International Journal of GEOMATE, April, 2022, Vol.22, Issue 92, pp.32-40
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2022.92.1656
Geotechnique, Construction Materials and Environment

FEATURES OF THE BEARING CAPACITY ESTIMATION OF THE COLLAPSING SOIL BASES

Askar Zhussupbekov[1], *Aizhan Zhankina[1], Assel Tulebekova[1], Askar Yessentayev[1] and Iliyas Zhumadilov[2]

[1]Department of Civil Engineering, L.N. Gumilyov Eurasian National University, Kazakhstan
[2]Shakarim University, Semey, Kazakhstan

*Corresponding Author, Received: 30 Nov. 2021, Revised: 01 Feb. 2022, Accepted: 23 Feb. 2022

ABSTRACT: Mass construction of structures is complicated on collapsing soils. The time course of deformations in collapsing soils is determined by their moisture content. Since collapsing soils are usually in a low moisture state, their compressive strain from external load occurs within a relatively brief time. Soil subsidence, and equally collapsing in the water-saturated state, occurs over a longer period since these processes are associated with water filtration through the soil column. Thus, the improvement of the quality and efficiency of construction on collapsing soils largely depends on the proper assessment of their properties. The paper presents the practical experience of designing a section of a big ring road. There are issues of design features discussed, engineering-geological investigations, and soil tests with stamps given. Based on the obtained results, the choice of structural solutions for road pavement is substantiated. Recommendations on the design and assessment of the bearing capacity of collapsing soils are developed.

Keywords: Collapsing Soil, Bearing Capacity, Test, Embankment, Road

1. INTRODUCTION

The design and construction of civil and industrial buildings and structures on structurally unstable soils are one of the most important and difficult problems today. Such soils include collapsing soils, the feature of which is that these soils have a macroporous structure and exhibit additional deformation, called subsidence when soaking [1-3]. In this regard, in the design of buildings and structures, there is a need to study the bearing capacity and deformability of soils. Durability, cost, and terms of construction largely depend on the quality of determination of these properties. Incorrect assessment of the deformability of soils may lead to the construction of unreasonably large foundations or to their excessive subsidence, which may cause an emergency condition of the entire building or structure [4].

To determine the deformability and bearing capacity of soils there are methods of field soil testing with piles and stamps used. In this regard, in the works [5-8], during the construction of buildings and structures on such soils, there are various construction measures to increase the load-bearing capacity of the collapsing soil base proposed. For example, tamping, ground piling, pre-soaking, and reinforcement with vertical elements.

Technological progress allows the use of artificial and man-made materials for reinforcement. Therefore, the search for new methods and techniques that meet all conditions of construction on collapsing soils is urgent.

2. RESEARCH SIGNIFICANCE

The stability of the road pavement determines the reliability and serviceability of the entire road structure. The criterion of stability of soil is represented by its physical and mechanical properties. The study presents the construction of a highway, constructed on soils exhibiting subsidence properties. When designing it is necessary to take into account the possibility of increasing the moisture content of such soils. Based on the results of soil tests there were constructive and technological decisions made. The recommendations which were given allow the construction of the road on collapsing soil with ensuring strength, reliability, and normal operation.

3. THE OBJECT CHARACTERIZATION

The object passes through the territories of Karasay, Ili, and Talgar districts of the Almaty region, Kazakhstan, with a length of 66 km [9]. The road to be laid is designed to unload the through streets of the city from transit transport. The route will become a key link in the transit corridor Western China - Western Europe (Fig.1).

The section of the designed highway is located within one geomorphological element - an inclined foothill alluvial-proluvial plain. The territory of the area occupies the foothills of Zailiysky Alatau and the plain part of the Kopa-Iliisky basin. In the geological and lithologic structure of the site, there are alluvial-proluvial deposits of quarternary age (tQIV), represented by bulk soil at the crossings of roadways and alluvial-proluvial deposits of upper quaternary age (apQIV) represented by lean clay of different consistence, sand fineness, and gravel soils, covered with topsoil. The territory of the area is potentially non-flooded, excluding a bridge overpass across the Aksay river.

