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Soil: a material having a complex variability of its geotechnical properties.

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ABSTRACT

It is well known that soils are made by a solid matrix and by voids, usually interconnected, filled by water and/or by air.

Starting from this intrinsic constitution, springs out a great difficulty in the schematization of the behaviour of these complex materials, particularly when the voids are very small and, therefore, the permeability values are very low.

In addition to these problems, well known from the beginning of geotechnics, there are the ones derived from the highlighting of the intrinsic variability of soils.

The possibility to have numerous and detailed data allowed to point out these variability in stochastic models based on the spatial knowledge of expressed average tendencies and of the variances. This knowledge allows to apply to the soils concepts of security based on collapse probability evaluations or, likewise, evaluating the reliability.

INTRODUCTION

Soil material represents a multiphase system constituted by mineral particles and voids filled with fluids (e.g. air and water).

It is difficult to schematise soil behaviour both for its intrinsic nature and for the remarkable influence that environmental and imposed conditions can have on it. On one side we have a substantial uniformity of physico-mechanical characteristics of materials structural engineer deals with. On the other side, for soil, we have a variable behaviour of these properties from one point to another and in time.

As soils show a consistent variability of their properties, in the planning phase of any geotechnical intervention two different difficulties arise:

- to point out this variability through tests in laboratory and/or in situ;
- to determine a "characteristic value" taking into account this variability.

This variability of soil properties is more and more evident due to the rise in importance and in number of geothecnical tests both situ and in laboratory, because of the increasing of the economical resources which are available.
Naturally, due to the increase in the number of data, the technique of considering the mean or the characteristic data chosen on subjective basis in the design, appears to be not really functional.
It seems to be necessary, judging on the data obtained, to have information about the statistical distribution of the data and about their own spatial variability, in order to be able to take the right design choices that's to say in a scale of increasing difficulties:
- to chose a characteristic value using objective criteria;
- to evaluate, knowing the mean the standard deviation of the data and the related fluctuation scale, the reliability linked to a known geothecnical problem (FORM, SORM, Monte Carlo Methods).

Naturally in both the two choices described is inborn the overcoming of the security concept pointed out by the classic coefficient.

VARIABILITY OF SOIL

Information regarding physical characteristics of soil are obtained through laboratory tests on samples taken from many drillings.

The quantity of these samples depends on the importance, the dimension of the work and the "homogeneity" of the soil below. The economic aspect is important, too.

Information can be obtained also through tests in situ, empirical correlation, backwards calculations taken from test load on the small scale or from theoretical methods (for example Cam Clay model) or from observational ones.

However they are obtained, information generally refer to an amount of soil reduced in comparison with the amount of soil actually involved and subjected to stress variation [5].

Considering the heterogeneity of soil in nature, the effects for the disturbance on the samples, the errors occurring during test execution and human factors, a correct data processing is possible only through statistical methodologies, through techniques that allows to evaluate the statistic distribution of the properties investigated.

So the spatial variability (in particular with the only depth z, Fig. 1) of the generic stochastic variable is defined adding two components [7]:

$$u(z) = \bar{u}(z) + e(z)$$

where:

$u(z)$ = is the measure of the property to a given depth z;

$\bar{u}(z)$ = is the mean value of the property (trend component);

$e(z)$ = is the "residual value" that is the deviation from u(z) (random component with mean equal to zero).

