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ASSESSMENT OF SOILS DEFORMABILITY UNDER VERTICAL LOAD

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ABSTRACT: Laboratory and experimental tests in huge amount are required during engineering surveys for large and critical buildings and structures especially in complex geological conditions. The laboratory investigations are applicable in cases with no possibility for field tests. However, as a rule the results obtained from laboratory investigations (in particular compression tests) show conservative values of deformation modulus, which leads to underestimate of soil foundations load-carrying capacity, cost increase of foundations for buildings and structures as well as significant overrun of expensive construction materials. The paper shows laboratory tests results (compression and stabilometric) for unixial and triaxial compression of soil samples; results of field plate-load tests for vertical pressed load over natural soil massif. It also brings comparison of stress-strain properties obtained by results of compression, stabilometer and plate-load tests with derivation of regional correction factors for Nur-Sultan City (Kazakhstan). In case of using the recommended regional coefficients while determining the overall deformation modulus by laboratory tests, a significant economic effect is achieved as a result of cost reduction for materials and construction of foundations for buildings and structures.

Keywords: Soil, Laboratory Test, Properties, Compression

1. INTRODUCTION

The investigation of soils deformability as foundations for buildings and structures appears as an important stage in designing of foundations for them. The designing of foundations for buildings and structures on soft ground seats may be carried out only under the presence of soil compressibility properties. The durability, cost and construction periods in many ways depend on the quality of determining these properties. An incorrect assessment of soils deformability may lead to the construction of unreasonable oversized foundations or to their excessive settlement, which may cause state of failure for entire building or structure.

The laboratory tests are those for testing of soil samples in odometers and stabilometers - triaxial compression devices, the second are the soils tests with loaded plates in pits and boreholes under static loads.

The simplest and most accessible method of soil deformability assessment is the compression test. The compression test appears as deformation (compression) of cylindrical soil sample in a rigid ring in vertical direction, i.e. unixial compression without lateral extension. The compression tests of soils in odometers very often provide conservative values of deformation modulus. It relates to structural ruptures of soil samples during their sampling, packing, transportation and loading into odometers [1,2]. A significant influence on the tests results is made by macro and microroughnesses on the sample's end surface, as well as the friction between its lateral surface and odometer's inner wall. The soils deformability properties determined by the results of compression tests, in most cases may be used in construction practices only after application of correction factors to them.

The laboratory tests under triaxial compression more exactly model soil stress conditions and allow complex determining of mechanical properties of stabilized and frictional soils: compaction factor, deformation modulus, coefficient of lateral pressure, Poisson number, soil adhesion and internal friction coefficient, filtration factor under predetermined pressure, etc. [3]. The practice shows that complex tests via laboratory and field methods allow far and wide estimating of physical and mechanical properties of soils [4]; and providing of reliable assessment of geotechnical profile over the construction site.

2. TESTING

2.1 Soil Sampling For Testing

The soils for the laboratory tests were sampled after plate-load tests at a distance not exceeding 1.0 m from the edge of the test pit arranged for plate-load tests at various soil depths. Three test pits were drilled down to the depth of 6-6.5 m for plate-load tests with 1 m intervals by the depth as well as 9 test boreholes for sampling with intervals of 0.25 m down to the depth twice wider than the plate's two diameters (7.5-8.0 m). The distances between boreholes were 1-1.2 m. The number of boreholes was selected with consideration of 6 samples to be taken for compression tests, 6 samples for stabilometer tests and three samples in reserve, in case of inapplicability for testing. Soil samples for geotechnical tests were taken at a depth of 30 m after sampling of soil for laboratory tests related to deformation modulus.

The construction site is located in the capital of the Republic of Kazakhstan Nur-Sultan city, on the left bank of the Yesil River. As a result of soils long genesis, the geological profile of the construction site is given by layers with six geotechnical elements. The main surveys were carried out for EGE 2 presented by loamy soils, for which the full density tests were made.

Engineering-geological profile is shown in Figure 1.

