On the nature and magnitude of variance of important geotechnical parameters

Nature et grandeur de la variance de quelques paramètres géotechniques

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ABSTRACT: Cohesion, internal friction and dry bulk density were measured on 86 samples from a study area in the French Alps. The samples show a lack of spatial dependence and are normal distributed. No influence of roots on the strength of the soil could be proved.

RESUME: Cohésion, frottement interne et poids volumique sec ont été déterminés pour 86 échantillons prises dans une région restreinte qui se situe dans les Alpes Françaises. Les échantillons montrent une manque de dépendance spatiale; leur distribution est normale. Il n'était pas possible de prouver une influence des racines sur la resistance mécanique du sol.

1. Introduction

Although everyone is familiar with the fact that soil material may be very heterogeneous, it is not yet a common practice in geotechnical engineering to take this variability into account.
A stochastic approach to the problem of hillslope stability and landslide hazard analysis takes account of the variability of controlling factors, like slope angle, pore pressure, strength and index characteristics This type of approach is presented by Lee et al(1983), Harr (1977), Ward et al (1981), Vanmarcke (1977) and Mulder and Van Asch (1988). In stability problems, the actual risk of failure is a function, not only of the safety factor, but also of the degree of the accuracy with which the safety factor is determined (Vanmarcke 1977). Therefore, the variability of the controlling factors is worth quantifying.
Estimates of the mean and variance of these controlling factors are usually determined without regarding spatial dependence of the factor. As result the maximum number of observations needed for a regional estimation of controlling factors is quite often exceeded.
This study is part of a research on the influence of forest on hillslope stability. Therefore emphasis is on the rootzone and the difference between the rootzone and the sub soil.

2. The study area

The study area lies in the basin of Barcelonnette, situ-ated in the Southern French Alps (fig 1). It is an area of about 15 by 25 km with an elevation from 1000 to nearly 3000 meters.
Geologically it is a window in the 'Flysch a Helmin-thoides' nappes in which the autochtoneous dark marls (terres noires) from early Malm (Oxfordien) crop out over considerable surfaces. The nappes consist of more restistant sand and limestone and entered the area from the East during the mountain building phase of the Alps (Tertiary).
From the East to the West the basin of Barcelonnette is traversed by the Ubaye river. During the Wurm glaciation the valley was covered with ice upto altitudes of 2000 m and more (Salome and Beukenkamp 1987). Forms due to glacial erosion and those influenced by snow and periglacial action are common. A large part of the area is now covered by glacial deposits. The presence of groundmoraine on top of the impervious marls and the marls themselves are, in combination with the local relief and available rain and snowmelt water responsible for a large variety of mass movements. Some average properties of the soils are: clay (<2 mu) percentage of 19-40, silt (2-50 mu) percentage of 50-60. The saturated hydraulic conductivity varies between 50-250 cm/day. The porosity is between 20 and 35 %.
The climate is sub-mediterranean. The mean annual precipitation is 752 mm (1926-1980). The driest month is July with 47.5 mm (1926-1980). During the winter the precipitation is mainly snow. Due to the East-West direction of the valley there is a distinct difference in evapotranspiration, temperature, precipitation and duration of the snow coverage between the slopes exposed to the South and the North.

3. Methods

Sampling points were chosen using an unbalanced nested sampling techniques. If a sampling area is divided into several classes, and these are in turn divided into smaller classes, we have a nested sampling sheme with two levels (Burrough 1986). In case of an unbalanced sampling the number of sampling points is not the same on each level.
The samples were taken in a landslide under forest, in both root-zone and sub soil. The sampling depth varied between 10 and 290 cm. The samples consists mostly of morainic material. The sampling was done using a thinwalled sampler (inner diameter 66 mm, outer diameter 67 mm), which was driven into the soil. with a hammer. Visible disturbance of the samples due to the sampling was restricted to the outer 2 mm. The samples were saturated by nearly submerging them in water for one to two weeks.
Consolidated drained shear tests were carried out on 86 samples in a standard direct shear box (60 mm diameter and 25 mm high). These tests were run at a deformation rate of 10 mm/hr at normal loads between 5 and 55 kPa. The bulk density and porosity were estimated on samples of 100 cm3.