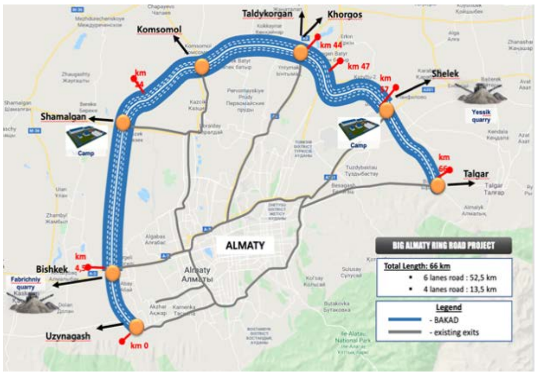

Fig.1 Map of big Almaty ring road construction

In borders of the site up to 30.0 m according to identification list and physic mechanical properties, there were 14 engineering and geological elements (EGE) subtracted:

- EGE-1. Topsoil layer;
- EGE-2. Asphalt-concrete (road pavement);
- EGE-3. Bulk soil;
- EGE-4. Lean clay brown loessal light very stiff subsiding.

According to compression tests lean clays show subsiding properties from additional loadings. Initial subsiding pressure is 0.050 kg/cm². Coefficient of a relative subsiding with the specific pressure of 0.5 kg/cm² - 0.012 to 0.056; with the specific pressure of 1.0 kg/cm² – 0.025 to 0.095; with the specific pressure of 2.0 kg/cm² – 0.030 to 0.112; with the specific pressure of 3.0 kg/cm ² – 0.058 to 0.132.

- EGE-5. Lean clay brown light dusty stiff non-subsiding;
- EGE-6. Lean clay brown light dusty firm consistency;
- EGE-7. Lean clay brown light soft consistency;
- EGE-8. Lean clay brown light very soft consistency;
- EGE-9. Lean clay brown light very soft consistency;
- EGE-10. Silty clay brown-grey very stiff;
- EGE-11. Sand brown average density average fineness water inundated;
- EGE-12. Sand grey average density cobble water-inundated;
- EGE-13. Gravel sand with sandy filling water inundated;
- EGE-14. Gravel soil with sandy filling slightly wet.

Standard values of the physical and mechanical indicators of strength and deformation properties of main EGEs are presented in Table 1. During the construction of the technological embankment, there was soil compaction carried out with subsequent research by tests conducted.

Table 1 Physical and mechanical properties of the soil ground

Parameter name	Engineering and geological elements							
	EGE-4	EGE-5	EGE-6	EGE-7	EGE-8	EGE-9	EGE-10	EGE-13
Natural humidity, %	12.8	12.8	21.8	18.9	22.4	26.8	27.4	
Humidity at the boarder:								
- flow	26.9	26.9	31.4	25.0	25.0	28.5	24.5	
- rolling out, %	18.1	18.1	21.5	15.1	17.3	19.2	17.0	
Plasticity index, %	8.8	8.8	9.9	9.9	7.7	9.3	7.5	
Index of liquidity, %	-0.6	-0.6	0.03	0.38	0.67	0.82	1.38	
Soil stability	1.89	1.89	1.94	1.88	1.95	1.91	1.82	
Soil particles density, g/sm^3	2.71	2.71	2.72	2.72	2.71	2.71	2.71	
Dry soil density, g/sm^3	1.68	1.68	1.59	1.58	1.59	1.51	1.43	2.07
Void ratio	0.62	0.62	0.71	0.72	0.70	0.79		
Specific cohesion, kPa	34.0/25.0*	34.0/25.0*	28.0/22.0*	25.0/21.0*	22.0			1
The angle of internal friction	25/19*	25/19*	23/18*	21/18*	18			40
Modulus of deformation, MPa	23.8/17.0*	23.8/17.0*	19.0/14.0*	15.5/13.5*	14,5			38
Design strength, kPa	362	362	341	160				500

*****characteristics are given for soil at a water-saturated state*

4. CONSTRUCTIVE SOLUTIONS

4.1 Construction Solution for Embankments

Soil settlement is possible in some areas because EGE-4 soils have settled properties. Geotechnical conditions in terms of collapsing refer to type I (first) and II (second). All crossing routes of designed roadway has got asphalt-concrete pavement with gravel basement. The thickness of asphalt- concrete is from 0.11 till 0.38 m. 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. 2.