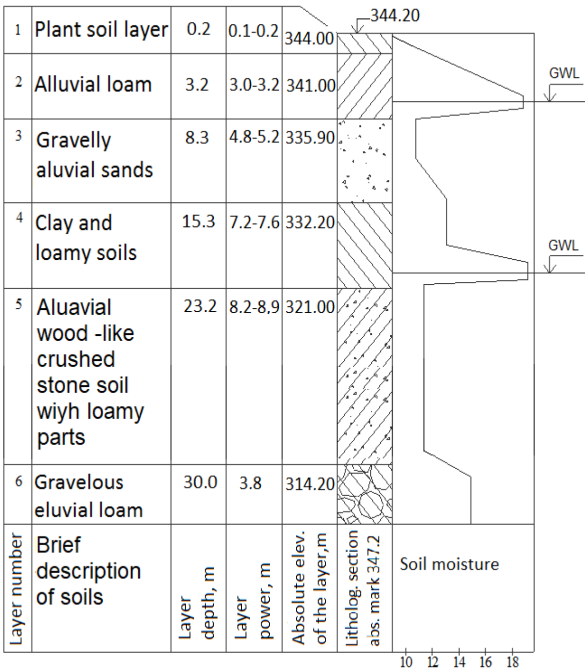

Fig.1 Profile of the construction site

2.2 Deformation Modulus

The assessment of constrained modulus was considered under the pressure ranging within 0.1-0.2 MPa and 0.2-0.3 MPa, consequently the comparison of deformation modulus determined by plate-load and stabilometer tests was considered in these ranges. The sample load values for compression, stabilometer and plate-load tests to create stresses relevant to these pressure ranges are given in Table 1. A distinctive property of soils is that the soils of same composition within one geological element represent anisotropic structure and have inhomogeneous strength, density, and water content in depth.

Table 1 The sample load values for compression, stabilometer and plate-load tests

Tests	Sample diameter d (cm)	Sample load P (kN), to apply pressure σ_1 (MPa)		
		σ_1=0.1	σ_2=0.2	σ_3=0.3
Compression	3	0.2826	0.5652	0.8478
Stabilometric	2,5	0.1962	0.3925	0.5887
Plate-load	40	50	100	150

For example, the water content of soils in Nur-Sultan City, Kazakhstan varies within 10.2 – 27.7%, density varies within 1.84 – 2.09, porosity factor within 0.51 – 0.68. Such diverse properties of soils do not provide an identical value of deformation modulus within the same geological element. Since the samples of loamy soils are within the limited range by water content and density typical only to the surveyed construction site, (namely 14.4-18.7%, in accordance with geotechnical surveys) so the survey data may be used for loamy soils of limited range by water content and cannot be used for loamy soils of the same composition, but different water content and density. Thus the soil samples were subjected to the survey, both in undisturbed and in disturbed condition as well, under various water content and density of sample, while the obtained results of samples with a disturbed structure were used to determine the principle of change of deformation modulus by water content in a wide range typical for loamy soils in Nur-Sultan City and the test results of samples in undisturbed condition (as a result of limited range of water content) were used for correction of conservative values of deformation modulus of samples in disturbed state for the structural strength.

In case of stabilometer tests of soils, there is no need to correct the soil's structural strength since it is compensated by uniform pressure in the chamber, simulating the common pressure of the soil. In case of plate-load tests, opposite to compression and stabilometer tests [2] the values of deformation modulus will be within the water content range typical only to the surveyed construction site. Consequently, comparison of deformation modulus lying outside the mentioned water content (14.4-18.7%), as well as the obtained correction factors, will be referred predicted ones.

2.3 Compression tests of soils

The compression tests for soil samples presented as loam in undisturbed condition were performed in the following sequence: weighing of the sample in the working ring with following covering of the ends with wet filters; setting of the sample in the compression equipment; adjustment of sample loading mechanism, setting of instruments for measuring sample's vertical deformations, recording of initial readings from the instruments; stepped loading over the sample.

