INTERNATIONAL SCIENTIFIC CONFERENCE
CIBv 2010
12 – 13 November 2010, Braşov

GEOTECHNICAL PARAMETERS OBTAINED WITH NONLINEAR COMPUTATIONAL MODELS USED IN GEOTECHNICAL ENGINEERING PROBLEMS

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Abstract: Optimal designing of any type of soil works, slope stability analysis, the choice of the type of foundation and foundation design are directly dependent on the accuracy of the determination of geotechnical parameters of the soil. This paper presents the most important geotechnical parameters used in geotechnical engineering problems and also methods for determining the geotechnical parameters using the various computational models. The main computational models approached are: Mohr-Coulomb model, which relies on a line defined by the Coulomb failure stress and the stress circles of Mohr. The field of failure is given by the cohesion and internal friction angle. Another model approached is the Cam –Clay model. The central idea of the Cam-Clay model (Roscoe) or critical state model (Critical State Model MSM)is that the soils failure is described by a single failure surface (critical)in (q, p, s), limited critical state line (CSL).
The paper also presents methods for determining the geotechnical parameters in the laboratory testing and also in situ testing.

Key words: geotechnical parameters, computational models, laboratory testing

1. THE IMPORTANCE OF GEOTECHNICAL PARAMETERS USED IN GEOTECHNICAL ENGINEERING PROBLEMS


Fig.1 Landslide (Sighisoara,Romania)


Fig.2 Landslide (Maramures,Romania)

Soils are inherently complicated and often mysterious in their observed behavior because their consistency is made up of natural components formed over millennia.

Knowing the geotechnical parameters of the soil helps to prevent unpleasant situations (for example soil sliding) and to build constructions safely.

The experience accumulated from the analysis of registered accidents or from tests performed on soil samples, clearly indicated that the failure of soil constructions and foundation terrain is produced because the soil shear resistance along various yielding surfaces (failure).

The optimal designing of soil constructions, the stability analysis of slopes, the determination of earth pressure against constructions, the choice of foundation system and foundation design depend on the accurate determination of soil shear resistance and of soil geotechnical parameters.

A complete characterization detailing the intricate and complex response of soils remains a challenging task that can only be realized on a partial basis via a careful drilling and sampling program coupled with detailed laboratory testing and comprehensive series of in-situ tests and field geophysics.

The values of the geotechnical parameters can be determined by one or more from the several modalities: a) directly, by tests in-situ; b) directly, by tests in the geotechnical laboratory using soil samples; c) indirectly, by tests (usually in-situ) using correlations between the results of the tests and the values of the geotechnical parameter; d) on the basis of the measurements concerning the behavior of geotechnical structures in the stages of execution and after the beginning of the exploitation; e) on the basis of the data resulted from similar accumulated experience; f) on the basis of relevant documentary data from reference materials.

The geotechnical parameters used in the designing process are determined by using the results obtained from the tests in the laboratory and on the soil, on the basis of the computational models used in the soil mechanics. The computational models used for the determination of geotechnical parameters represent an idealization of soil behavior, considered to be sufficiently exact for the study's domain of interest.

2. GEOTECHNICAL PARAMETERS USED FOR SOLVING GEOTECHNICAL ENGINEERING PROBLEMS

2.1 Geotechnical parameters for non-cohesive soils

The shear resistance of non-cohesive soils, emphasized through direct shear, depends of the size and form of particles and their degree of humidity and densification. After direct shear tests, we can determine the shear force variation .

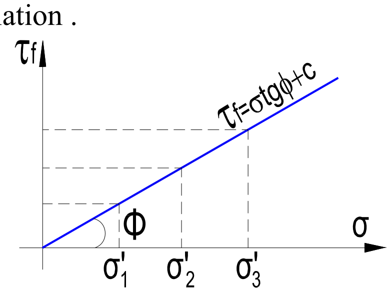


Fig.3 Critical line for non-cohesive soils. Determination of internal friction angle.