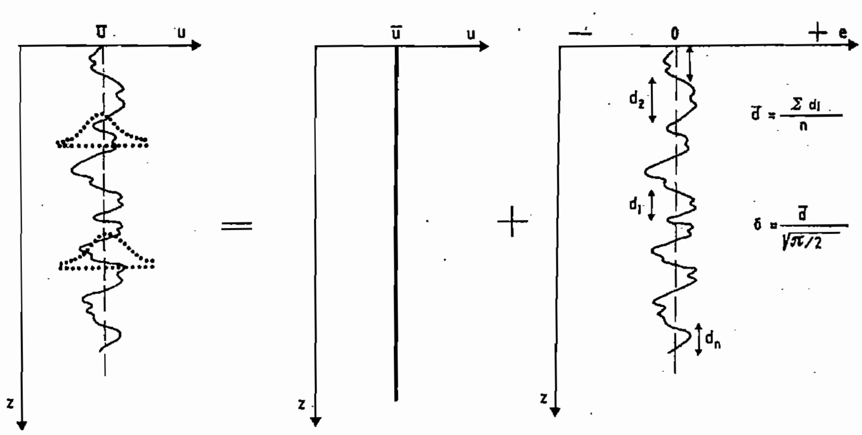

Fig. 1: Soil property components

For a more complete description of a soil property we need two more parameters [6]

- $\sigma(u)$: standard deviation;
  this value measures the intensity of fluctuations, that it is the entity of the deviation between the obtained values of u and u itself
- $\delta(u)$: scale of fluctuation;
  this measures the distance in which the soil property u(z) shows a strong correlation or persistence by point to point.

Information regarding $\bar{u}$, $\sigma(u)$ and $\delta(u)$ parameters give a good visualisation of the variation of u(z) in the vertical direction.

The concepts and terminology involved deal also with two- and three- dimensional cases, whenever the u variable is function of more coordinates.

The trend component $\bar{u}(z)$ can be expressed as a polynomial estimated using the method of least squares (or similar) from test results at various locations z.

In Fig. 2 are plotted the three main types of soil profiles [7].
For example for type I profile we have:

$$E\{u(z)\} = u(z) = \text{constant}$$
$$Var\{u(z)\} = Var\{\varepsilon(z)\} = \sigma^2 = \text{constant}$$
$$Cov\{u(z_i), u(z_j)\} = Cov\{\varepsilon(z_i), \varepsilon(z_j)\} = C(v) = \sigma^2 \cdot \rho(v)$$

where:

E{.} indicate the expected value
Var{.} the variance
Cov{.} the covariance
C(v) the autocovariance function

$\rho(v)$ the autocorrelation function
σ the standard deviation

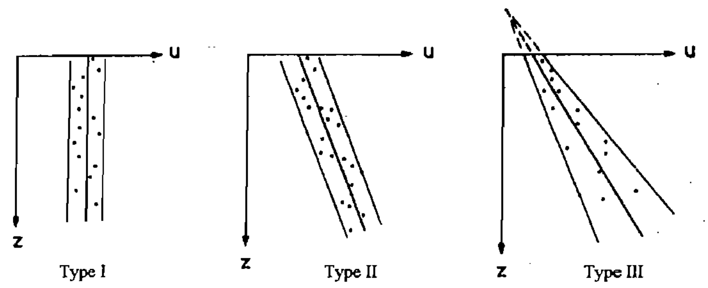

Fig. 2: Types of variation with depth of a soil property

Similar, but more complicated relations we can derive for type II and III profiles.

Data on mean value and coefficients of variation of geotechnical properties are not numerous.

In Fig. 3 are plotted the coefficients of variation of some geotechnical properties of Dunaújváros loess versus depth. The deport is considered homogeneous but it is possible to observe strong differences of c.v. in the first 4-5 m. computed from field level. From 5 to 15 m. the coefficients of variation tend to become stable with the highen values for water content and saturation degree, the lower for bulk unit weight.

Bishop [1] Reported coefficient of variation of 18-42% in the undrained shear strength of London clay (Tab. I). It is possible to notice that these is no particular trend of ceofficient of variation with depth, according to the circumstance that London clays are strongly overconsolidated.

In Fig. 4 [2] for thicknesses of 4 meters are plotted the mean values and the standard deviations of natural water content of Blue Clays of Matera (Overconsolidated silty clays of medium plasticity). We can observe that means and standard deviation are substantially constant with depth.

Data on coefficients of variation and on fluctuation scales of some physico-mechanical properties of some soils are reported by Cherubini et al. [3] and Cherubini [4].