The results of compression tests of loam of disturbed composition, different water content are shown in Figures 2-3.

a)

b)

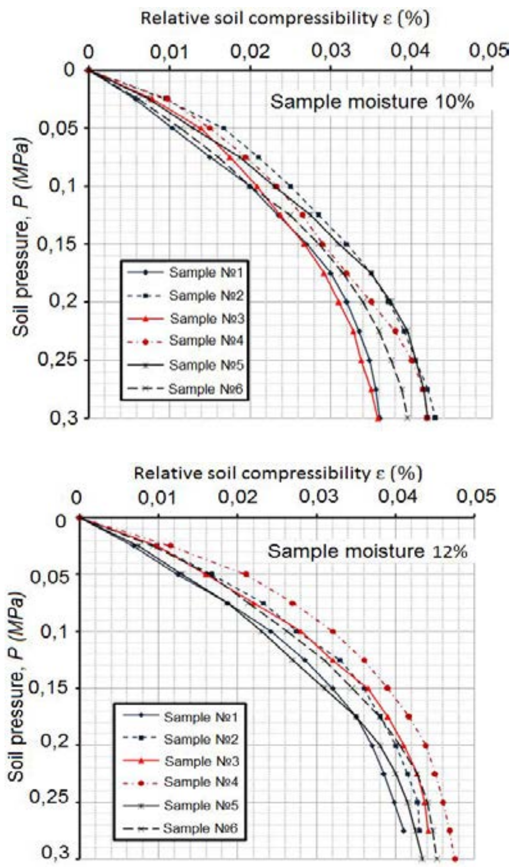

Fig.2 Results of compression tests of loamy soil samples with water content: a) 10%; b) 12%

The obtained values of deformation modulus for loamy soils at different stages of sample loading, as well as the relevant values of the porosity factors are shown in Table 2.

Table 3 brings the results of sandy soils sampled from various depth of occurrence at 3 and 6 m. The test results for samples of natural composition are given in Table 4.

a)

b)

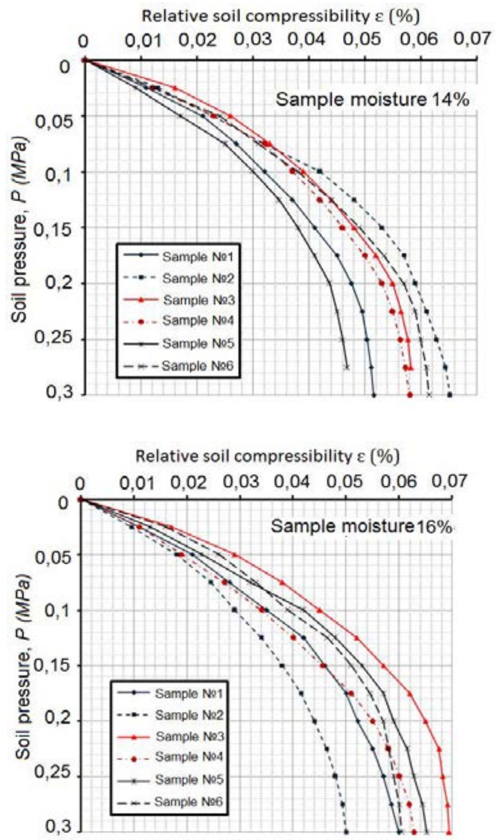

Fig.3 Results of compression tests of sandy soil samples with water content: a) 14%; b) 16%

Table 2 Results of compression tests of loamy soils in disturbed condition

Soil water content, w (%)	Pressure, σ (kPa)	Compression modulus of deformation $E_к$ (kPa)	Porosity factor, e
10	1000	3685	0,675
	2000	5546	0,573
	3000	18110	0,562
12	1000	3017	0,683
	2000	5104	0,578
	3000	17603	0,554
14	1000	2231	0,687
	2000	4000	0,565
	3000	16810	0,543
16	1000	2188	0,691
	2000	3509	0,556
	3000	14935	0,525
18	1000	2431	0,669
	2000	3114	0,553
	3000	14103	0,52
20	1000	2012	0,689
	2000	2908	0,572
	3000	13151	0,537