4. Statistical characteristics

The true value of the stability controlling factors or soil parameters is never known, although it can

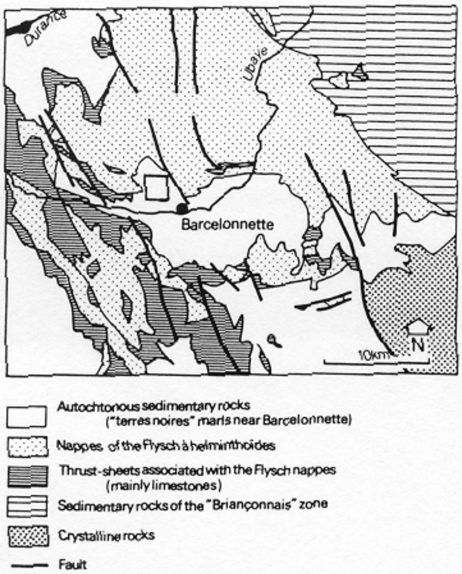


figure 1. Location of the study area.

table 1. statistical parameters

	angle of friction (degree)	cohesion (kPa)	dry bulk density (gr/cm3)
number observations	86	86	77
mean	39.66	17.48	1.718
median	39.74	17.02	1.72
variance	74.49	39.59	0.027
coef.variation (%)	21.76	35.98	9.56
maximum	58.49	34.09	2.13
minimum	19.6	4.94	1.15

be estimated from a number of measurements. Measurements are subject to error and introduce a variance in the value of the soil parameter. Several sources of error can be distinghuished.

a. Random error, i.e. errors of unpredictable or unknown nature.
b. Systematic errors. Systematic errors occur:
   1. because the sample measured is not representative for the soil. (spatial soil variability)
   2. because the sample properties have been altered or disturbed in the process of sampling and transportation. (sampling errors)
   3. because the tests themselves are not accurate. (testing errors)

The total variance is the result of the accumulation of all the different types of errors. In table 1 statistical parameters are given of angle of internal friction (degrees), apparent cohesion (kPa) and the dry bulk density (gr/cm3).

4.1 Probability distribution

Many probability distributions have been proposed for angle of internal friction, cohesion and the bulk density. Wu and Kraft (1967) reported that the log-normal distribution provides a reasonable representation. Lumb (1966) shows that both the cohesion and the friction angle fit the normal distribution. Lumb (1970) suggests the beta-distribution for soils exhibiting both cohesion and frictional strength. Ward et al (1976) suggests a uniform distribution, while Oboni & Bourdeau (1983) and Harrop-Williams (1986) assume a beta-distribution. Acccording to Nielsen et al (1973) and

