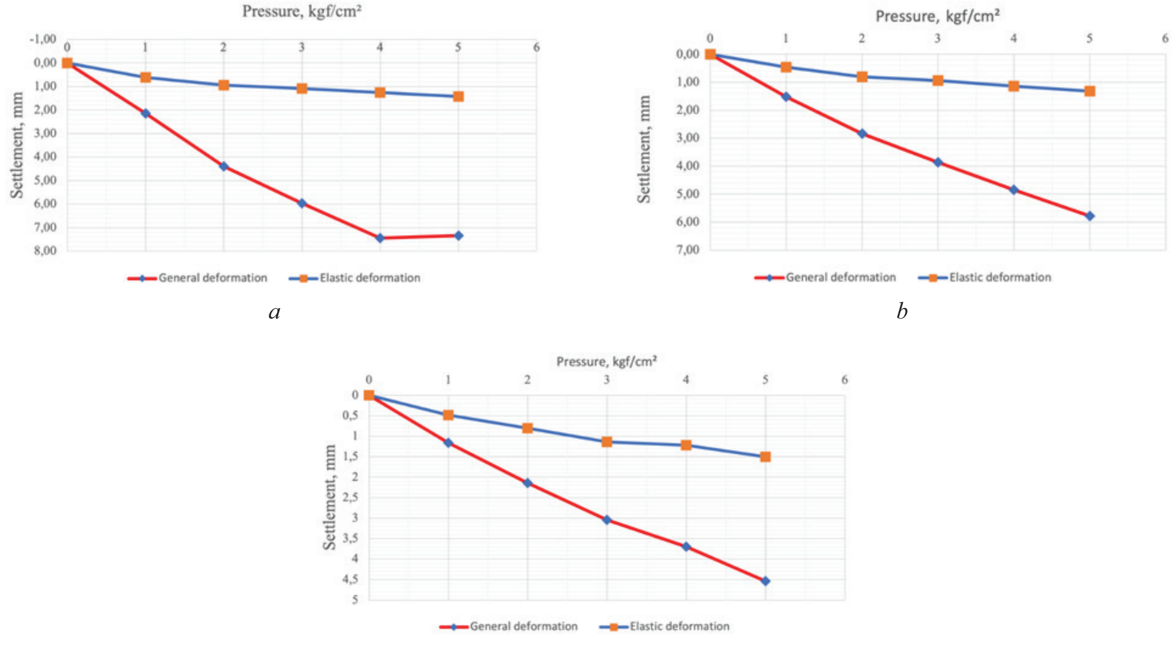

Fig. 3. Plate-bearing test results: *a* — point 1; *b* — point 2; *c* — point 3

Рис. 3. Результаты штамповых испытаний: *а* — точка 1; *b* — точка 2; *c* — точка 3

• the compaction factor of artificial base layers ranges from $K \approx 0.88$–0.99.

The following conclusions can be drawn based on the results of the tests carried out on km P 2 in the study of the bearing capacity of the artificial soil of the base under the pipe.

About the 1st and 2nd points:

• the average modulus of deformation of the structure at 2 test points is the following: $E_d = 25.20$ MPa;

• the average modulus of elasticity of the structure for 2 test points is the following: $E_e = 64.63$ MPa;

• the average compaction factor of the structure for the 2nd test point follows $K \sim 0.97$.

About the 3rd point:

• structural deformation modulus $E = 11.70$ MPa.

The modulus of structure elasticity is not considered correctly in the 3rd point due to extremely small elastic deformations and accumulation of residual deformations. During the tests, it was seen that the 3rd point is in the local depression area with standing water, respectively, due to the presence of standing water, friction forces and interlocking between crushed stone particles do not occur. This leads to a low compaction factor of the artificial base $K < 0.9$, extremely low elastic deformations, and an accumulation of residual deformations under the plate during testing.

The following conclusions can be drawn based on the results of the test for (km P 2) on the study of the bearing capacity of the artificial base soil under the pipe:

• the average compaction factor of the natural base at 3 points varies within the range: at a depth of about 10–30 cm from the surface of the K plate of the soil $\approx$ ≈ 0.956 — at a depth of more than 40 cm from the plate surface, where K soil is < 0.945;

• the average modulus of structure deformation at 3 test points is the following: $E_d = 23.04$ MPa;

• the average modulus of structure elasticity for all 3 test points is $E_e = 95.57$ MPa.