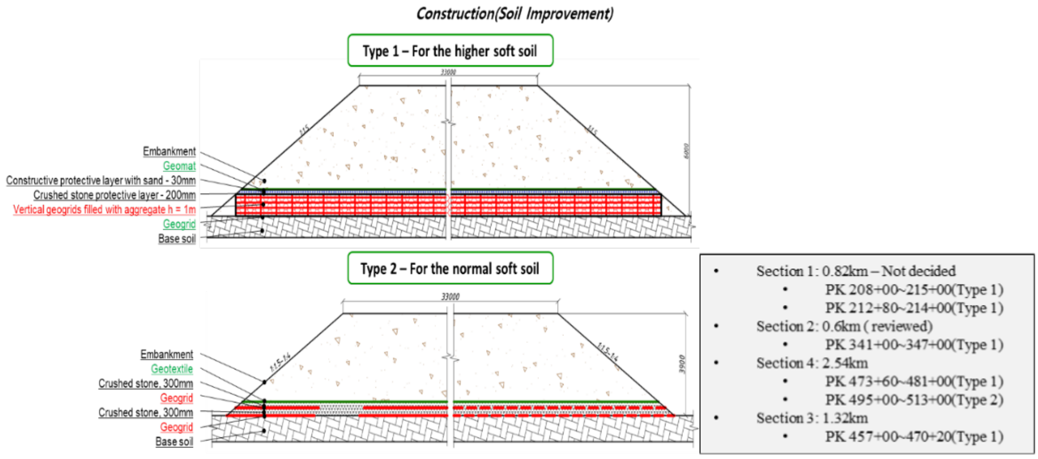

Fig. 2 General design solution

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 in 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 hurt the road surface.

The choice of drainage design should be made based on a technical and economic comparison of options. Geogrid provides a strong mattress foundation that significantly increases the stability of the soil. The effect of geogrid generated in the embankment body and the geogrid layer [10-13].

4.2 Construction Solution for Road Pavement

The pavement structure of the road consists of polymer asphalt concrete, dense hot paving asphalt concrete, grade I, hot-laid asphalt concrete, porous, grade II, base layer, subbase layer. The pavement design is presented in Fig. 3.

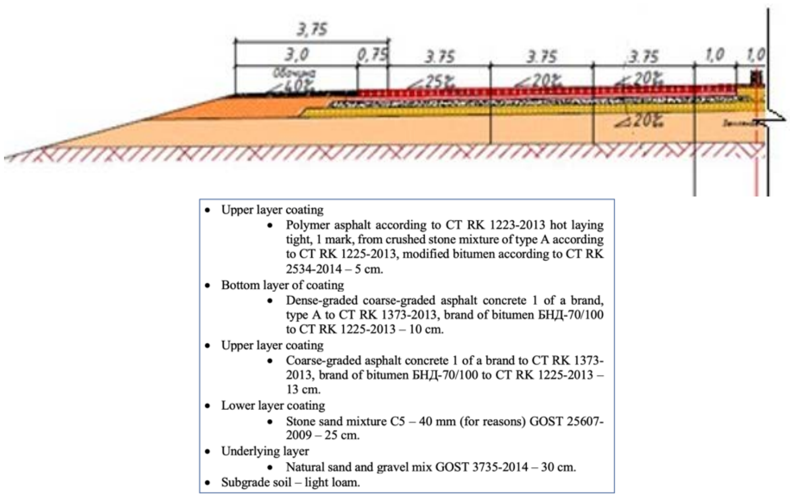

Fig.3 Road pavement

This embankment and road clothing design will prevent and suspend the aging of the road structure and will be used mainly on highways of a high technical category [14-15].

