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 sont déterminés pour 86 échantillons prises dans une région restreinte de montagne, les échantillons montrent une absence de dépendance spatiale; leur distribution est normale. Il n'est pas possible de prouver une influence des racines sur la résistance 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 (1980). 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 regard to 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, situated in the Southern French Alps (Fig. 1). It is an area of about 15 x 25 km with an elevation from 1000 to nearly 3000 meters. Geologically it is a window in the 'Flysch a Helminthoides' nappes in which the autochthonous dark marls (terres noires) from early Malm (Oxfordian) crop out over considerable surfaces. The nappes consist of more resistant 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 up to altitudes of 2000 m and more (Salamé 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 ground moraine 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 mm) percentage of loam-silt (2-50 mm) 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 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 in turn divided into smaller classes, we have a nested sampling scheme 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 thin-walled 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/h 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

<table>
<thead>
<tr>
<th></th>
<th>Angle of cohesion</th>
<th>Dry bulk density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of observations</td>
<td>85</td>
<td>86</td>
</tr>
<tr>
<td>Mean</td>
<td>39.66</td>
<td>17.48</td>
</tr>
<tr>
<td>Median</td>
<td>39.74</td>
<td>17.02</td>
</tr>
<tr>
<td>Variance</td>
<td>74.49</td>
<td>36.09</td>
</tr>
<tr>
<td>Coefficient of variation (%)</td>
<td>21.76</td>
<td>9.56</td>
</tr>
<tr>
<td>Maximum</td>
<td>58.49</td>
<td>34.09</td>
</tr>
<tr>
<td>Minimum</td>
<td>19.6</td>
<td>4.94</td>
</tr>
</tbody>
</table>

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 (g/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 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 Arup-Williams (1986) assume a beta-distribution. According to Nielsen et al (1973) and Russo and Breeser (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 straight line (Norusis, 1985). The chi-square goodness-of-fit test was used to compare the experimental distribution of the cohesion, internal friction and the dry bulk density with a normal distribution. The test rejects the null hypothesis of inequality of the distributions for cohesion, internal friction and dry bulk density.
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 semivariance (\( \gamma(r) \)) of a property is defined as half the expected squared difference between the values at places \( x \) and \( x+r \), 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 separated 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 Journel 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. Furthermore 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 25 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 weight 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 test 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 15%.
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 hillside stability and landslide hazard analysis it is important to know the variability of the geotechnical parameters, like cohesion, internal friction, and dry bulk density. The variance of values for cohesion 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 solifluction 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 essential 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.

Acknowledgements

The authors would like to thank A. de Jong, G. Hazue and H. Schutjes for their assistance during the field period; Dr H. Th. Riezebos and Dr H. van Steyn for discussions and for their valuable suggestions on the manuscript; the CEMAGREF, Grenoble for grants and technical and logistic assistance.

literature