In the case of sands with minimal densification and maximal porosity, the particles slip tending to the state of maximal densification. In this way, the soil is compressed by shearing. This densification phenomenon of loose soils by shear is named contraction.

In the case of sands with maximal densification and minimal porosity, the particles slip tending to the state of maximal loosening. In this way, the soil is loosed by shearing. The loosening phenomenon of dense sands by shearing is named dilatancy.

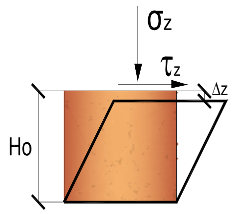


Fig.4 Contraction of the sand by shearing

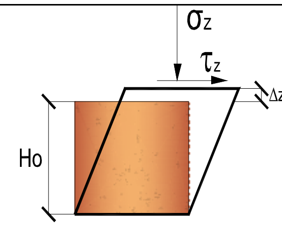


Fig.5 Dilatancy of the sand by shearing

$$\tau_f = \sigma \cdot tg(\phi + \alpha)\,; \qquad (1)$$

Where: Φ- is the internal friction angle and α is the dilatancy angle.

The dilatancy for the model presented induces an increase of the shearing resistance caused by the supplementary energy needed in order to loose the soil.

In the case of soils that have sand or gravel granular structure, the external pressure determines the apparition of tensions at the contact between the particles, that could provoke their rearrangement and even the shearing of some particles.

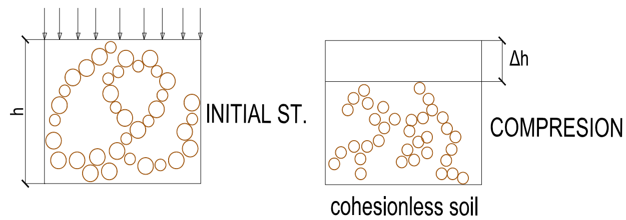


Fig.6 Deformation of cohesion less soils

The oedometric test determines the compression – compaction and compression – porosity curves. On this basis, we can determine the geotechnical parameters which characterize the tested soil compressibility.

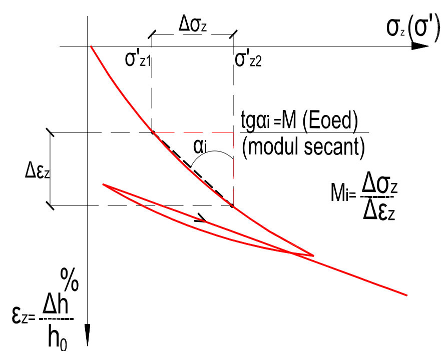


Fig.7 The oedometric deformation modulus

$$M_i = tg\alpha_i = \frac{\Delta\sigma_z}{\Delta\varepsilon_z}\,; \qquad (2)$$

M_i - The oedometric deformation modulus (M=Eoed)

2.2 Geotechnical parameters for cohesive soils

The shearing resistance of cohesive soils is given by the formula:

$$\tau_f = c + \sigma \cdot tg\phi \qquad (3)$$

Where: c- cohesion of the soil and ϕ is the friction angle.

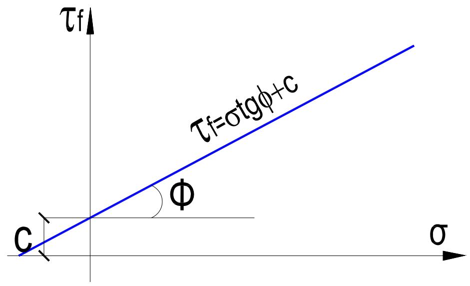


Fig.8 Critical line for cohesive soils. Determination of internal friction angle and cohesion.

The determination of shearing parameters can be made in 3 ways, depending on the construction, on the situation on the site and on the type of construction.

The CD (consolidated-drained) test. This type of test is usually realized when the water drain is possible, while the consolidation pressure grows. The parameters that result after this test are effective shear parameters φ' and c'.