The following conclusions can be drawn based on the results of the tests performed (km P 3) on the study of the bearing capacity of the artificial base soil under the pipe:

• the average compaction factor of the natural base at 3 points varies within the following: at a depth of about 10–30 cm from the surface of the K plate of the soil $\approx$ ≈ 0.955 — at a depth of more than 40 cm from the plate's surface, where K soil is < 0.945;

• the average modulus of structure deformation at 3 test points is the following: $E_d = 23.04$ MPa;

• the average modulus of the structure elasticity for all 3 test points is $E_e = 95.57$ MPa.

The test results showed that the load-carrying capacity of pile No. 3 at support No. 3 is sufficient to take the design load with maximum soil pressure. The test results are presented in Table 4 and Fig. 4. Unloading was carried out in stages of 212, 159, 106, 53 t.

The maximum displacement of the pile when reaching the ninth stage of loading, when averaging the indicators (GOST 5686) control devices deflection meters when reaching the load — 239.0 tons, at the 9th stage of loading on the tested pile was 1.48 mm. The number of control devices for the analysis of settlement — 2, which meets the minimum requirements of standard GOST 5686. The test results showed that the bearing capacity of pile No. 3 at support No. 3, on soil is sufficient to support the maximum indentation design load.

The design of road pavement structures consists of two sequentially performed stages — design and calculation, which are interrelated and should not be opposed to each other. The design of the pavement consists of the selection of the most suitable materials based on local resources and the organization of the work, in the appropriate dimensioning of the individual layers and their placement in depth. Construction solutions for the embankment are presented in Fig. 5. The drainage layer by the principle of volumetric absorption is built in a situation where water, which will enter the layer, will be able to be placed in its pores at full volume. In this case, no release is made from these layers, and the 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 harm the road surface. The choice of drainage design should be selected based on a technical and economic comparison of options. Geogrid provides a strong mattress foundation that significantly increases the stability of the soil.

Table 4. Design loading scheme

Табл. 4. Расчетная схема нагружения

Location	Load No.	Pile No.	Maximum load, t	Average settlement, mm
P 1	1	3	27	0.00
	2	3	53	0.04
	3	3	80	0.05
	4	3	106	0.09
	5	3	133	0.15
	6	3	159	0.26
	7	3	186	0.49
	8	3	212	0.78
	9	3	239	1.47
	10	3	265	–

