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GEOTECHNICAL DOCUMENTATIONS FROM ASSESMENT TO REALITY

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Abstract: Taking into consideration the importance of soil investigations for geotechnical design, the paper makes an analysis of the factors influencing geotechnical parameters of foundation ground. It is analyzed, first of all, the geological particularities effect on the foundation ground for sites in urban areas, with a large number of buildings in the vicinity and with an intense process of construction. Based on this analysis there are presented some criteria to select in situ investigation tests to solve some of the main problems in geotechnical engineering. For each ground category there are presented some considerations about the most important geotechnical parameters characterizing failure criteria and the influencing factors.

Key words: soil investigation, geotechnical parameters, in situ tests.

1. INTRODUCTION

Romanian norms require for all buildings of importance classes 1, 2 and 3, a geotechnical report, requiring a large amount of geotechnical studies performed. If in rural areas, site conditions are not affected by modifiers factors, for sites located in urban areas geotechnical conditions can be completely modified towards free areas of construction. Engineering activities can lead to major changes in the state of efforts in the ground, with important influences on physical and mechanical parameters of foundation soils of the ground.

At least two factors may lead to significant influence: the existence of an existing infrastructure: sewers, electricity and heating networks and the existence of material remaining from demolition or filling and the development of investment projects, from underground structures (garages, drainage systems, etc.) to structures with heights up large and very large (more than 15-20 levels). All these factors are a challenge, contributing to the preparation of the geotechnical documentation programming. Geotechnical Studies (SG) and detailed geotechnical studies (SG-D) are a separate component of a construction project (TP + DE), which must meet the expectations of the structural engineers, concerning:

- Obtaining characteristic sections (profiles) of the terrain, identifying the different formations (layers) for which it determinates the characteristic values of the main geotechnical parameters,

- Hydro geological regime conditions,
- Depth of foundation, recommended foundation system and structural system performance (absolute settlement, relative and differential settlements and their acceptable values), etc.,
- The soil – structure interaction all along the designed objective life (70-100 years), etc.

A frequent discrepancy is between the values of determined geotechnical parameters of the ground and many theoretical, modeling and numerical simulations. It is still difficult to find a balance between the characteristic values of geotechnical parameters (in particular the shear strength and compressibility) determined in laboratory or on field (in situ), covering data modeling and numerical simulation of existing computer programs. Progress in developing equipment for laboratory and field tests contribute to first determine the geotechnical parameters so called "credible", but on the other hand it also requires that structural engineers to have expertise in understanding and application of parameters provided by the geotechnical engineer.

Currently, the concept of credible geotechnical parameters is important. This concept includes many factors that contribute to their achievement:

- Quality in terms of accuracy of laboratory tests, the applied statistical analysis and the performance of in situ test. Be highlighting the importance of in situ tests (response test) to assess the quality of laboratory tests,
- Effect of foundation soil heterogeneity, which allows isolation of determining a parameter representative of a uniform layer from geotechnical point of view,
- Correct interpretation of the in situ test results,
- Collected and transported samples quality and the laboratory sample preparation quality,
- Effect of unloading and reloading in the collection of laboratory samples (influence of soil formation history).

Scientific papers published in the last twenty years on in situ tests research, indicate a focused primarily on the correct interpretation of in situ tests and identifies factors affecting geotechnical parameters. The main factors were analyzed: the influence of sample quality and over consolidation process influence on shear parameters, although it is important to establish whether the effect of these factors on the parameters determined in situ is or is not significant.

2. GEOTECHNICAL PARTICULARITIES AND EGGINEERING ACTIVITIES EFFECT

In most cities, urbanization was historically linked to the vicinity of rivers. Erosion and accumulation processes have always existed; they materialized through the landfill excavations in older deposits and fillings with younger deposits. There also appear numerous geo materials resulting from engineering activities such as unorganized filling, remains of mining activities, etc.