Table 3 Results of compression tests of sandy soils

Normal pressure σ, MPa		Vertical deformation, ε		Deformation modulus, E,kPa		Porosity factor, e	
3m	6m	3m	6m	3m	6m	3m	6m
0.025	0.025	0	0	-	-	0.672	0.662
0.1	0.1	0.0193	0.0119	4150	6794	0.663	0.654
0.2	0.2	0.0239	0.0155	22380	27960	0.656	0.649
0.3	0.3	0.0281	0.0177	30710	36980	0.649	0.645

Table 4 Results of compression tests of loamy soils of natural composition

Test №	1	2	3	4	5
Water content,w (%)	14.4	14.7	18.7	17.2	18.3
Deformation modulus E (kPa)	5163	5079	3997	4499	4186
Test №	6	7	8	9	10
Water content,w (%)	15.5	14.3	14.8	17.8	16.2
Deformation modulus E (kPa)	4800	5228	5014	4270	4667

2.4 Stabilometer Tests of Soils

The soil tests for triaxial compression were carried out in the following sequence: preparation of sample in a specially arranged test stand with dimensions of 40x40x60; setting of sample in triaxial chamber, preparation of testing equipment in accordance with GOST [3]; stepped compaction of the sample under uniform pressure in the chamber in accordance with the tests program with open drain valves to ensure water removal from the soil sample; vertical stepped loading over the sample composing 20% from the uniform pressure. The results of stabilometer tests [2] of soil samples under various values of density and water content are given as diagrams in Figure 4 for loamy soils.The obtained values of stabilometric modulus of deformation are given in Table 5 for loamy soils, in Table 6 for sandy soils.

Table 5 Results of stabilometric modulus of deformation of loamy soils under various values of uniform pressure

Water content, w (%)	Stabilometric modulus of deformation, E (kPa)		
	σ_3 at 1 m depth	σ_3 at 2 m depth	σ_3 at 3 m depth
under pressure within 0.1-0.2 MPa			
10	7630	8930	9270
12	7290	8350	8992
14	6280	7890	7890
16	5980	7220	7250
18	5680	6430	7130
20	5550	6120	6380
under pressure within 0.2-0.3 MPa			
10	7120	8550	8760
12	6780	7850	8240
14	5930	7330	7320
16	5510	6780	6980
18	5170	6120	6430
20	4820	5780	5990

Table 6 Results of stabilometric modulus of deformation of sandy soils under various values of uniform pressure

Sample №	Results of stabilometric modulus of deformation, E	
	σ_3=77kPa	σ_3=121kPa
1	17668	22591
2	17121	23779
3	18853	21131
Average value, E	17880	22500
Variation coefficient, v	0.06	0.05

a)

b)

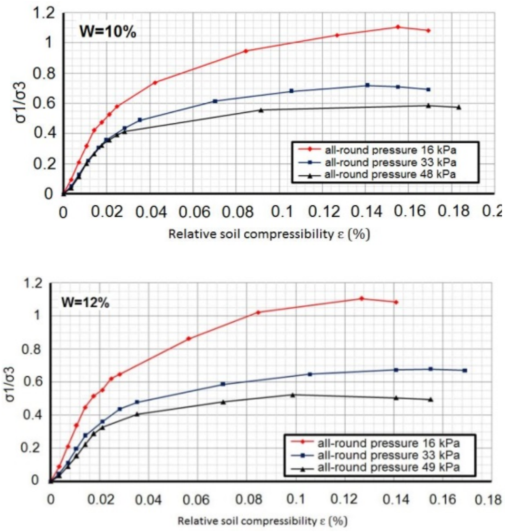

Fig. 4 Results of stabilometer tests of loamy soil samples with water content: a) 10%; b) 12%

In accordance with the results of statistical data processing of obtained values for deformation modulus of sands it may be concluded about high density of test results with insignificant spread of 5-6%.