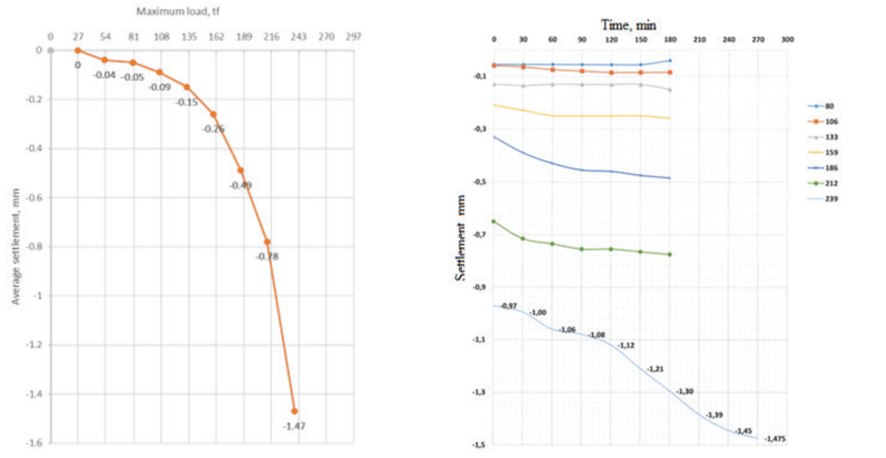

Fig. 4. Results of static load test

Рис. 4. Результаты испытания статической нагрузкой

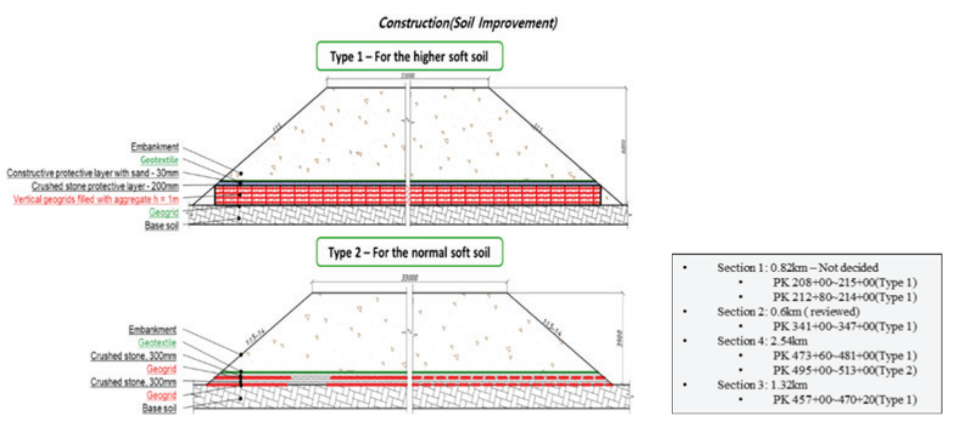

Fig. 5. General design solution

Рис. 5. Общее проектное решение

The effect of geogrid generated in the embankment body and the geogrid layer.

CONCLUSION AND DISCUSSION

The study presents the features of the design of structures in difficult soil conditions and when designing roads, it is necessary to:

1. When designing structures on collapsing soils, the possibility of increasing their moisture content due to soaking the soil from external sources (rainwater, meltwater) from above should be considered. It is necessary to provide a set of measures, including the elimination of collapsible properties (water protection and structural measures).

2. Provide measures to prevent the penetration of surface and anthropogenic water into the foundations.

3. Provide runoff and channel-regulating structures and measures to prevent flooding adjacent to unregulated medium and small rivers and protect crossings under highways.

4. It is necessary to apply to the pavement "capping layer" structure in areas where the groundwater level is close to the bottom of the embankment for a more rigid resistance to loads from the above structure. It also reduces the chance of differential settlement in the slab by supporting it more homogeneously than an unimproved subgrade. It is also much easier to compact a subbase on a capping layer than on saturated clay, meaning that by installing a capping layer, delays in constructing the subbase due to wet weather can be reduced.

5. To determine the bearing capacity of the soil foundations of the road highway under construction, one should rely on the results of the field tests.

6. Application of a comprehensive approach to improving soil bases.

REFERENCES

1. Bayramukov S.Kh. Mutual influence of prestress losses and ways for their accounting. *Concrete and Reinforced Concrete.* 2001; 2:13-15. (rus.).

2. Zhussupbekov A., Zhankina, A., Tulebekova A., Yessentayev A., Zhumadilov I. Features of the bearing capacity estimation of the collapsing soil bases. *International Journal of Geomate.* 2022; 92(22):32-40. DOI: 10.21660/2022.92.1656

3. Pshembayev M., Kiyalbay S., Yessentay D., Tleulenova G. Regulation of the water-heat regime of the subgrade of cement-concrete road. *International Journal of Geomate.* 2023; 111(25):145-152. DOI: 10.21660/2023.111.4035

4. Zhu Y., Chen Z. A new method of studying collapsibility of loess. *Frontiers of Architecture and Civil Engineering in China.* 2009; 3(3):305-311.

5. Lei B., Kong L., Guo Y., Sun B., Li X., Wu K. et al. Optimizing decarbonation and sustainability of concrete pavement : a case study. *Case Studies in Construction Materials.* 2024; 21:e03574. DOI: 10.1016/j.cscm.2024.e03574

6. Zhussupbekov A., Tulebekova A., Zhumadilov I., Zhankina A. Tests of Soils on Triaxial Device. *Key Engineering Materials.* 2020; 857:228-233. DOI: 10.4028/www.scientific.net/KEM.857.228

7. Utepov Y.B., Aldungarova A.K., Mkilima T., Pidal I.M., Tulebekova A.S., Zharassov S.Z. et al. Dynamics of Embankment Slope Stability under Combination of Operating Water Levels and Drawdown Conditions. *Infrastructures.* 2022; 5(7):65. DOI: 10.3390/infrastructures7050065

8. Houston S.L., Houston W.N., Lawrence C.A. Collapsible soil engineering in highway infrastructure development. *Journal of Transportation Engineering.* 2002; 128(3):295-300. DOI: 10.1061/(ASCE)0733-947X(2002)128:3(295)

9. Lv Q., Wang S., Wang D., Wu Z. Water stability mechanism of silicification grouted loess. *Bulletin of Engineering Geology and the Environment.* 2014; 73(4):1025-1035. DOI: 10.1007/s10064-014-0646-0

10. 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. *Bulletin of Engineering Geology and the Environment.* 2021; 9(80):6689-6704.