5. FIELD SOIL TESTS

5.1 Stamp Soil Tests

The work was carried out to study the bearing capacity of the embankment and base excavation. The structure of the unit for soil testing by punch includes a stamp; a device for creating and measuring the load on the stamp; an anchoring device (for installations without a load platform); a device for measuring the sediments of the stamp; a device for soaking and control of soil moisture (when testing subsidence soils).

The design of the unit provides the possibility of loading the stamp in steps of the pressure of 0.01-0.1 MPa, centered transfer of the load on the stamp, and the constancy of the pressure at each stage of loading. Stamp loading is carried out by a jack or calibrated weight. The load is measured with an error of no more than 5% of the pressure stage. Deflectometer for measuring stamp settlement are fixed on the reference system. The measuring system provides the measurement of settlements with an error of not more than 0.1 mm.

To measure the stamp settlement, it is allowed to use instruments that provide the measurement of settlements with an error of not more than 0.1 mm. The study of the bearing capacity of the foundation soil was carried out at 6 points of stamp tests.

The research was carried out at 3 drypoints and 3 wet ones [16]. Stamp tests are the most reliable method for determining the deformation modulus, elastic modulus, bedding coefficient of soils, natural foundations, and structural layers of road pavements. To carry out the tests, a punching machine with a rotary arm was used, acting on the principle of the balance beam provided in Fig. 4.
Stamping test results are presented in Table 2 and Fig. 5-10.

Fig. 4 Field test process

Table 2 Stamping test results

Soil	Plate diameter, cm	Plate area, cm^2	Plate load, t	Pressure under the plate, kgf/cm^2	Total average plate settlement, $S_{tot.av}$	Deformation modulus, E_{def}, kgf/cm^2	Elastic average plate settlement, mm	Elastic modulus E_{elas}, kgf/cm^2	Coefficient of subgrade, kgf/cm^3
1	2	3	4	5	6	78	8	9	10
Point №1 Dry soil	30	707	0.71	1.00	0.60	359.5	0.36	599.1	16.67
			1.41	2.00	0.98	440.1	0.62	695.7	20.41
			2.12	3.00	1.40	462.2	0.82	789.0	21.43
			2.83	4.00	1.72	501.6	0.98	880.3	23.26
			3.53	5.00	1.88	573.6	1.20	898.6	26.60
1	2	3	4	5	6	7	8	9	10
Point №1.1 Wet soil	30	707	0.71	1.00	2.20	98.0	0.78	276.5	4.55
			1.41	2.00	3.82	112.9	1.18	365.5	5.24
			2.12	3.00	5.74	112.7	1.56	414.8	5.23
			2.83	4.00	7.92	108.9	1.96	440.1	5.05
			3.53	5.00	10.26	105.1	2.22	485.7	4.87
Point №2 Dry soil	30	707	0.71	1.00	0.80	269.6	0.42	513.5	12.5
			1.41	2.00	1.52	283.8	0.86	501.6	13.16
			2.12	3.00	2.18	296.8	1.22	530.3	13.76
			2.83	4.00	2.74	314.8	1.50	575.1	14.60
			3.53	5.00	2.94	366.8	1.78	605.8	17.01

Table 2 continued

1	2	3	4	5	6	78	8	9	10
Point №2.1 Wet soil	30	707	0.71	1.00	3.14	68.7	0.74	291.4	3.18
			1.41	2.00	7.82	55.2	1.20	359.5	2.56
			2.12	3.00	12.22	52.9	1.76	367.6	2.45
			2.83	4.00	17.76	48.6	1.94	444.7	2.25
			3.53	5.00	20.80	51.8	2.76	390.7	2.40
Point №3 Dry soil	30	707	0.71	1.00	0.94	229.4	0.58	371.8	10.64
			1.41	2.00	1.70	253.7	1.04	414.8	11.76
			2.12	3.00	2.66	243.2	1.56	414.8	11.28
			2.83	4.00	3.42	252.2	2.04	422.9	11.70
			3.53	5.00	3.94	273.7	2.48	434.8	12.69
Point №3.1 Wet soil	30	707	0.71	1.00	3.50	61.6	0.90	239.6	2.86
			1.41	2.00	8.10	53.3	1.48	291.4	2.47
			2.12	3.00	12.84	50.4	1.96	330.1	2.34
			2.83	4.00	16.52	52.2	2.56	337.0	2.42
			3.53	5.00	20.18	53.4	3.00	359.5	2.48