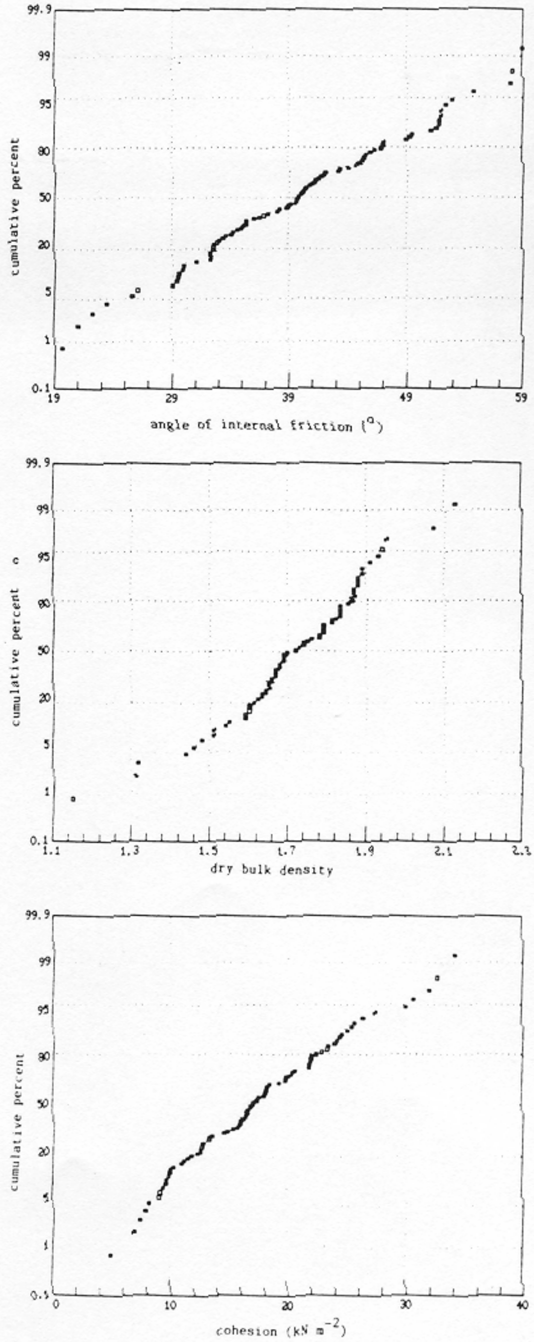
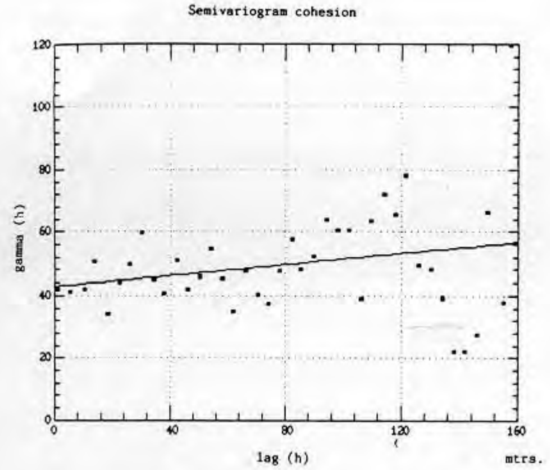
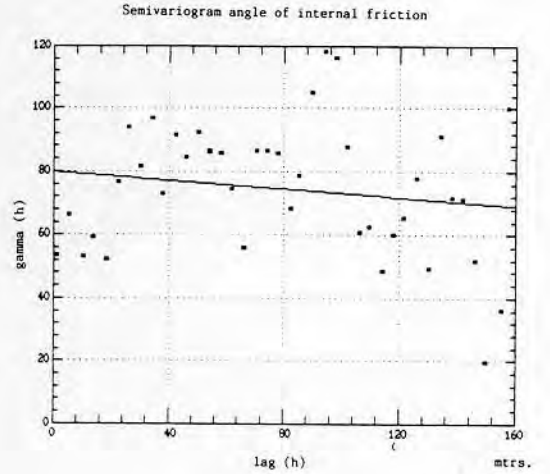


figure 2. Normal plot of cohesion (kPa), angle of internal friction (°) and dry bulk density (gr/cm3)

Russo and Bresler (1980) the normal distribution is an appropriate assumption for the dry bulk density. Figure 2 gives the normal probability plots of angle of internal friction, cohesion and dry bulk density. A normal probability plot is obtained by ranking the observed values from the smallest to the largest and then pairing each value with an expected normal value of a sample of that size from a standard normal distribution with the same mean and variance. If the observed scores are from a normal distribution, the plot should approximate a straigth line (Norusis, 1985).
The chi-square goodness of fit test was used to compair the experimental distribution of the cohesion, internal friction and the dry bulk density with a normal distribution. The test rejects the null hypothesis of unequality of the distributions for cohesion, internal friction and dry bulk density