Effect on the process of building on the foundation soil compaction is also important. Most important processes that affect the geotechnical parameters of soil are:

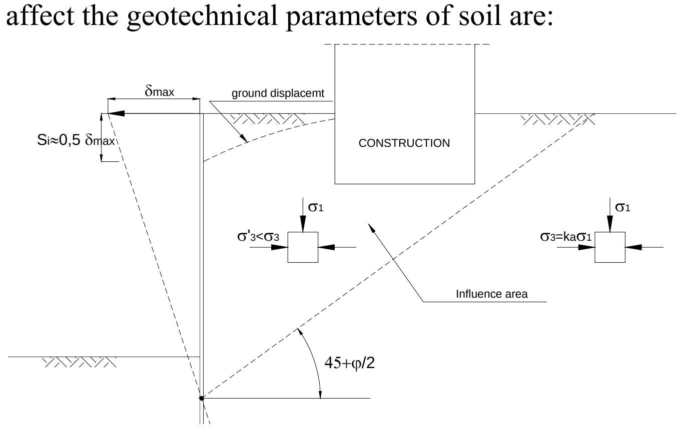


Fig. 1. Deep excavations influence on surrounding land

- Stress state changes as a result of deep excavations and in particular with reference to the influence of deep excavations on the surrounding terrain, Fig. 1.
- Demolition, especially those of high rise buildings and the swelling phenomenon,
- Groundwater table modification due to execution of deep excavations in the vicinity, Fig. 2.a., due to the execution of excavations for sewers, Fig. 2.b., etc.

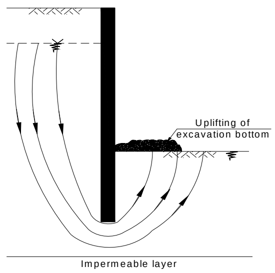


Fig. 2 a.

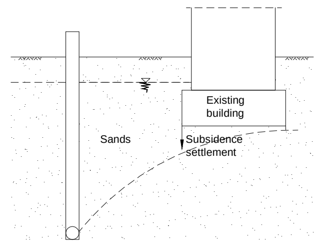


Fig. 2 b.

Fig. 2 Ground water table variation

- Changes of riverbeds, having significant impact on hydrological regime of the area,
- Foundation soil contamination with oil or other chemicals, affecting the correct evaluation of geotechnical parameters (limits of plasticity, etc.), water and aggressive growth,
- The collapse of the ground or development of landslides in areas with old mining activities.

3. CRITERIA TO SELECT METHODS OF IN SITU TESTING IN SOLVING GEOTECHNICAL ENGINEERING PROBLEMS

Investigation of foundation soil necessarily entails ground exploration and laboratory testing and depending on the foundation soil, type of the structure and work category - in situ testing on the ground, chemical determinations, hydro geological research, surveys and unveiling on the foundations of existing buildings. Work volume and complexity of methods used depend on the phase of the investment (CAP, PT or DE) and, first of all, the geotechnical category (CG 1 or CG 2 CG 3). The choice of recommended methods for prospecting the soil foundation is taking into account three factors: construction safety, performance and economy.

A typical phenomenon is that the investor is particularly interested in safety at a low price, in the phase of geotechnical investigations. This trend leads to a limitation of investigations (laboratory and site tests) and the result is an over / under estimation of shallow foundations settlements or bearing resistance of piles. Another problem is the knowledge of structural engineers or designers or even the knowledge of geotechnical engineers about in situ testing methods, their correct application and the interpretation of the measurements. A key element in the programming laboratory or in situ tests is selecting appropriate geotechnical parameters according to the foundation design solution.