2.5 Plate-Load Tests of Soils

The field plate-load tests of soils were carried out [5-7] in the following sequence:

- installation of plate, setting of benchmark system for instruments and anchor support stand;
- vertical stepped loading of the plate, until conditional stabilization of the soil.
- composing 20% from the uniform pressure.

The diagrams of plate S settlement from the applied load P for loamy soils with various natural water content values at a depth up to three meters are shown in Figures 5-7. Plate-load modulus of deformation were determined for the pressure ranges within 0.1-0.2 MPa and 0.2-0.3MPa, Table 7 brings the results of plate-load modulus of deformation of loam depending on the soils occurrence depth and their natural water content.

The diagrams of plate S settlement from the applied load P for sandy soils at various depths (up to 6 m) are shown in Figure 8, and the results of plate-load modulus of deformation for sandy soils are given in Table 8.

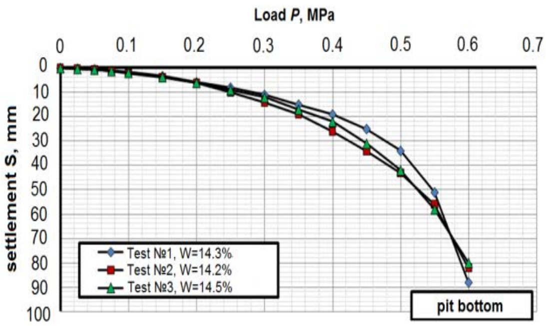

Fig.5 Results of plate-load tests of soils from the excavation pit bottom (loamy soils)

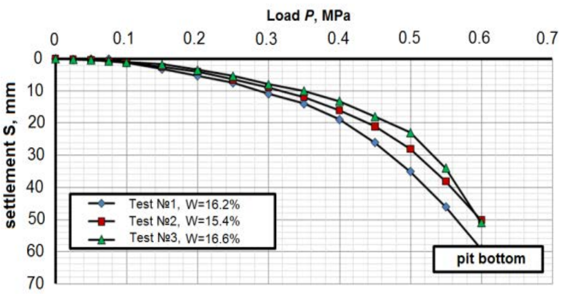

Fig.6 Results of plate-load tests at 1 m depth (loamy soils)

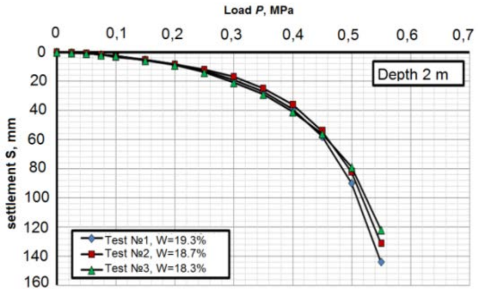

Fig.7 Results of plate-load tests at 2 m depth

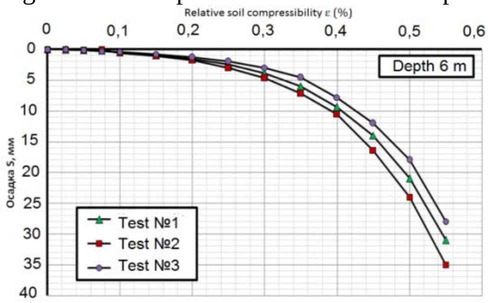

Fig.8 Results of plate-load tests at 6 m depth (sandy soils)

Table 7 Values of plate-load modulus of deformation for loam

Testing depth, m	Deformation modulus values, E (kPa) sample №1	sample №2	sample №3
under pressure within 0.1-0.2 MPa			
0.2-0.4	8232	8423	8890
1	7940	7429	7109
2	7898	8698	9213
3	6545	5465	6092
under pressure within 0.2-0.3 MPa			
0.2-0.4	8040	8220	8240
1	7780	7260	6990
2	7570	8180	8760
3	6210	5320	5780