11. Hameedi M.K. Field study on soft soil improvement using continuous flight auger (CFA) piles. *International Journal of Geomate.* 2021; 21(86). DOI: 10.21660/2021.86.j2329

12. Tamara A., Nina L. Methods to Increase Effectiveness of Injective Chemical Stabilisation of Loess Soils. *Engineering Geology for Society and Territory.* 2015; 5:1289-1292. DOI: 10.1007/978-3-319-09048-1_246

13. Jian T., Kong L., Bai W. Investigation on Compressibility and Microstructure Evolution of Intact Loess at Different Wetting States. *Frontiers in Earth Science.* 2022; 10:923358.

14. White J.L. Characteristics and Susceptibility of Collapsible Soils in Colorado: Results of a Statewide Study. *GEO-Volution.* 2006; 86-98.

15. Dong L. Numerical model for the settlement of loess subgrade in operation period reinforced by rotary jet grouting pile. *Vibroengineering Procedia.* 2022; 48-53. DOI: 10.21595/vp.2022.22400

16. Chindaprasirt P., Sriyoratch A., Arngbunta A. Estimation of modulus of elasticity of compacted loess soil and lateritic-loess soil from laboratory plate bearing test. *Case Studies in Construction Materials.* 2022; 16:e00837

17. Tulebekova A., Zhussupbekov A., Zhankina A., Aldungarova A., Mamyrbekova G. Practical experience in the construction of roads in difficult soil conditions. *Journal of Water and Land Development.* 2024; 60:138-148. DOI: 10.24425/jwld.2024.149115

18. Pershakov V., Bieliatynskyi A., Akmaldinova O. Geosynthetic reinforced interlayers application in road construction. *Advances in Intelligent Systems and Computing.* 2021; 94-103.

19. Working Project “Road Construction”. *KGS, LTD (a) Technical report.* Astana, KGS, LTD, 2020.

20. SP RK 3.03-101–2013. *Automobile roads.* Astana, KazNIISA JSC, 2015; 74.

21. Yessentay D.E., Kiyalbaev A.K., Kiyalbay S.N., Borisyuk N.V. Reliability criterion and a model for determining the optimal speed of movement on automobile roads in winter sliding conditions. *News of National Academy of Sciences of the Republic of Kazakhstan.* 2020; 444(6):119-125. DOI: 10.32014/2020.2518-170X.138

22. GOST 20276.1–2020. Soils. Stamp test method. Moscow, Standartinform, 2020; 22. (rus.).

23. Tulebekova A., Zhussupbekov A., Zhumadilov I., Nurakov S., Kudaibergen A. Geotechnical issues of testing piles on construction site of Astana. *Proceedings of the 16th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering*. 2020.

24. GOST 5686–2012. Soils. Methods of field testing with piles. Moscow, Standartinform, 2012. (rus.).

Received August 28, 2024.
Adopted in revised form on September 20, 2024.
Approved for publication on September 25, 2024.

Bionotes: **Assel S. Tulebekova** — PhD, Professor of the Department of "Civil Engineering"; **L.N. Gumilyov Eurasian National University**; 2 Satpayeva st., Astana, 010008, Kazakhstan; krasavka5@mail.ru;

Askar Zh. Zhussupbekov — Doctor of Technical Sciences, Professor of the Department of "Civil Engineering"; **L.N. Gumilyov Eurasian National University**; 2 Satpayeva st., Astana, 010008, Kazakhstan; **Moscow State University of Civil Engineering (National Research University) (MGSU)**; 26 Yaroslavskoe shosse, Moscow, 129337, Russian Federation; astana-geostroi@mail.ru;

Aizhan K. Zhankina — PhD; **L.N. Gumilyov Eurasian National University**; 2 Satpayeva st., Astana, 010008, Kazakhstan; zhankina90@mail.ru;

Dana G. Bakirova — master, senior lecturer of the Department of the Department of "Civil Engineering"; **L.N. Gumilyov Eurasian National University**; 2 Satpayeva st., Astana, 010008, Kazakhstan; trelec6767@mail.ru;

Amina Ilyubaeva — master; **L.N. Gumilyov Eurasian National University**; 2 Satpayeva st., Astana, 010008, Kazakhstan; amina-bidaik@mail.ru.