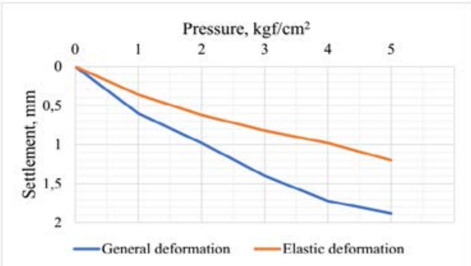

Fig. 5 Results of Point 1 (dry soil)

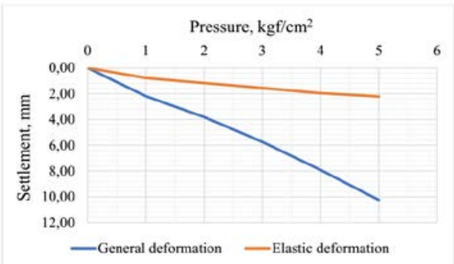

Fig. 6 Results of Point 1.1 (wet soil)

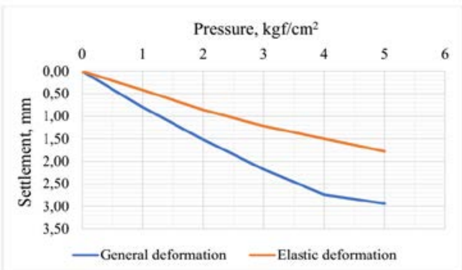

Fig.7 Results of Point 2 (dry soil)

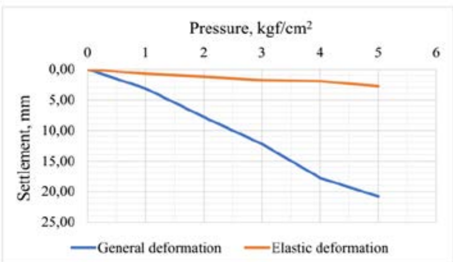

Fig. 8 Results of Point 2.1 (wet soil)

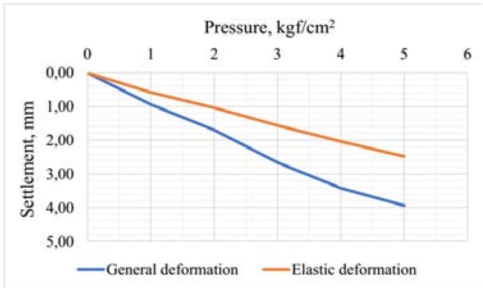

Fig. 9 Results of Point 3 (dry soil)

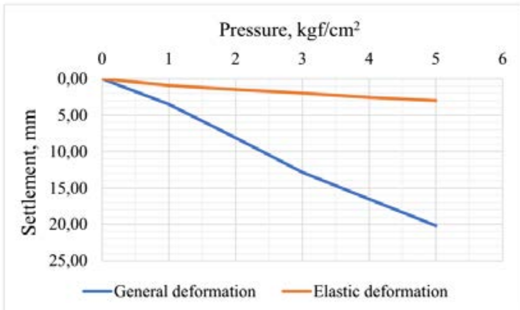

Fig. 10 Results of Point 3.1 (wet soil)

5.2 Static Load Tests

Soil tests with piles are conducted by static pressed loads evenly, without impacts, in loading stages, with the value set by the test program, but it is accepted not more than 1/10 of the maximum load on the pile specified in the program [17-18]. When deepening the lower ends of full-scale piles into coarse-grained soil, gravelly and compact sands, and clay soils of solid consistency, the first three loading stages are allowed to be taken equal to 1/5 of the maximum load.