Table 8 Values of plate-load modulus of deformation for sand

Testing depth, m	Deformation modulus value, E (kPa)		
3-3.2	16785	17734	17330
6	22980	24312	23458
3-3.2	16785	17734	17330
6	22980	24312	23458

2.6 Measurements Comparison for Compression, Stabilometer and Plate-Load Tests

Comparison diagrams of the deformation

modulus for loamy soil obtained by various tests are shown in Figures 9 and 10. The diagram shows the compression tests results for a sample with disturbed composition without correction and corrected for the soil's structural strength [10]. The results for samples with disturbed composition may be conditionally attributed to loamy soils occurred on the surface (0 m), while the corrected results characterize a dependence of the deformation modulus on the water content of the soil occurred at 2 m depth. The diagram also shows the results of the stabilometric modulus of deformation under various values of uniform pressure characteristic at various occurrence depths of the soil (1, 2 and 3 m). Values of plate-load modulus of deformation are also shown on the diagram in the shape of averaged values of deformtion modulus at various depths and various water content values.

Comparison diagram for the deformation modulus for sandy soil obtained by various tests is shown in Figure 11. It is visible by the diagrams, in case with sandy soils the compression modulus of deformation exceeds the stabilometric and plate-load values, opposite to loamy soils. The correlation of the obtained values for deformation modulus by the occurrence depth and soil water content was made to determine the correction factors [11,12]. Figure 10 presented comparison of deformation modulus for sandy soil.

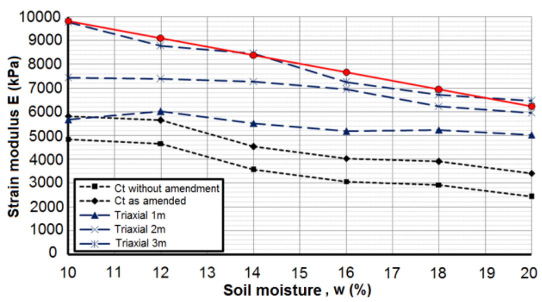

Fig.9 Comparison of deformation modulus for loamy soil obtained by various tests (0.1-0.2 MPa)

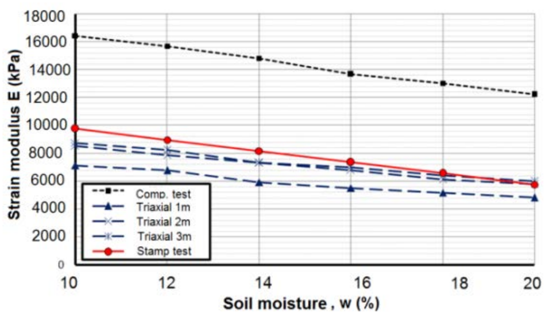

Fig.10 Comparison of deformation modulus for loamy soil obtained by various tests (0.2-0.3 MPa)

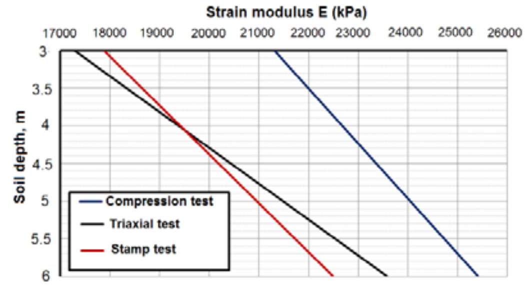

Fig.11 Comparison of deformation modulus for sandy soil obtained by various tests

3. CORRECTION OF DEFORMATION MODULUS

The soil deformation modulus, determined by compression or stabilometer test methods, is recommended to be corrected according to the regional correction factors obtained in this study for Nur-Sultan City for field plate-load tests [8-9] by to the formula (1):

$$\mathbf{E_p} = \mathbf{m_k}(\mathbf{m}_{st}) \cdot \mathbf{E_k}(\mathbf{E_{st}}) \quad (1)$$

where, $\mathbf{E_p}$ – value of the plate-load modulus of deformation, kPa;

$\mathbf{m_k}$ – conversion factor from the compression modulus to the plate-load, determined from comparative experiments;

$\mathbf{m_{st}}$ – conversion factor from the stabilometric modulus to the plate-load, determined from comparative experiments;

$\mathbf{E_k}$ – value of the compression modulus of deformation, kPa;

$\mathbf{E_{st}}$ – value of the stabilometric modulus of deformation, kPa.