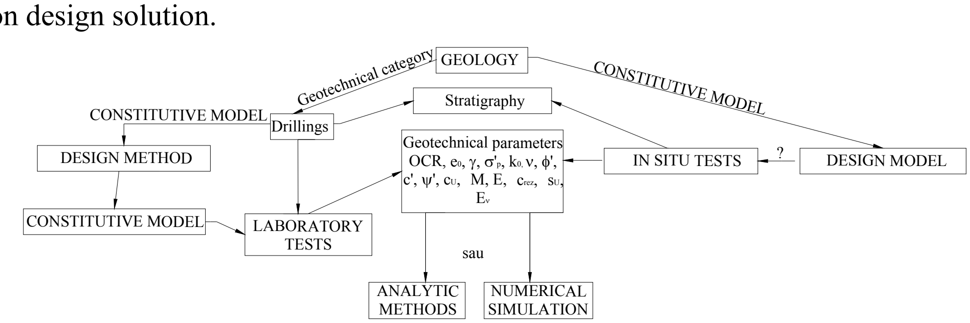
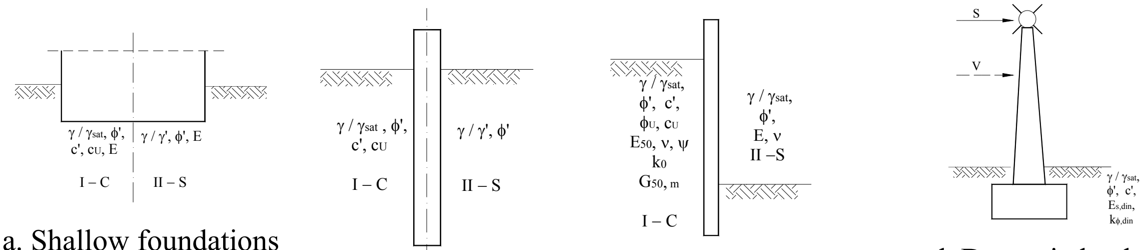


Fig. 3 Scheme to solve the problem of geotechnical investigation

Knowledge of design methods can be helpful in selecting the method of investigation of the foundation ground and understanding of the method to determining the parameters of shear strength and compressibility. Steps required in resolving the problem can follow the subsequently scheme, Fig. 3.

Determining geotechnical parameters depend on both the category of soil, but mostly on the structure category for which they are determined, Fig. 4.



a. Shallow foundations structures

b. Piles fondations

c. Retaining structures

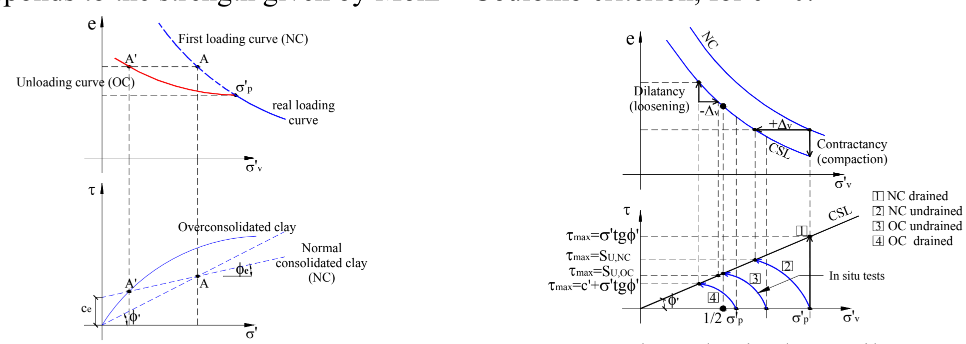
d. Dynamic loaded structures – Wind mills

Fig. 4. Geotechnical parameters required, depending to the type of structure

A starting point in selecting methods for in situ or laboratory testing is conventional soil classification of foundation soil in two types of soil I – cohesive soil (clays) and II – non cohesive soil (sands). This classification highlights the difference in size composition and drainage conditions. Between the two types of soil there are so-called transitional grounds, for which drainage conditions and geotechnical parameters determine their condition and they are more complex. Traditional classification for soil types into two categories is very convenient for engineers. Generally, most representative geotechnical parameters are:

- For the Ist category: clay, assessing undrained shear strength (s_u=c_u). It can be considered the criterion of critical state soil reaction (CSSM) that all soils are friction materials and their shear strength is best represented by effective internal friction angle (Hvorslev). To characterize soil compressibility most representative values are for deformation modulus $E_{50,ref}$ and E_{Uc} (HSM).
- For the IInd category: sands, the most representative is the effective internal friction angle Φ'. The determination of the value of Φ 'can be made considering the value of density index (I_D) with consideration of overconsolidation effects, strain – stress state, grain mineralogy, etc.