Contribution of the authors:
Assel S. Tulebekova — conceptualization, methodology, writing.
Askar Zh. Zhussupbekov — resources, data processing.
Aizhan K. Zhankina — visualization, observation.
Dana G. Bakirova — editing.
Amina Ilyubaeva — writing, preparation of the initial draft.
The authors declare no conflict of interest.

СПИСОК ИСТОЧНИКОВ

1. *Байрамуков С.Х.* Взаимное влияние потерь предварительного напряжения и способы их учета // Бетон и железобетон. 2001. № 2. С. 13–15.

2. *Zhussupbekov A., Zhankina, A., Tulebekova A., Yessentayev A., Zhumadilov I.* Features of the bearing capacity estimation of the collapsing soil bases // International Journal of Geomate. 2022. Vol. 92. Issue 22. Pp. 32–40. DOI: 10.21660/2022.92.1656

3. *Pshembayev M., Kiyalbay S., Yessentay D., Tleulenova G.* Regulation of the water-heat regime of the subgrade of cement-concrete road // International Journal of Geomate. 2023. Vol. 111. Issue 25. Pp. 145–152. DOI: 10.21660/2023.111.4035

4. *Zhu Y., Chen Z.* A new method of studying collapsibility of loess // Frontiers of Architecture and Civil Engineering in China. 2009. Vol. 3. Issue 3. Pp. 305–311.

5. *Lei B., Kong L., Guo Y., Sun B., Li X., Wu K. et al.* Optimizing decarbonation and sustainability of concrete pavement : a case study // Case Studies in Construction Materials. 2024. Vol. 21. P. e03574. DOI: 10.1016/j.cscm.2024.e03574

6. *Zhussupbekov A., Tulebekova A., Zhumadilov I., Zhankina A.* Tests of Soils on Triaxial Device // Key Engineering Materials. 2020. Vol. 857. Pp. 228–233. DOI: 10.4028/www.scientific.net/KEM.857.228

7. *Utepov Y.B., Aldungarova A.K., Mkilima T., Pidal I.M., Tulebekova A.S., Zharassov S.Z. et al.* Dynamics of Embankment Slope Stability under Combination of Operating Water Levels and Drawdown Conditions // Infrastructures. 2022. Vol. 5. Issue 7. P. 65. DOI: 10.3390/infrastructures7050065

8. *Houston S.L., Houston W.N., Lawrence C.A.* Collapsible soil engineering in highway infrastructure development // Journal of Transportation Engineering. 2002. Vol. 128. Issue 3. Pp. 295–300. DOI: 10.1061/(ASCE)0733-947X(2002)128:3(295)

9. *Lv Q., Wang S., Wang D., Wu Z.* Water stability mechanism of silicification grouted loess // Bulletin of Engineering Geology and the Environment. 2014. Vol. 73. Issue 4. Pp. 1025–1035. DOI: 10.1007/s10064-014-0646-0

10. *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 // Bulletin of Engineering Geology and the Environment. 2021. Vol. 9. Issue 80. Pp. 6689–6704.

11. *Hameedi M.K.* Field study on soft soil improvement using continuous flight auger (CFA) piles // International Journal of Geomate. 2021. Vol. 21. Issue 86. DOI: 10.21660/2021.86.j2329

12. *Tamara A., Nina L.* Methods to Increase Effectiveness of Injective Chemical Stabilisation of Loess Soils // Engineering Geology for Society and Territory. 2015. Vol. 5. Pp. 1289–1292. DOI: 10.1007/978-3-319-09048-1_246

13. *Jian T., Kong L., Bai W.* Investigation on Compressibility and Microstructure Evolution of Intact Loess at Different Wetting States // Frontiers in Earth Science. 2022. Vol. 10. P. 923358.