It should be pointed out that laboratory tests of soil samples taken under the foundation of a designed or reconstructed building or structure and, respectively, for a long time under their load, should be carried out with consideration of existing pressures under the foundation base.

The results for soil samples tests in laboratory conditions and soil tests with a static vertical pressing load, as well as the results of mathematical processing of the obtained data were edited in diagrams and tables to determine the correction factors of the laboratory modulus of deformation to the plate-load modulus for Nur-Sultan City.

Table 9 brings the values of averaged correction factors of the deformation modulus determined by compression tests for loamy soils depending on their water content. As it is visible from the table, the obtained correction factors vary from 1.75 to 1.25 for pressure range within 0.1-0.2 MPa, from 0.47 to 0.59 for pressure range within 0.2-0.3 MPa.

Table 9 Correction factors m_k for reduction of compression modulus of deformation to the plate-load ones (loam)

Soil water content, w (%)	Correction factor m_k	
	0.1-0.2 MPa	0.2-0.3 MPa
10	1.75	0.59
12	1.84	0.57
14	2.15	0.55
16	2.22	0.54
18	2.30	0.50
20	2.50	0.47

Correction factors of compression tests for loamy soil may be obtained using Figures 12 and 13, graphically showing the modification of this coefficient depending on water content and respectively on the depth of soil sampling. Table 10 shows the values of the averaged correction factors for deformation modulus determined by stabilometer tests for loamy soils depending on their water content.

As it is visible from the table, the obtained correction factors vary from 1.05 to 1.17 for pressure range within 0.1-0.2 MPa, from 1.04 to 1.20 for pressure range within 0.2-0.3 MPa.

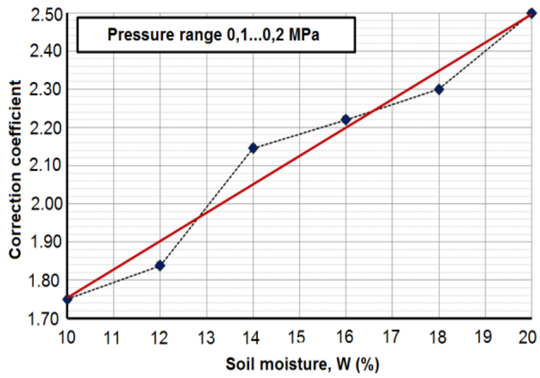

Fig.12 Correction factors for reduction for loamy soils (0.1-0.2 MPa)

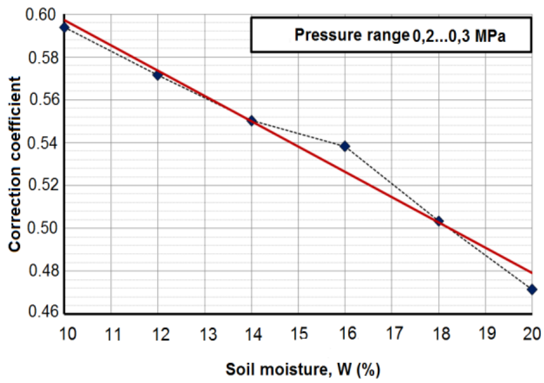

Fig.13 Correction factors for reduction for loamy soils (0.2-0.3 MPa)

Table 10 Correction factors m_{st} for reduction of stabilometric modulus of deformation to the plate-load ones (loam)

Soil water content, w (%)	Correction factor m_k	
	0.1-0.2 MPa	0.1-0.2 MPa
10	1.17	1.20
12	1.14	1.18
14	1.16	1.19
16	1.13	1.15
18	1.07	1.11
20	1.05	1.04

Correction factors of deformation modulus determined by stabilometer tests for loamy soil may be obtained using Figures 14 and 15, graphically showing the modification of this coefficient depending on water content and respectively on the depth of soil sampling and results of correction factors for reduction of compression modulus of deformation presented in Table 11.