It can be concluded that all types of soils, regardless of initial state of stress or drainage conditions, end up on the critical state line (CSL). In this case in the τ - σ_v system, this state of strains corresponds to the strength given by Mohr – Coulomb criterion, for c'=0.



a. Cohesive soil

b. Cohesionless soil

Fig. 5 Determination of shear strength parameters for cohesive and non cohesive soils

Dispute is generated by the term "cohesion". In some cases this term refers to undrained shear strength (c=c_U), in other cases to the effective cohesion (c') or residual cohesion (c_{rem}≅0), Fig. 5 a and b.

The most important parameters are:

- Cohesive soil: oedometric modulus (M), Poisson ratio (ν), overconsolidtaion ratio (OCR), effective friction angle (ϕ'), effective cohesion (c'), cohesion in the total efforts (c_U);

– Cohesionless soil: effective friction angle (ϕ'), linear deformation modulus (E'), dilatancy / contractancy angle (ψ), Poisson's ratio (ψ '), linear deformation mode (E'),

In addition to these for specific problems is necessary to determine the critical damping ratio (D'), the coefficient of secondary consolidation (c_α), coefficient of pressure at rest (K_0), shear modulus (G_{max}).

4. A REVIEW OF CURRENT INTERPRETATIONS FOR GEOTECHNICAL SOIL PARAMETERS ESTIMATION

Determination of "credible" geotechnical parameters of shear strength and compression are of great importance for geotechnical engineering problems. Their evaluation can be made either by theoretical solutions and laboratory tests, or empirical relationships based on in situ tests. These empirical relationships are divided into two groups: general and local groups. Empirical relations generally treat the soil as an independent material by his geographical location, being described as a general criterion usually by granulometry or mineralogy etc. Those correlations may be valid for sandy soils. Due to the wide range of existing empirical literature relations, establishing empirical relationships for local conditions, are of great importance for determining the parameters of shearing strength and deformation of the soil in category I and II.

Table 1. Scope of in situ tests

METHOD	TYPE	SOIL PARAMETERS														SOIL TYPE				
		Soil type	Stratigraphy	U	Φ'	S_U	I_D	m_V	C_V	k	G_0	σ_h	OCR	σ-ε	Stiff soil	Soft soil	Gravel	Sand	Silt	Clay
PENETROMEER METHODS	DP	C	B	-	C	C	C	-	-	-	C	-	C	-	-	C	B	A	B	B
	CPT	B	A	-	C	B	A/B	C	-	-	B	B/C	B	-	-	C	C	A	A	A
	CPTU	A	A	A	B	B	A/B	B	A/B	B	B	B/C	B	C	-	C	-	A	A	A
	SCPT/ SCPT	A	A	A	B	A/B	A/ B	B	A/ B	B	A	B	B	B	-	C	-	A	A	A
	DMT	B	A	C	B	B	C	B	-	-	B	B	B	C	C	C	-	A	A	A
	SPT	A	B	-	C	C	B	-	-	-	C	-	C	-	-	C	B	A	A	A
PRESIOMETER METHODS	PBP	B	B	-	C	B	C	B	C	-	B	C	C	C	A	A	B	B	B	A
	SBP	B	B	A	B	B	B	B	A	B	A	A/ B	B	A/ B	-	B	-	B	B	A
	FDP	B	B	-	C	B	C	C	C	-	A	C	C	C	-	C	-	B	B	A
OTHER METHODS	FVL	B	C	-	-	A	-	-	-	-	-	-	B/ C	B	-	-	-	-	-	A
	PLT	C	-	-	C	B	B	B	C	C	A	C	B	B	B	A	B	B	A	A
	Screwing	C	C	-	C	B	B	B	C	C	A	C	B	-	-	-	-	A	A	A
	Permeability in the drilling	C	-	A	-	-	-	-	B	A	-	-	-	-	A	A	A	A	A	A
	Hydraulic failure	-	-	B	-	-	-	-	C	C	-	B	-	-	B	B	-	-	C	A
	Seismic method	C	C	-	-	-	-	-	-	-	A	-	B	-	A	A	A	A	A	A

