DEFORMATION PROPERTIES OF THE PLIOCENE CLAYS FROM THE SOFIA BASIN

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ABSTRACT. The intensive construction works during the recent years are related to deeper foundation works. These require more precise determination of the strength and strain parameters of the mottled and bluish-green clays of Pliocene sediments from the Sofia basin. The article discusses the deformation parameters of the Pliocene clays and sands from the site of the 200 m high 'Capital Fort' building in Sofia obtained from laboratory and elastimeter field tests. Their comparison revealed that the elastimetric deformation modules are much higher than the oedometric modules used as a common practice. Their application in the design will allow a considerable improvement in the foundation of the buildings and structures.

Keywords: Pliocene clays, elastimetric test, oedometric test, modules, comparison

ДЕФОРМАЦИОННИ СВОЙСТВА НА ПЛИОЦЕНСКИТЕ ГЛИНИ ОТ СОФИЙСКИЯ БАСЕЙН

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РЕЗЮМЕ. Интензивното строителство на високи сгради в София през последните години налага все по-дълбоко фундиране. Това изисква и по-точно определяне на якостно-деформационните свойства пъстрите и синьозелените глини и пясъци, изграждащи плиоценските отложения на Софийския басейн. В статията са разгледани деформационните свойства на плиоценските глини и пясъци за територията на площадката на 200 m високата сграда „Капитал форт" в гр. София, определени чрез лабораторни и пресиометрични полеви изследвания. Направеният сравнителен анализ, показва, че еластиметричните деформационни модули на плиоценските материали са значително по-високи от използваните в инженерната практика компресионни модули. Тяхното използване позволява значително оптимизиране на проектите за фундиране на сградите и съоръженията.

Ключови думи: плиоценски глини, еластиметричен опит, компресионен опит, модули, сравнение

Introduction

It is a long-term practice in Bulgaria to derive the soil deformation modules from laboratory oedometric tests while pressure-meter tests and their variation of elastimetric tests were rarely conducted due to their specific equipment and high price the tests. The national Ordnance № 1 (1996) allowed the deformation module of the massif to be obtained by multiplication of the tangent oedometric module for 0.2 MPa load by a factor from 2 (normally used as safe value) to 5 (practically not applied). Higher factors are accepted after comparative justification but that was rarely practiced. The purpose of this study is to make a comparative analysis of the deformation modules of the Pliocene clays and sands obtained from laboratory and elastimeter field tests from the site of the 200 m high 'Capital Fort' building in Sofia that is currently under construction.

The site is located on the south-east outskirts of the town next to 'Tsarigradsko shosse' Boulevard (Fig. 1). The building will be 200 m high including 4 underground levels buried at 14-15 m depth. The seismic structural design requires a raft foundation on 35 m long piles with 180 cm diameter. As previous experience for depth up to 30-35 m was available for the adjacent existing 120 m high building, additional drilling of 3 boreholes with a length of 80 m and 1 borehole 101 m deep was completed. The boreholes were used for establishing the geological structure at a greater depth, for sampling for new laboratory tests, for carrying out SPT's and elastimeter tests in the boreholes, as well as for seismic sounding in the deepest borehole.

Fig. 1. Location of the studied site (Google Earth)

Geological structure of the site

The area is located in the southeast periphery of the Sofia Pliocene graben-type basin. The basis of the graben is built up mainly by intrusive rocks forming irregular step-like denivelated blocks. In the graben, a sedimentary basin of the Crimean type was formed, which was gradually filled up by lacustrine sediments in the center part and mixed with alluvial materials in the peripheral areas. The total thickness of the Pliocene complex ranges from 250 to 500 m. They form the Pliocene clay-sandy formation (the so called 'Lozenets Series') including two lithological complexes that have been established in its upper section:

The lower (gray-green) complex is built up by irregular alternation from thick hard clays, sandy clays, clayey sands, and well-graded sands. The upper (yellow-brown) complex includes a series of alternating mottled clays, sandy clays, sands, and gravels.

The Pliocene materials are covered with Quaternary deposits presented mainly by dark brown to gray-black deluvial silty clays and gravel with sandy-clayey filling. The site is covered by an artificial embankment with limited thickness.

Based on the drilling and the laboratory data, the following layers (geotechnical soil types) were distinguished on the site:

- Layer 1 – Artificial embankment;
- Layer 2 – Buried top soil;
- Layer 3 – Deluvial brown clayey silt (clSi) and silty clay (siCl) to sandy (sa) - Quaternary;
- Layer 4 – Well-graded medium (MGr) to fine (FGr) gravel with sandy silty (sasi), silty sandy (sisa) filling - Quaternary;
- Layer 5 – Mottled clayey silt (clSi), sandy silt (saSi), hard – Pliocene;
- Layer 6 – Fine silty to clayey sand (siFSa and clFSa), medium dense to dense – Pliocene;
- Layer 7 – Medium silty (sMFSa), dense to very dense – Pliocene.

The Pliocene layers occur at a depth from 10 m as an alternation from 1-2 m up to 4-5 m thick intervals of the main layers but frequently they are interlayered by the others. As Layer 6 usually occurs only as separate comparatively thin intervals within Layers 5 and 7, its deformation properties will not be considered separately.