At each stage of loading a full-scale pile, all devices for measuring deformations in the following sequence is read out: zero count - before loading the pile, the first count - immediately after loading, then three sequential counts at 30 minutes' intervals, for piles of bridge foundations - in 15 minutes and then every hour until the conditional stabilization of the deformation (damping of displacement). The criterion of conditional stabilization of deformation during testing with a production pile is taken as the pile settlement at this loading stage, which does not exceed 0.1 mm for the last 60 minutes of observations. If sandy soils or clay soils from hard to tight-plastic consistency lie under the lower end of the pile, or if for 2 hours of observations, clay soils from soft-plastic to fluid consistency lie under the lower end of the pile are used [19-21]. Pile plan field presented in Fig. 11.

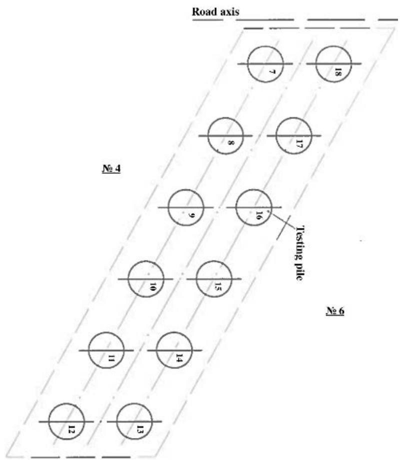

Fig.11 Pile plan field

Pile No. 16 was identified for testing at the projected site. The test work is shown in Fig. 12 and the equipment in Fig. 13-14.

Fig.12 Test works

Fig.13 Loader with hydraulic jack

The maximum load on the tested pile was 361.0 Tf. The design loading and unloading steps are presented in Tables 3-4. The holding time of each stage, from the first to the ninth, under indentation loads was 120 min for each stage. At the last tenth stage, the holding time was 270 min.

Fig. 14 General view of the measuring system

Table 3 Loading steps

Loading steps	Force by the jack, Tf
1	36.0
2	72.0
3	108.0
4	144.0
5	180.0
6	217.0
7	252.0
8	289.0
9	325.0
10	361.0

Table 4 Unloading steps

Unloading steps	Force by the jack, Tf
1	289.0
2	217.0
3	144.0
4	72.0
5	0

The number of test gauges for sediment analysis is two. The pile was unloaded in steps, with each step lasting for 15 minutes. The test results are shown in Fig. 15-16.

The maximum displacement of the pile at the last stage of loading, when averaging the values of the control devices of the deflectometer when reaching the control load 361.0 at the tenth stage of loading on the tested pile, was 4.05 mm. As a result of removal of the control load, the residual deformations were monitored, the value of the residual deformations (according to deflectometer 2 and 3, as the most accurate) was 2.63 mm.

The test results showed that the bearing capacity of pile No. 16 on the ground is sufficient to perceive the maximum pressing design load.