Symbols:

– Φ'- effective internal friction angle, value depending on soil type;
– U – pore water pressure (from in situ test)
– S_U – undrained shear strenght;

- m_V – volumetric deformation modulus (1/M);
- C_V – coefficient of consolidation;
- k – permeability coefficient;
- G_0 – shear modulus;
- σ_h – horizontal unit stress;
- OCR – over consolidation ratio;
- σ-ε – strain – stress relation;
- I_D – density index

For non cohesive soil (sandy soils), one of the most important geotechnical parameters is internal friction angle (ϕ'). The value of this parameter consists of two components: the basic component of friction (ϕ'_{CS}) and a component that takes into account the increasing or decreasing of the sample volume in the shear zone, called dilatancy or contractancy angle (ψ_d și ψ_c)

$$\phi' = \phi'_{CS} \pm \psi \tag{1}$$

Base value of friction angle (ϕ'_{CS}) corresponds to critical state of soil and depends on mineralogy, particle shape, size and her roundness (Cho 2004, Jamiolkowsi et all, 2001). Dilatancy / contractancy angle, characteristic of particle rearrangement process depends on the compaction ratio, test method and the value of effective pressure (Rowe, 1969, Bolton, 1986). A simple proposal is given by Bolton (1986): $\phi'_{CS}=33^0$. For the angle of dilatancy the simplest proposal is given by Bolton: ψ=30-ϕ'.

Table 2.

Sandy soils			
Test	Author	Relation	Observations
TRIAXIAL	Bolton(1986)	$\phi'_{TR} = \phi'_{CS} + 3\left[D_r + \frac{Q - \ln p_f'}{\sigma_{atm}} - R\right]$	R=1; Q=10; $\phi'_{CS} = 33^\circ$; $p_f' = 2\sigma'_{v0}$
SPT	Hatanocho, Uchido (1996)	$\phi' = 20^\circ + \sqrt{15,4 + (H_1)_{60}}$	
CPT	Robertson, Campanella, (1983)	$\phi' = arctg\left[0,1 + 0,38\log\frac{q_t}{\sigma'_{v0}}\right]$	$\frac{q_t}{\sigma'_{v0}} < 60$
CG	Mayne (2006)	$e_{\max} - e_{\min} = 0,23 + \frac{0,06}{D_{50}(mm)}$	
CPT	Jamiolkowski (2001)	$I_D = \frac{1}{C_2}\ln\left[\frac{q_C}{C_0(\sigma'_{v0})} - C_1\right]$	$C_0 = 24,94$, $C_1 = 0,46$ $C_2 = 2,96$
TR (triaxial test)	Dysli (2001)	$\nu = \frac{1 - \sin\phi'}{2 - \sin\phi'}$	
DSS (direct shear test)	Jaky (1948)	$K_0 = 1 - \sin\phi'$	
SPT	Licia, Whitman (2005)	$E_S = 7HI_{60} \times 95,76(kPa)$ $E_S = 10HI_{60} \times 95,76$, $HI_{60} = \sqrt{\frac{p_a}{\sigma'_{v0}}}$	Fine + medium sand Coarse sand+ gravel $p_a = 100KP_a$

Symbols:

- ϕ'_{CS} - effective internal friction angle for critical porosity,
- ϕ'_{TR} - effective internal friction angle determined by triaxial test,
- σ'_{v0} - effective vertical unit stress,
- $(N_1)_{60}$ - NSPT value corrected for a reference energy (ER_r) of 60% and vertical unit stress σ_v=100kPa
- q_t - cone pressure,

– d_{50} - diameter corresponding to 50% on granulometry curve,
– ν - Poisson ratio.

One of the most effective methods for assessing the geotechnical parameters for sands is the correlation method or empirically methods based on in situ test results. They are characterized as derivative values of geotechnical parameters and faithfully represent the behavior of soil for a particular structure.