The CU (consolidated-undrained) test. This type of test is usually realized when new loads appear after the consolidation of a foundation soil under a construction. The parameters that result after this load are ϕ_{cu} and c_{cu}.

The UU (unconsolidated-undrained) test. This type of test is realized when the rhythm of the execution is more rapid than the rhythm of cohesive soils consolidation. The parameters that result after this load are ϕ_u and c_u.

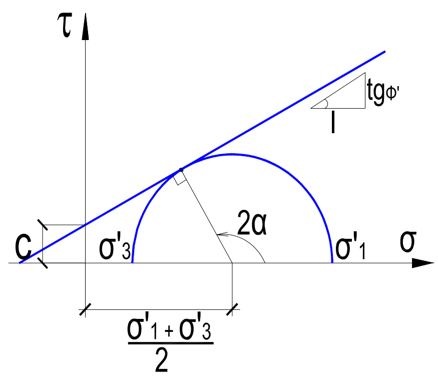


Fig.9.Determination of internal friction angle and cohesion.

An important and difficult problem in geotechnical engineering is to estimate the value of the linear deformation modulus E_u. The difficulty is given by the assay to follow and retrace the stress path and by the dependence of modulus E value of density, porosity and humidity.

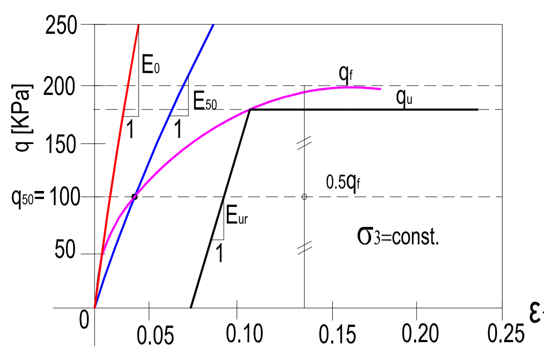
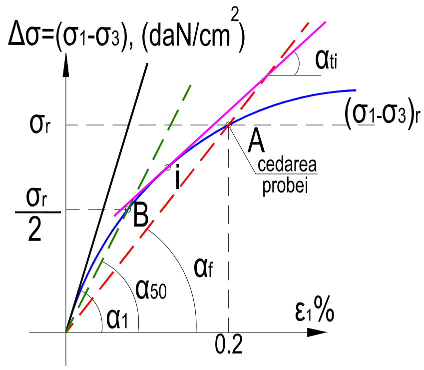


Fig.10 Notions regarding the determination of linear deformation modulus

3. METHODS FOR DETERMINING DEFORMATION PARAMETERS

The stiffness of a soil or rock is determined by its modulus value.The modulus is the ratio of the stress versus strain at a particular point or area under consideration.Materials with the same strength can have different stiffness values.It is very important to have a good determination of E value. E decides the values of compaction. The calculus usually uses the tangent modulus or the secant modulus.



E_i – the initial deformation modulus (tangent) $E_i = tg\alpha_i$

$E_{50\%}(E_s)$ – secant modulus $E_{50\%} = tg\alpha_{50\%}$

E_{ti} – tangent modulus $E_{ti} = tg\alpha_{ti}$

E_f – secant final modulus $E_f = tg\alpha_f$

Fig.11. Deformation modulus

The determination of the linear deformation modulus value in the case of undrained conditions E_u can be performed by laboratory or in-situ tests. The tests in the laboratory that help to determine the linear deformation modulus are the monoaxial and triaxial tests.

Comparing with other test methods, the monoaxial test provides the smallest values registered. If these values are used, it can lead to an over dimensioning of founding systems.

The triaxial test is closer to reality than the monoaxial test, but the results obtained can be sometimes smaller than those obtained from the in-situ tests.