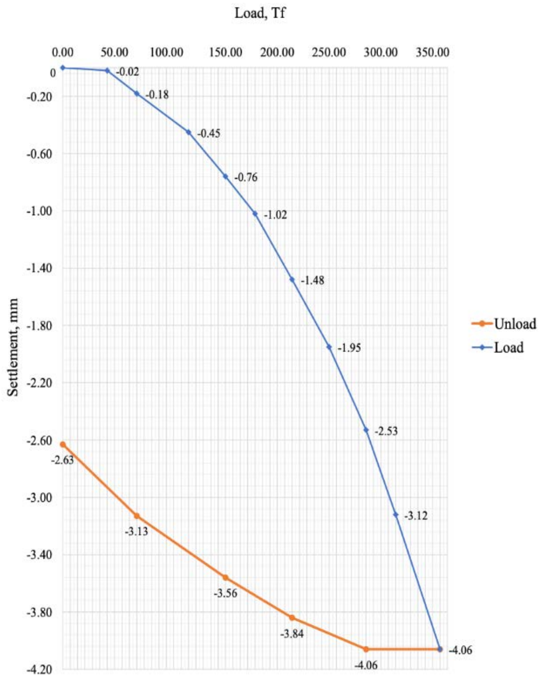

Fig. 15 Graph of results of the total settlement of the pile No. 16

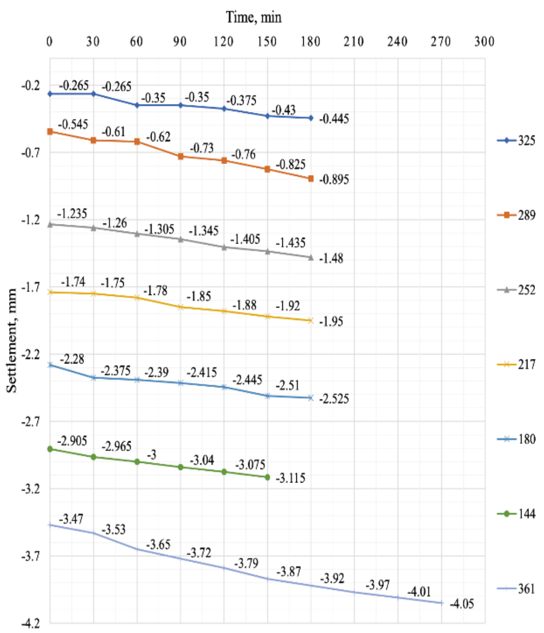

Fig. 16 Graph of results of the settlement of the pile No. 16 by loading stages

6. RESULTS AND DISCUSSIONS

Soil collapse is caused by the peculiarities of formation and existence of strata of these soils, as a result of which they are under consolidated. Under-compaction of loess soils can be maintained throughout the life of the strata unless moisture and load increase. In this case, additional compaction of soil in lower layers under the influence of its weight can take place. Therefore, the foundations formed by collapsing soils should be designed, taking into account the specific characteristics of such soils. Table 5 presented the compression ratio according to the results of stamp testing.

Table 5 Results of Points

Point name	Modulus of deformation, MPa	Modulus of elasticity, MPa	Compression ratio
Point 1	46,74/ 10,75*	39,65/ 39,65*	0,99/ 0,94*
Point 2	30,64/ 5,54*	37,08/ 37,08*	0,99/ 0,9*
Point 3	25,05/ 5,42*	41,18/ 31,15*	0,99/ 0,9*

**characteristics are given for soil at a water-saturated state*

On dry soil:

- Average modulus of deformation of the structure for 3 points test is: E_d = 34.14 MPa;
- Average modulus of elasticity of the structure for all 3 points test is E_{el} = 57.65MPa.

According to the tests carried out, the coefficient of compaction of soil layers the basis ranges from K ≈0.99.

The shape of the graph of general deformations corresponds to the linear dependence of the increment of total deformations on the increase in the load on the base. There is no loss of bearing capacity.

On wet soil:

- Average modulus of deformation of the structure for 3 points test is: E_d = 7.24 MPa;
- Average modulus of elasticity of the structure for all 3 points test is E_{el} = 35.96 MPa.

According to the tests carried out, the coefficient of compaction of soil layers in the base fluctuates within K <0.9.

The results of the pile static test showed that the bearing capacity of the soil is sufficient for the maximum load.

7. CONCLUSION

According to the research, it is necessary to follow recommendations, considering the specifics of collapsing soils:

1. It is possible to construct the road without the use of a "capping layer". This conclusion is justified by the fact that the height of the earth embankment and the road dressing in the project is sufficient for this region, and it ensures the stability of the roadbed and the earth embankment, as well as protects against the effect of frost penetration.
2. 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 (stamp experience). The results of which are as follows for soil at natural moisture, deformation modulus, E_d= 34.14 MPa, for water-saturated soil, deformation modulus, E_d= 7.24 MPa.
3. It is necessary to apply to the structure of the pavement «capping layer», in areas where the groundwater level is close to the bottom of the embankment for a more rigid resistance to loads from the structure located above. 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 sub-base on a capping layer than it is to compact it on saturated clay, meaning that by installing a capping layer, delays in the construction of the sub-base due to wet weather can be reduced.
4. Lean clay can be used as an artificial embankment if it is well compacted, and a large amount of water is not allowed into the soil body.

8. ACKNOWLEDGMENTS

The authors would like to thank **"**Alsim Alarko" JSC.