Tabular values (STAS 3300 / 2, etc.) may only be used for designing structures of CG1 and preliminary design phases of CG2 structures. Practical application of these documentation data must be demonstrated on the basis of similarity of soil clear correspondences (classification, fingerprints, etc.). Prospective in-situ methods are recommended to be used depending on the type of soil that appears in the influence area of the construction and on geotechnical category. Recommended field methods are presented in Table 2.3.1 of Romanian norm NP 074/2007. A more comprehensive in-situ test recommended by the nature of the soil is given in Table 1 (Mayne, 2006). Applicability of each method is, according to Table 1: (A) - high (B) - moderate (C) - reduced (-) - not used.

Based on in site measured values, it can be used correlation relations, which allow to calculate the main characteristic parameters of the soil. An overview of common relations of literature is given in Table 2.

To use different types of tests is important to establish a liaison relationship between the number of strokes (N_{10}, N_{30}) obtained with different types of devices, and setting the recurrence relations for evaluating geotechnical parameters (eg $N_{10\ DPU} - N_{30\ SPT}$, $N_{10\ DPS} - N_{30\ SPT}$, etc.). They are given in different specific norms (SR EN 1997-2, DIN 4019, P169, etc.) or can be assessed based on the principle of equivalence of mechanical work for driving. Evaluation of geotechnical parameters for clayey soils based on liaison relationships with field measurements is a complex problem, both because of the geotechnical parameters more features and greater number of factors affecting them. Should be noted that, in urban areas, frequently in deep excavations, distortion of stress state in laboratory tests may have a significant effect on undrained shear strength. Quality samples taken can also affect the determination of ϕ' in laboratory.

Table 3.

Test	Author	Relation	Observations
CPTU		$\sigma'_p = 0{,}33(q_t' - \sigma_{v0})$	
SPT	Kulhovz, Mayne(1990)	$\sigma'_p = 0{,}47 N_{60}\sigma_{atm}$	
DSS	Mayne (2006)	$\left(\frac{s_U}{\sigma'_v}\right)_{DSS} = 0{,}22 OCR^{0,80}$	OCR<2
CPTU	Lunne (1997)	$s_U = \frac{(q_t - \sigma_{v0})}{N_{kt}}$	$N_{k_1} = 10 - 20$ Or determined based on I_P after Lunne(1997)
CPTU	Sanneset et all (1982)	$s_U = \frac{(q_t - U_2)}{N_{kt}}$	$N_{kt} = 9 \pm 3$
CPTU	Lunne et all (1997)	$\frac{K_{0,OC}}{K_{0,NC}} = OCR^m$	$K_{0,NC} = 1 - \sin\phi'$ $m = \frac{0{,}45}{0{,}65}$
CPTU	De Graat (2005)	$K_0 = 0{,}60(OCR)^{0,91}$	
LAB	Kanji, Whole (1977)	$\phi'_r = \frac{46{,}6}{(I_p)^{0,466}}$	
CC	Mayne (2006)	$K_p = \frac{1+\sin\phi'}{1-\sin\iota'} + \frac{2c'}{\sigma'_{v0}}\sqrt{\frac{1+\sin\phi'}{1-\sin\phi'}}$	$c' = 0{,}002\sigma_p'$

Symbols:

σ_p' -preconsolidation pressure (OCR),

q_t' - corrected cone resistance (Lunne et all, 1997),

U – pore water pressure,

q_t - cone resistance,

ϕ_r' - residual friction angle.

Large discrepancies occur in the understanding of the concept of cohesion. Various forms where this discrepancies occur: undrained shear strength ($c=c_U=s_U$), effective cohesion and residual cohesion makes its determination based on field tests a more complex problem. Main liaison relationships are used in the literature data in Table 3.

5. CONCLUSIONS

Using empirical relations to determine geotechnical parameters induces some restrictions on their application, results of dimensional analysis. Each in situ test is a physical process, being affected by variables related to state of the ground. Also, field testing is done using different devices, handled by operators with different educational knowledge. Another analysis refers to restrictions resulting from samples quality for laboratory analysis. Starting from the conclusion of such studies it is necessary to use several types of tests and need for geotechnical parameters for each site separately (and related links).

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