Because it is impossible to create situ conditions in the laboratory, some tests are performed directly on the site. The in-situ tests offer the most credible results. The linear deformation modulus is determined by the following in situ tests: SPT –Standard Penetration Test, CPT –Cone Penetration Test, PLT – Plate Load Test, PMT –Pressuremeter test, VST –Vane Shear Test.

PLT – Plate Load Test consists in loading a circular or square rigid plate and measuring the compaction obtained. The determination of the linear deformation modulus (E) is performed by the assimilation of plate's compaction with the vertical deformation of an elastic semispace surface, under an uniform load.

CPT –Cone Penetration Test consists of establishing the number of falls of a weight, so that the penetration cone penetrates the soil at a certain depth (Δh). In what concerns soil's compressibility, the penetration test does not offer linear deformation modulus values. There are a series of empiric formulas that approximate the linear deformation modulus value, depending on the number of penetrations.

4. METHODS FOR DETERMINING SHEAR PARAMETERS IN THE LABORATORY

The determination of shear resistance parameters by different methods has to take into account the soil structure modality of work, and the stress paths that it covers until failure.

The tests performed will take into account the speed of load application, the draining conditions and also in what type of project the results will be used.

The direct shear test (DSB) consists in testing a sample in the shear box that has two parts - fix and mobile. The shear box allows two types of tests: imposed effort and controlled deformation test and imposed deformation and controlled effort test.

A close cousin testing device is the direct simple shear (DSS) whereby the sides move as a parallelogram rather than as two split box halves as in the DST. Nevertheless, results from DST and DSS one the same soil are quite similar. The advantage of the DSS is that the angle of movement is the shear strain (γ_s), a more fundamental measurement than horizontal displacement δ. If needed, a pseudo-strain can be defined as $\gamma_s = \delta / h$, where h represents the height of the specimen.

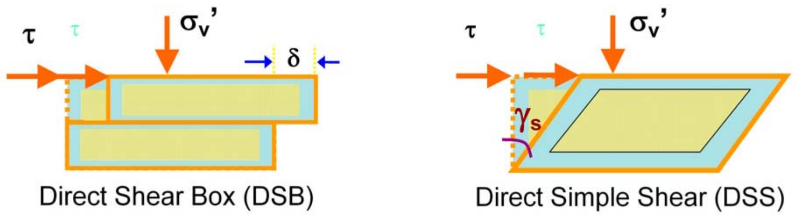


Fig.12 Direct Shear (DS) box and direct simple shear (DSS)

The triaxial test is the laboratory test that manages to simulate the best the situation on the site. In this way, the results obtained after this kind of test are the closest to the reality.

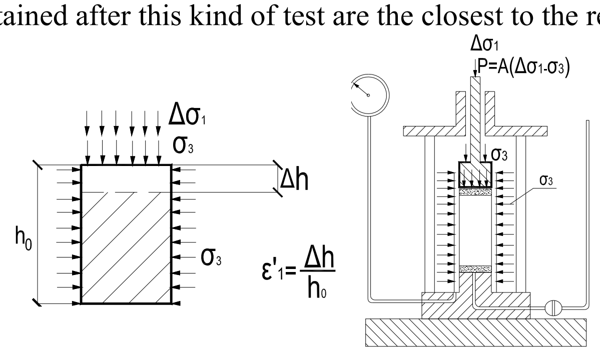


Fig.13 Triaxial shear equipment

The triaxial test is performed on a cylindrical sample, usually having the diameter 100 mm, and the height twice as big as the diameter.