Oedomertic tests

The laboratory oedometric tests were carried out according to the requirements of CD CEN ISO/ 17892-5:2007 at load increments of 5, 12, 25, 50, 100, 200, 400 and 800 kPa and 24 hour consolidation for each of them. For the purposes of the software design of the piled foundation, the pre-consolidation pressures and the compression coefficient values were not considered. The oedometric modules were calculated as secant to the compression curve within the loading intervals and were referred to the mid-point stress values. In total, 9 tests were carried out for Layer 5 and 5 tests for Layer 7. The obtained oedometric modules (E_{oed}) – average, minimum and maximum values - are presented in Table 1.

Table 1.
Oedometric test modules for Layers 5 and 7.

Mean load increments values, MPa	Oedometric modules E_{oed}, MPa					
	Layer 5 (9 tests)			Layer 7 (5 tests)		
	Ave.	Min.	Max.	Ave.	Min.	Max.
0.075	2.63	0.71	5.52	2.63	0.71	2.63
0.15	2.77	1.06	5.30	2.77	1.06	2.77
0.30	3.37	1.56	5.94	3.37	1.56	3.37
0.60	4.67	2.454	8.00	4.67	2.45	4.67

The average scatter of the minimum and maximum values from the average ones are (-1.4).SD and (+2.0).SD for Layer 5 and (-1.15).SD and (+1.5).SD for Layer 7 respectively (SD is the standard deviation). The broader range of variation of the eodometric modules for Layer 5, though more samples were tested from it, is explained with the higher variations in its grain-size distribution.

Elastimetric tests

The elastimetric tests were carried out with the OYO-Elastimeter-100 model 4141 device with a logger for direct measurement of the radial deformations and a manual pressure pump unit (Fig. 2).

Fig. 2. OYO-Elastimeter-100 model 4141 device

The device is compatible to the requirements of ASTM D4719-07. A probe with a length of 60 cm and stiffness of 5 MPa was used. Prior to the site tests, initial calibration of the device was carried out in thick-walled steel tubes and proper corrections were input in the logger. The pre-boring procedures included casing of the borehole to 1.5 m above the test level with an external diameter of 112 mm. Pre-drilling 1,5 times the test interval with a 76 mm rotary core barrel. The probe was installed in the middle of the test interval and initial pressure was applied. After achieving good contact with the borehole wall, the test was carried out with 0.1 MPa pressure increments applied for a period of 2 min. The readings of the radial displacements were electronically logged and processed according to the device specifications. A test curve 'radial deformation R' vs 'Pressure p' was plotted and its linear section was identified. Typical test curve from the site in presented in Figure 3.

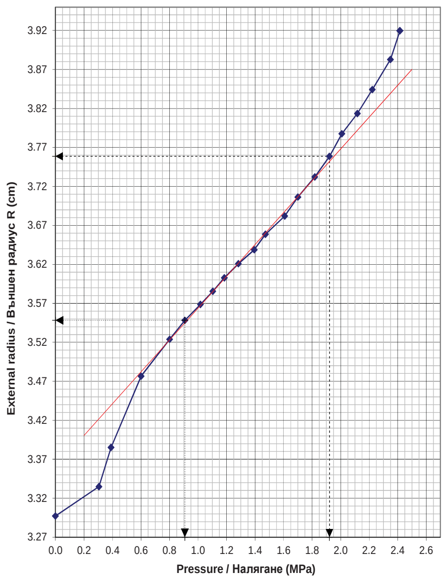


Fig. 3. Elastimeter test curve

Table 2.
Elastimetric modules for Layers 5 and 7

Layer 5				
Borehole	Test no.	Depth, m	(0÷Δp)/2, MPa	E_{el}, MPa
MC-7a	1	17.70	0.51	22.89
MC-7a	3	30.70	0.98	102.3
MC-8a	1	16.20	0.58	15.3
MC-8a	2	20.70	0.90	46.3
MC-9a	1	15.80	0.95	27.2
		Average		42.8
		Min.		15.3
		Max.		102.3
		N		5
		SD		31.48
		t_α		2.57
		E_{el}k (lower)		6.6
		E_{el}k (upper)		79.0
Layer 7				
Borehole	Test no.	Depth, m	(0÷Δp)/2, MPa	E_{el}, MPa
7a	2	21.80	0.57	89.07
7a	4	37.40	0.55	116.74
7a	5	52.60	1.30	108.89
7a	6	65.60	1.39	97.52
8a	3	31.40	0.70	66.68
8a	4	48.50	0.88	59.33
8a*	5	70.50	1.19	69.45
9a	2	20.40	0.51	29.36
9a	3	26.10	1.05	46.63
9a	4	34.00	0.55	75.46
9a	5	52.40	1.31	74.88
9a	6	68.10	1.01	58.32
		Average		74.4
		Min.		29.4
		Max.		116.7
		N		12
		SD		24.33
		t_α		2.18
		E_{el}k (lower)		59.1
		E_{el}k (upper)		89.7

The deformation modulus value E_{el} is calculated as:

$E_{el} = (1+\mu).R_m.(\Delta p/\Delta R)$,

where: $\Delta p/\Delta R$ is the slope of the linear section; R_m is the mean radius of the probe for the center of the linear section; μ is the Poisson's coefficient assumed to be 0.3.