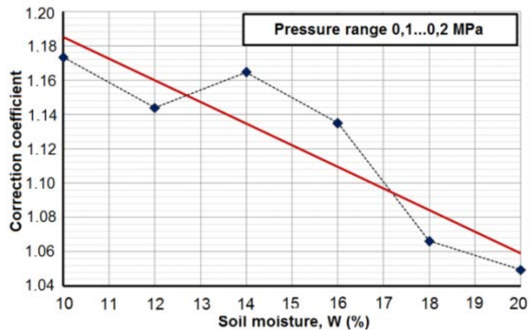

Fig.14 Correction factors for reduction for loamy soils (0.1-0.2 MPa)

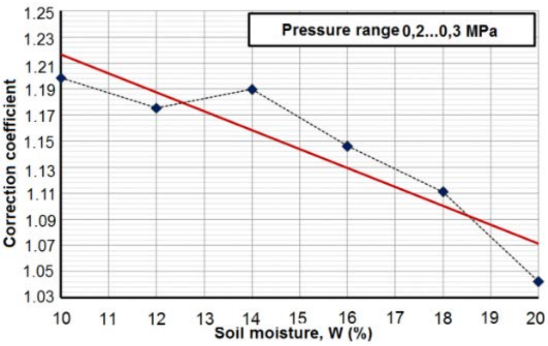

Fig.15 Correction factors for reduction of the stabilometric modulus of deformation to the plate-load ones for loamy soils (0.2-0.3 MPa)

Correction factors may be obtained using Figure 16, graphically showing the modification of this coefficient depending on the depth of soil sampling.

Table 11 Correction factors m_k and m_{st} for reduction of compression modulus of deformation to the plate-load ones (sand)

Occurrence depth, m	Compression to the plate-load	Stabilometric to the plate-load
3	0.81	1.03
6	0.93	0.95

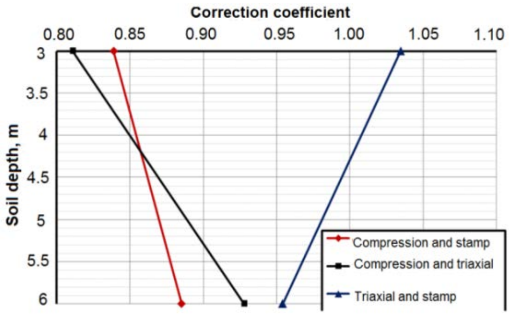

Fig.16 Correction factors for reduction of the compression modulus for sandy soils

4. CONCLUSION

As a result of the study, the correction factors were obtained for reduction of the compression and stabilometric modulus to plate-load ones for loamy soils depending on soil's water content, for sandy ones depending on the occurrence depth. The obtained correction factors for reduction of compression modulus to load-plate ones vary from 1.75 to 2.5 in the pressure range within 0.1-0.2 MPa, 0.47- 0.59 in the pressure range within 0.2-0.3 MPa. The reason for such spread of coefficients depending on the pressure is the limitedness of the compression device dimensions, as well as the nature of the soil deformability in a closed (compression) and free (under plate) state. The values of coefficients in the pressure range within 0.1-0.2 MPa for loamy soils are 2-3 times different from the classical ones, which in turn confirms the influence of soil's regional properties on the values of these coefficients. The obtained correction factors for reduction of compression modulus to plate-load ones for sandy soils showed a principle opposite to loamy soils and vary from 0.81 to 0.93 depending on the occurrence depth of the sandy soil. Its reason may be a large difference in the relation of the soil fraction to the compression device chamber's dimensions; this relation for sandy soils is 10-30 times higher than for loamy ones.

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