From numerical data, it is possible to put in evidence that the vertical fluctuation scale is evaluable in some decimetres, while the horizontal one is evaluable in some tens meter. The variation coefficient of volume weight is generally very low (5 - 10%). More higher is the one related with the shearing resistance angle and with the undrained cohesion. Intermediate are the values of coefficients of variation of liquid limit, plastic limit, etc.

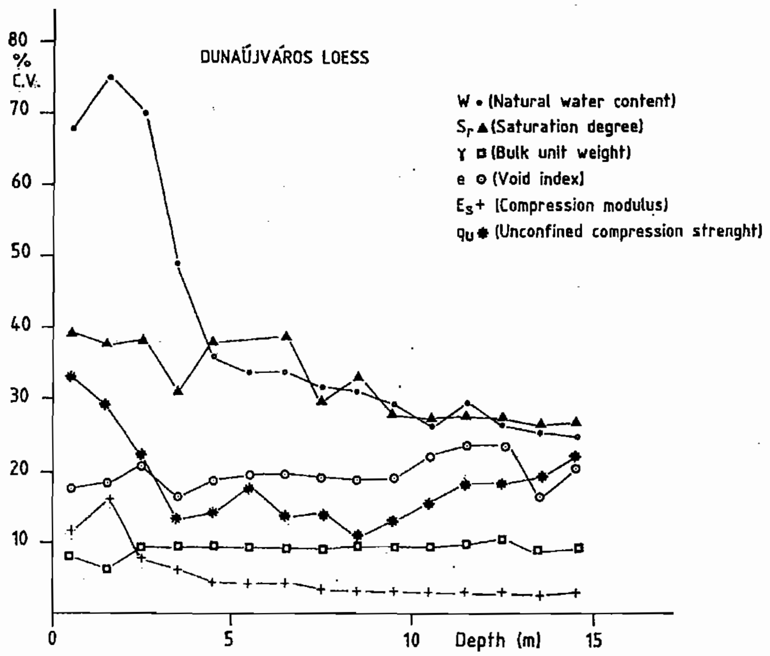

Fig.3: The coefficients of variation of some geotechnical properties versus depth for Dunaújváros loess (Hungary).

Depth (feet)	Samples from whole site		Samples from pit 218 only	
	N. of samples	Coeff. of variation	N. of samples	Coeff. of variation
0-1	38	25%	19	20%
1-2	49	18%	17	26%
2-4	77	38%	19	42%
4-8	65	30%	13	35%
8-12	86	36%	-	-
12-16	46	35%	-	-
16-20	32	29%	-	-
23-27	12	30%	-	-
30-60	43	42%	-	-
75-105	23	33%	-	-

TAB. I: Coefficient of variation respect to depth of undrained shear strength of London clay [1]

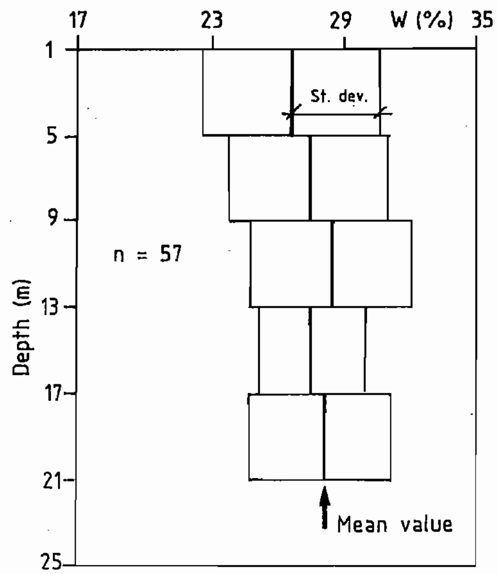

Fig. 4: Mean values and standard deviations of natural water contenent of Blue Clay of Matera (Italy), for layers of 4 m.

CONCLUSION

It is a very complex matter the modelling of soil variation; it requires appropriate economical investments for brings and test and adequate mathematic models, some times complicate. This is, however, the only way we have, in future, to deal with the security of a geotechnical structure with effective "reliability".

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