14. *White J.L.* Characteristics and Susceptibility of Collapsible Soils in Colorado: Results of a Statewide Study // GEO-Volution. 2006. Pp. 86–98.

15. *Dong L.* Numerical model for the settlement of loess subgrade in operation period reinforced by rotary jet grouting pile // Vibroengineering Procedia. 2022. Pp. 48–53. DOI: 10.21595/vp.2022.22400

16. *Chindaprasirt P., Sriyoratch A., Arngbunta A.* Estimation of modulus of elasticity of compacted

loess soil and lateritic-loess soil from laboratory plate bearing test // Case Studies in Construction Materials. 2022. Vol. 16. P. e00837.

17. *Tulebekova A., Zhussupbekov A., Zhankina A., Aldungarova A., Mamyrbekova G.* Practical experience in the construction of roads in difficult soil conditions // Journal of Water and Land Development. 2024. Vol. 60. Pp. 138–148. DOI: 10.24425/jwld.2024.149115

18. *Pershakov V., Bieliatynskyi A., Akmaldinova O.* Geosynthetic reinforced interlayers application in road construction // Advances in Intelligent Systems and Computing. 2021. Pp. 94–103.

19. Working Project "Road Construction". KGS, LTD (a) Technical report. Astana : KGS, LTD, 2020.

20. SP RK 3.03-101–2013. Automobile roads. Astana : KazNIISA JSC, 2015. 74 c.

21. *Yessentay D.E., Kiyalbaev A.K., Kiyalbay S.N., Borisyuk N.V.* Reliability criterion and a model for determining the optimal speed of movement on automobile roads in winter sliding conditions // News of National Academy of Sciences of the Republic of Kazakhstan. 2020. Vol. 444. Issue 6. Pp. 119–125. DOI: 10.32014/2020.2518-170X.138

22. GOST 20276.1–2020. Грунты. Метод испытания штампом. М. : Стандартинформ, 2020. 22 с.

23. *Tulebekova A., Zhussupbekov A., Zhumadilov I., Nurakov S., Kudaibergen A.* Geotechnical issues of testing piles on construction site of Astana // Proceedings of the 16th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering. 2020.

24. GOST 5686–2012. Грунты. Методы полевых испытаний сваями. М. : Стандартинформ, 2012.

Поступила в редакцию 28 августа 2024 г.
Принята в доработанном виде 20 сентября 2024 г.
Одобрена для публикации 25 сентября 2024 г.

О б а в т о р а х : **Асель Сериковна Тулебекова** — PhD, профессор кафедры «Строительство»; **Евразийский национальный университет им. Л.Н. Гумилева**; 010008, г. Астана, ул. Сатапаева, д. 2, Казахстан; krasavka5@mail.ru;

Аскар Жагпарович Жусупбеков — доктор технических наук, профессор кафедры «Строительство»; **Евразийский национальный университет им. Л.Н. Гумилева**; 010008, г. Астана, ул. Сатапаева, д. 2, Казахстан; **Национальный исследовательский Московский государственный строительный университет (НИУ МГСУ)**; 129337, г. Москва, Ярославское шоссе, д. 26; astana-geostroi@mail.ru;

Айжан Курайышевна Жанкина — PhD; **Евразийский национальный университет им. Л.Н. Гумилева**; 010008, г. Астана, ул. Сатапаева, д. 2, Казахстан; zhankina90@mail.ru;

Дана Габдуалиевна Бакирова — магистр, старший преподаватель кафедры «Строительство»; **Евразийский национальный университет им. Л.Н. Гумилева**; 010008, г. Астана, ул. Сатапаева, д. 2, Казахстан; strelec6767@mail.ru;

Амина Илюбаева — магистр; **Евразийский национальный университет им. Л.Н. Гумилева**; 010008, г. Астана, ул. Сатапаева, д. 2, Казахстан; amina-bidaik@mail.ru.

Вклад авторов:
Тулебекова А.С. — концептуализация, методология, написание.
Жусупбеков А.Ж. — ресурсы, обработка данных.
Жанкина А. — визуализация, наблюдение.
Бакирова Д. — редактирование.
Илюбаева А. — написание, подготовка первоначального проекта.
Авторы заявляют об отсутствии конфликта интересов.