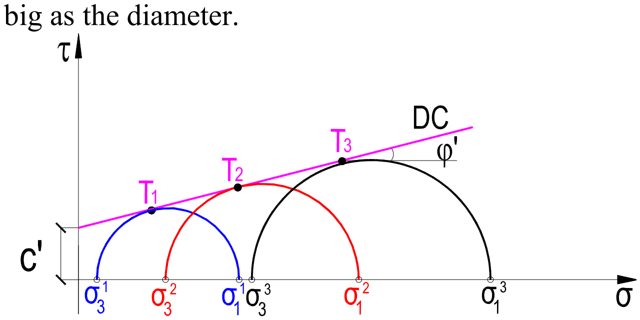


Fig. 14. The determination of effective parameters (φ',c') by the triaxial test in a C-D open system (consolidated - drained) using the model Mohr-Coulomb

The sample is subjected to a triaxial stress state $\sigma_1 \neq 0; \sigma_2 = \sigma_3 \neq 0;$ in a triaxial box. The forces that are applied on the soil sample are transmitted through a piston, and horizontally by the controlled pressure of the fluid in the box.

Under these actions, the optic, electronic and hydraulic devices attached to the triaxial box allow us to measure the sample deformations vertically, horizontally, to measure water pore pressure and also the variations of the sample volume.

For the categories of soil that are difficult to obtain as samples for the laboratory, the determination of shear parameters is done by in-situ VST test -(Vane Shear Test).

The test consists in the introduction of blades in the soil (from the 1st position to the 2nd position) at 50 cm (>5d) under the base of the drilling, and then the execution of perimetral shear of the soil on the superior and inferior base, depending on the situation.

The failure moment corresponding to the yield is given by the undrained shear resistance ($\tau_u = s_u$), mobilized on the two basis of the cylinder and on the lateral surface.

Another in-situ test for the determination of shear parameters is the in-situ shear. This test tries to reproduce the shear test in the laboratory at a natural scale. The test consists in the extraction of a soil sample that is placed in a concrete or metal box. Then a retaining structure is constructed, upon which it is applied a vertical and horizontal load. The vertical and horizontal deformations are measured with a micro comparator system disposed on the concrete or metal box.

After obtaining the results from the in-situ and laboratory tests using the computational models the determination of geotechnical parameters is made.