4. REFERENCES

[1] Shen Z. and Hu Z., Duality medium model of loess. Chin. J. Hydraul. Eng., Vol. 25, Issue 7, 2003, pp.1–6.

[2] Xie D. Exploration of some new tendencies in research of loess soil mechanics. Chin. J. Geotech. Eng., Vol. 23, Issue 1, 2001, pp. 3–13.

[3] Zhang S., Zhang W., Collapsibility of loess during moistening and de-moistening process. Chin. J. Geotech. Eng., Vol.14, Issue 1, 1992, pp.57–61.

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

[5] Prommin T. and Nuntasarn R. Ultimate bearing capacity of collapsing Khon Kaen loess. International Journal of GEOMATE, Vol. 17, Issue 63, 2019, pp.87-94.

[6] Mustakimov V., Study of collapsing soils reinforced by vertical elements, LAP LAMBERT Academic Publishing, 2016, p 94.

[7] Zhusupbekov A.Z., Enkebaev S.B., Lukpanov R.E., and Tulebekova A.S., Analysis of the settlement of pile foundations under soil conditions of Astana. Soil Mechanics and Foundation Engineering, Vol. 49, Issue 3, 2012, pp.99-104.

[8] Wang L., Liu B. and Bai Y., Study on Interaction Mechanism between Collapsible Loess and the Subway Underground Structure. Modern tunneling technology, Vol. 56, Issue 1, 2019, pp.72-78.

[9] Working Project «Big Almaty Ring Road Construction» Survey Materials, Geological Report // «Research and Manufacturing Company Kazdorinnovaciya» LLP, Almaty 2019.

[10] Rachmawati S.H., Hossain Z. and Shiau J., Ground improvement using the waste shell for farm roads and embankments, Journal of Agricultural Engineering, Vol. 49, Issue 1, 2018, pp. 29–33.

[11] Koerner R.M., Hwu B.L., and Wayne M.H., Soft Soil Stabilization Designs Using Geosynthetics, Journal Geotextiles and Geomembranes, Vol. 6, Issue 1–3, 1987, pp. 33–52.

[12] Rowe R.K. and Li A.L., "Geosynthetic-reinforced Embankments over Soft Foundations." Geosynthetics – 7th ICG – Delmas, 2002, pp. 5-34.

[13] Rowe R.K. and Li A.L., Behaviour of Reinforcement Embankments on Soft rate-sensitive Soils, Géotechnique, Vol. 52, Issue 1, 2002, pp. 29–40.

[14] Peben M.R. Scurfield D., Mohan D., Huder F., Jarawan E., and Mathers C., World Report on Road Traffic Injury Prevention. – Geneva: WHO, 20,2004.

[15] Kiyalbaev A.K., Kiyalbay S.N., The maintenance of roads. Textbook. /under the editorship of prof. Kulbaeva A. K 2017, 343 p.

[16] GOST 20276.1-2020. Soils. Plate bearing test methods, Gersevanov Research, Design and Survey and Design and Technological Institute of Foundations and Underground Structures (NIIOSP), Moscow, Russia, p.13.

[17] GOST 5686-20. Methods for field testing by piles, Research Institute of Bases and Underground Structures, Moscow, Russia, p.44.

[18] Ghani A. N. A., Roslan N. I., Hamid A.H., Road submergence during flooding and its effect on subgrade strength. International Journal of GEOMATE, Vol. 10, Issue 21, 2016, pp.1848-1853.

[19] Zhussupbekov A.Z., Tulebekova A.S., Lukpanov R., Zhumadilov I.T., Comparison

analysis of features in Eurocode and Kazakhstan norms requirements. Challenges and Innovations in Geotechnics - Proceedings of the 8th Asian Young Geotechnical Engineers Conference, 8AYGEC, 2016, pp. 251–255.

[20] Kurakina E.V., On the deviation of the normative characteristics of the indicators of the motor road (on the example of accident-prone sections of roads in the Leningrad region). Modern problems of science and education, 2014, pp. 12-16.

[21] Tulebekova A.S. Control equipment for pile tests according to American and Kazakhstan standards. Modern Applied Science, Vol. 9, Issue 6,2015, pp. 192–198.