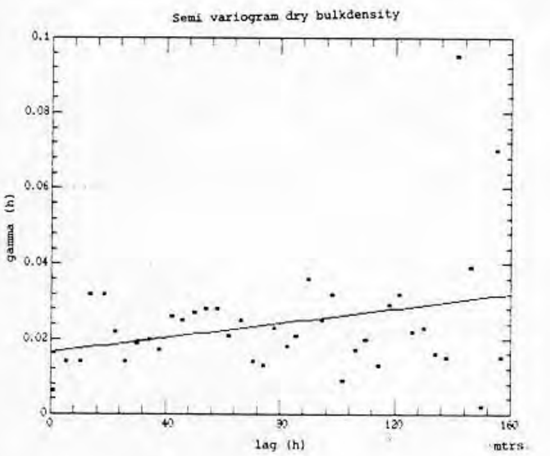


figure 3. Semivariograms of cohesion (kPa), angle of internal friction (°) and dry bulkdensity (gr/cm3)

at a level of significance of resp. 0.11, 0.23 and 0.03.
This all indicates that the assumption of normal distribution for cohesion, internal friction and the dry bulk density is reasonable.
The fact that the controlling factors are normally distributed and knowning the variance of the sample population, opens the possibility of calculating the number of observations needed to reach a certain error of the mean (Walpole & Meyers 1972). Seventy-one observations have to be made before the estimated mean differs less than 2 degrees of the true mean of the internal friction angle with 95 % confident. One degree error needs 286 observations. We can be 95% confident that a error 1 kPa is reach for cohesion with 67 observations. An error of 0.05 in the dry bulk density needs 41 observations.

4.2 Spatial variation

The spatial structure of the variance can be studied using semivariograms. A semivariogram is a plot of the semivariance vs. lag or distance. It is a display of how the variance changes with sample spacing. The semi-variance (gamma (h)) of a property is defined as half the expected squared difference between the values at places x and x+h, where h is the lag between the places (McBratney and Webster (1983)). Two conditions have to be satisfied: the expected difference between the values at any two places seperated by h is zero and the variance of the difference depends on h and not on the place (Burrough 1986).
The more the observations are alike the less is the semivariance. Ideally the semivariances increases with distance h until it reaches a maximum value which according to Journal and Huijbregts (1978) should approximate the total variance of the sample population.
Figure 3 gives the semivariograms of the angle of internal friction, cohesion and dry bulk density. For these semivariograms only the samples taken at a depth of 100-150 cm were used. In this way the variance due to a variation with depth is reduced. None of the semivariograms shows a tendency to increase with the lag in distance. Futhermore the intercepts of the y-axes do not differ significantly from the variance. This indicates that there is no spatial dependence.
In these situations the best estimate of a value of an attribute is the usual mean, computed from all sample points in the region of interest without taking spatial dependence into account (Burrough 1986).

4.3 Variation with depth

According to Wu et al (1979), Gray and Leiser (1982), Ziemer (1981), Greenway (1987) and Waldron (1977) tree roots increase the apparent cohesion of the soil and have no influence on the angle of internal friction. From this it was expected that the cohesion would decrease with the depth or at least show a difference between the rooting zone and the sub soil. The rootzone (the soil layer with 80 % of the roots) was found to be between 40-60 cm. The maximum rooting depth was more than 250 cm.
Figure 4 shows that none of the parameters is related to the depth. This and the low correlation between the peak strength of 70 unconfined compression tests on samples from the rootzone with the total weigth of the roots, indicates that roots have no influence on the strength of the soil. Our hypothesis is that roots and burrowing animals decrease the cohesion of the matrix of the soil. Further research is needed to test this hypothesis.

4.4 Variation due to sampling and testing errors

The estimation of the variance due to sampling and testing errors is very difficult. In most cases these errors are assumed to be negligible.
Plotting the results of the direct shear tests in a similar way as in figure 5 and using simple linear regression methods, it is possible to estimate the coefficient of variation for each of the tests for the cohesion and the tangent of the angle of internal friction. This coefficient of variation for the cohesion was between 5-15 % and for the friction it