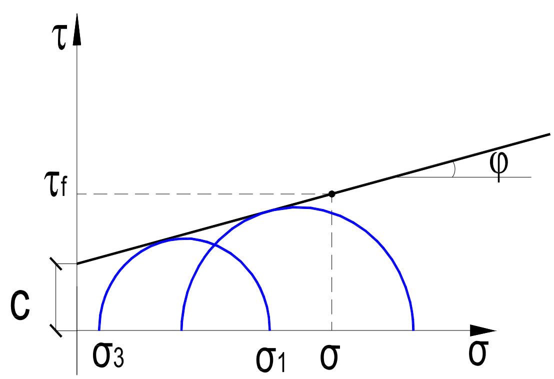


Fig.15 Mohr-Coulomb computational model

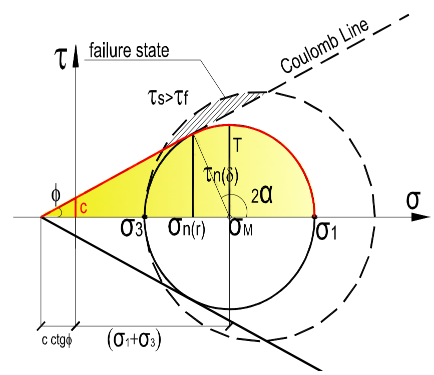


Fig.16 Mohr-Coulomb failure criteria

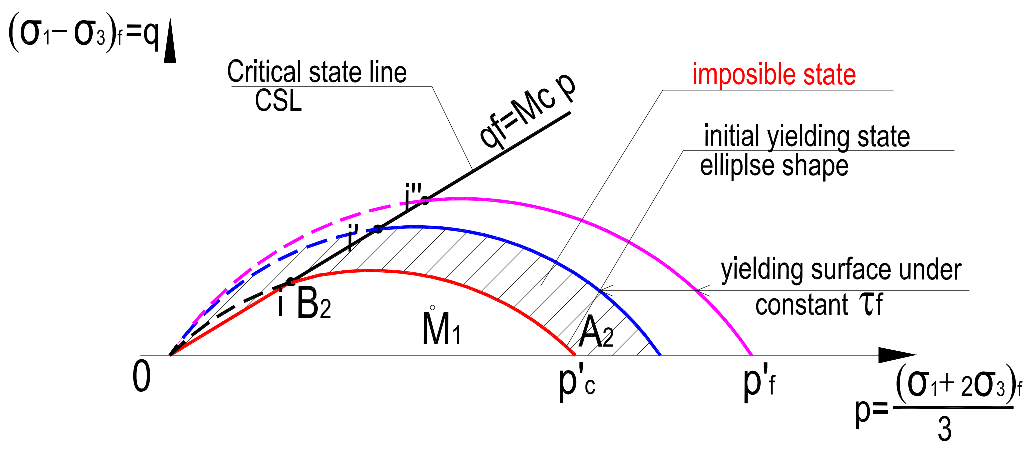


Fig.17 The Cam-Clay model. The approximation of potential yielding surfaces in the (p, q) plane through a line made up of ellipse segments and line segments.

In critical state soil mechanics (CSSM), consolidation and shearing are interlinked by their stress state spaces. The consolidation response is shown in e-log σv' space and the shearing behavior is represented by τ-aσv' space. A third and intermediate space is also shown (e-σv') only to allow projection between the other two spaces, but this requires no new information as it is just an arithmetic scaling of the consolidation space. The critical state soil mechanics premise is that, regardless of the initial state of the soil, any shearing will tend towards and eventually reach the critical state line (CSL). [3]

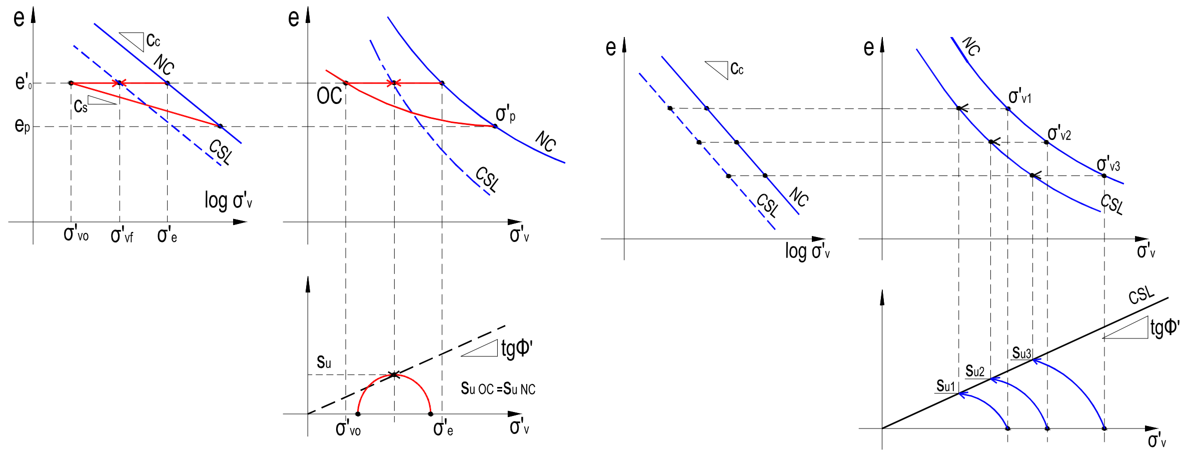


Fig.18 State spaces for NC and OC soil using simplified CSSM (Mayne,2009)

The critical state soil mechanics can be formulated in terms of work-energy relationships to express stress paths and stress-strain curves in mathematical terms called constitutive soil models.

Critical state soil mechanics offers a rational and simple framework that can be used to organize and present field and laboratory results.

Paper elaborated within Project
„PhD Studies in Engineering Sciences for the Development of the Knowledge Based Society – SIDOC”,
Contract POSDRU/88/1.5/S/60078

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Received September 21, 2010