In total, 5 elastimetric tests were conducted in Layer 5 and 12 tests in Layer 7. The values for the deformation modules are presented in Table 2. The table includes the middle point of the stress ranges of linear deformation (0÷Δp)/2 as well.

Some basic statistics are added to the table in order to determine the lower and upper characteristic values of the deformation modules for 95% two-sided confidence level. According to Eurocode EN 1990, the characteristic values of the elasimetric modules are determined as follows:

$$E_{elK} = E_{ave} \pm k \times SD$$

where SD is the standard deviation value and 'k' is a coefficient, determined by the following formula:

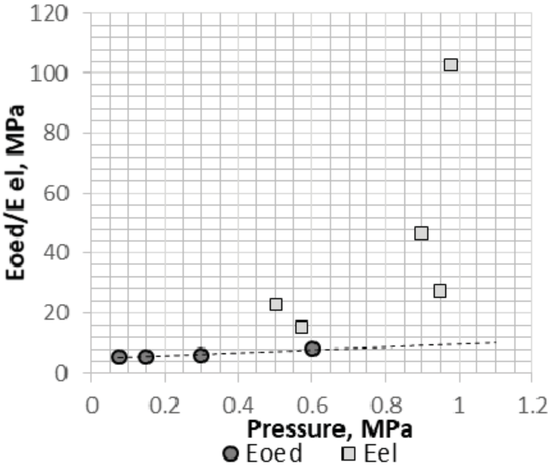
$$k = t_\alpha \times \sqrt{\frac{1}{N}}$$

where N is the count of the values.

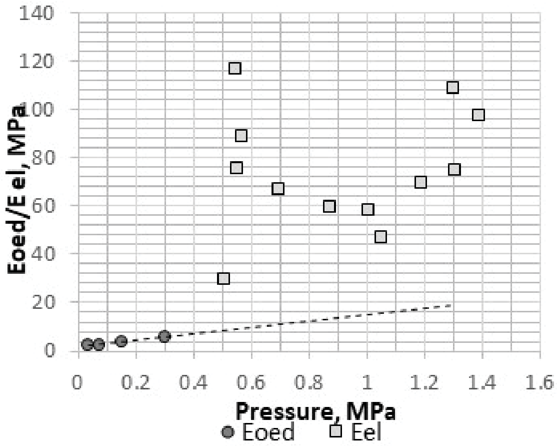
Comparison between oedometric and elastimetric modules

The average oedometric modules and the elastimetric modules for each layer are plotted towards the mean stress values of the secant and linear portions of the stress-strain test curves respectively (Fig. 4a and b). Simple linear trend lines are added to the oedometric values to illustrate the trends of E_{oed} increase with the vertical load increments.

The test results show clearly that the oedometric modules are with much lower values than the elastimetric ones. The lowest ratios E_{el}/E_{eod} for the maximum oedometric vs minimum elastimetric values are at least in the orders of 3 times for Layer 5 and 6 times for Layer 7 but the highest ratios exceed 20-24 times. A certain decrease of this ratio may be expected for oedometric modules derived for test stress levels higher than 0.8 MPa (to 1.6 MP and 3.2 MPa) that may approach the minimum elastimetric modules values, but for the average ones the ratio will be still at least 3-5 times. Further, we should mention that the elastimentric modules characterize a real linear behaviour of the soil base that, in the case of vertical foundation loading, may be considered as 'quazi-elastic' which allows the application of the elastic theory in the foundation design.



(a) For Layer 5



(b) For Layer 7

Fig. 4. Plots with oedometric modules (E_{oed}) and elastimetric modules (E_{el}) vs mean pressures for Layer 5 (a) and Layer 7 (b)

These differences can be explained by several scale effect factors:

- much faster and complete one-dimensional consolidation of the oedometric specimen due to its minor thickness (filtration path) and much pressure-effective gradients (above 300) that practically overpass the soil's initial gradient ($I_{crit.}$);
- complex partial 3-dimentional radial consolidation around the borehole wall with pressure gradients that decrease in radial direction even beyond the critical one and a practically 'infinite' flow path.
- the laboratory test specimen is usually affected by different manipulations related to drilling, sampling, transportation and cutting in the test ring that result in less intactness and lower stiffness relative to its size that the borehole walls and the soil base itself.

Conclusions

The elastimetric tests produce a stress-strain stress in the soils much more adequate to its behaviour as foundation base. The elastimetric modules for the Pliocene sediments from the studied site are much higher compared to the oedometric modules. For high vertical loads (0.5-0.6 MPa and more), the ratio factor is at least 3-5. For lower vertical loads, the oedometric modules should be factored at least by values of 5 to 10. These factors may be applied in general to the oedometric modules for the Pliocenie clays and sands on other sites in the town of Sofia that will allow significant improvement of the foundation design.

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