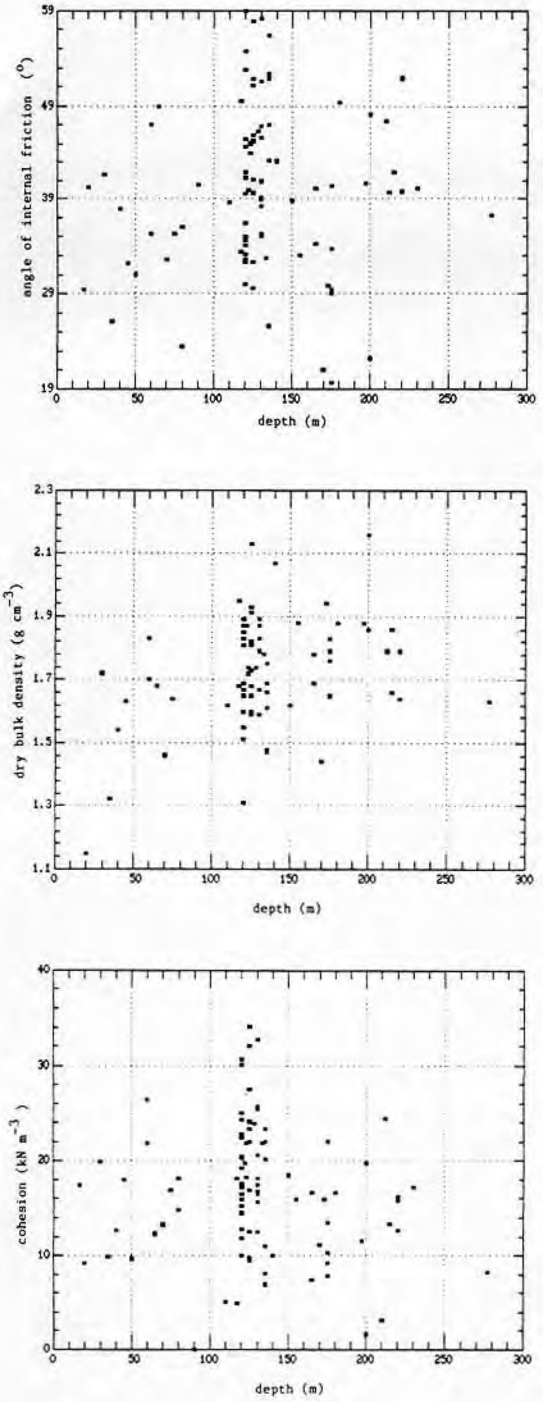


figure 4. Plots of depth (cm) vs cohesion (kPa), angle of internal friction (°) and dry bulk density (gr/cm3)

is 2-20 %. These coefficients are well below the coefficient of variation of the total population (see table 1), indicating that measured variance is a property of the study area and not solely a result of the testing procedure.

5. Conclusions

For a stochastic approach to the problem of hillslope stabilty and landslide hazard analysis it is important to know the variability of the geotechnical parameters, like cohesion, internal friction angland bulk density. The variance of values for cohesion

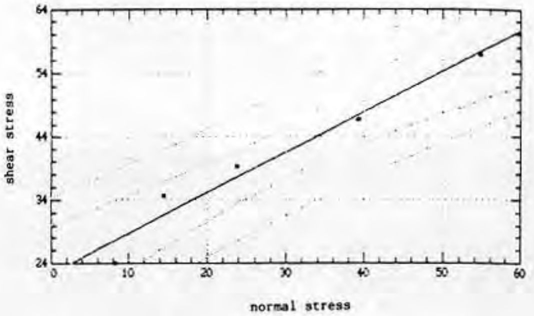


figure 5. Plot of shear strength (kPa) vs normal stress (kPa) of a consolidated drained shear test.

and those of the angle of internal friction, measured on samples from morainic and solifluction material is great. But it is well in the range mentioned by Lee et al (1983). The great variability is due to the long history of movement and instability of the study area (see Weiss 1988) and the character of morainic and solifuction material.
The experimental probability distributions of the parameters cohesion, internal friction and dry bulk density can be approximated by a normal distribution. If there is a lack of spatial dependency the best estimate of a value of an parameter is the usual mean, computed from all sample points in the region of interest without taking spatial dependence into account. The lack of spatial dependency of the controlling factors and their normal distributions makes it nessecary to take at least 30 samples, evenly spread over the area of interest, before it is possible to give a reliable estimate of the mean and variance of controlling factors and therefore of the stability of study area.
The absence of a relation between the cohesion with the depth and with the amount of roots in the soil, makes it possible to calculate the stability of a forested hillslope as if it is only one layer. Furthermore it seems that the direct influence of forest on strength parameters is negligible.

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