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SOIL TEXTURE AND SOIL STRUCTURE

Chapter I

THE MEANING OF THE SOIL TEXTURE OR GRAIN-SIZE DISTRIBUTION

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CHAPTER I

THE MEANING OF THE SOIL TEXTURE OR GRAIN-SIZE DISTRIBUTION

Introduction

To determine the grain-size distribution of a soil, a so called soil mechanical analysis is needed. It means the percentage of the fractions limited by the sizes of individual particle-groups should be known.

In the early days many people tought that these data would probe to be the most important characteristics. The experience has proven however that this is not the case. Nowadays one believes that the grain-size distribution is one of the important parameters. The procedures of analysis will not be explained here as it is supposed to be known. Just as a reminder it is stated that the grain-size distribution requires in general two different procedures of analysis : sieving and sedimentation.

A sieve analysis consists of shaking the soil through a steck of wire screens with openings of known sizes ; the definition of particle diameter for a sieve test is therefore the side dimension of a square hole.

The sedimentation is based on Stokes' equation for the velocity of freely falling spheres ; the definition of particle diameter for a sedimentation test is therefore the diameter of a sphere of known density which falls at a given velocity in a physically well defined medium. As can be seen from the Stokes equation here after when all other parameters are constant the velocity (v) of a falling particles is determined by its diameter (d).

$$v = \frac{\upsilon_k - \upsilon_w}{\eta} \cdot \frac{d^2}{18}$$

υ_k and υ_w : density of the grain (2.65) and of the water (1) dependin_ on t° respectively

η : dynamic viscosity (depending on t°)

From the above, it is abvious that the particle diameters in a sedimentation test is supposed to be an equivalent value. Stokes law is only applicable for particles $d < 2\mu$. Above this size, turbulent water movement occurs around the sedimenting particles. When applying the Stokes law in the early days (19th century) cylinders of a special shape were used to collect each size fraction. Today an hydrometer or aerometer is used. It is a floating small glass cylinder measuring the density of the suspension at a given depth in a sedimentation cylinder. From the depth and the time needed, v can be deduced, hence the size. From the density of the liquid given by the weight of the floating hydrometer, the amount of particles with density 2,65 can be assessed.

The derived formula for Stokes law when using an hydrometer is

$$d = \sqrt{\frac{18\ \eta}{\upsilon_k - \upsilon_w}} \cdot \sqrt{\frac{z_k}{t}}$$

$Z_k/t = V$; Z_k = distance from the surface of the suspension to the center of volume of the hydrometer

t = elapsed times since start of the sedimentation.

1. Pedological interpretation of the grain-size distribution

In soil science research grain-size distribution is one of the most fundamental data in order to know with which kind of soil one is dealing.

A first point of discussion is to agree on the limits of the different fractions.

The International Soil Science Society agrees on the following boundaries : (see fig. 1.0.)

clay : 0 - 2 μ
silt : 2 - 20 μ
sand : 20 - 200 μ

Fractions sizes can be adopted according to the needs in a given area. The limits used in a polder region will be different from the one in a region with wind deposits. Limits to serve soil taxonomy has been adopted and reads as follows :

clay : 0 - 2 μ
silt : 2 - 50 or 60 μ
sand : > 50 or 60 μ

In order to avoid discussions on fraction-sizes it is costumary to present the grain-size distribution as a cumulative fraction-curve or a grain-size distribution diagram (see fig. 1.1.). From it any subdivision on size-classes can be inferred.

In the early days, the name given to a soil was inspired by the presents of the dominant fraction. So it was common to speak about a clayed or loamy or a sandy soil. As the research wanted more precision, the nature of these soils was better defined. So one speaks about a silty clay, a loamy sand etc...

As one experienced since 1945 that there are three major fractions the name given to a soil should depend on the relative amount of each one. The major fractions are : clay, loam or silt and sand. As a normal diagram is not sufficient to locate three different fraction, a soil textural triangles were introduced (see fig. 1.2.). Depending on the relative amount (%) of each of the three main fracion a different name was given to define a given soil. The subdivision of a textural triangle the world over is by far not uniform. A comparaison of a textural triangle used in a polder-area (clayey soils) and in wind-blown deposits (sandy soils) will be quite differents. To use a textural triangle one proceeds as follows. The soil textural classes or fractions should be grouped into the three majors sizes corresponding to each of the size limits mentioned on each ordinate
e.g. : clay : 0 - 2 μ
loam : 2 - 60 μ
sand : > 60 μ.

Clockwise one starts from point 0 for the clay fraction on the ordinate 0 - 2 μ ; the percentage say 25 %, should be marked. Next on the 2 - 60 μ ordinate starting from point 0 the percentage of the loam fraction say 45 % should also be marked. When following the horizontal line at 25 % clay entering the triangle, the cross-point with the 45 % loam fraction will be found on the oblique line parallel to the 0 - 2 μ fraction ordinate. As a control the 30 % point on the > 60 μ ordinate should be followed on the line parallel to the 2 - 60 μ ordinate. That line will meet the cross point of the two former fractions. The site where this triple cross-point is located will indicate the name of the kind of soil (see fig. 1.2.).

2. Physical interpretation of the grain-size distribution

Physically speaking one is interested in the behaviour of the soil concerning :

- aggregation
- pressure resistance at different moisture content
- plasticity

2.1. Aggregation

The question is how easy a soil can be put into a porous structure and be well aggregated. In this respect the grain-size distribution can be very informative.

A soil with a Gaussian distribution curve (see fig. 1.1.) will have major problems to get well structured. It means it will be realtive difficults to prepare a good seedbed. In the opposite case when there is not a continuous transition from one textural class to an other the soil will be easy to be aggregated (i.e. in a graded soil).

In the cumulative grain size distribution curve the absence of a fraction is marked by almost an horizontal segment of the curve (fig. 1.1.).

2.2. The grading as opposite to the uniformity index of the soil

Besides the visual method using fig. 1.1. to assess the grading the opposite or the uniform index can also be used. It is a ratio of two sizes. It is often more precise. Thereofre on fig. 1.1. the diameter of the particles corresponding with a ordinate value of 10 % is compared with the one at 60 %. In other cases the diameters at 33 and 66 % ordinate value are compared This ratio can not exceed the unity. A soil of which all particles have the same size has an uniformity index g equal to 1. Don't forget fig. 1.1. represents a cumulative grain size distribution. Following scale has be established :

$g > 0.5$	: very uniform ; poorly graded
$0.5 > g > 0.2$	: uniform ; fairly graded
$0.2 > g > 0.05$	: not uniform ; well graded
$0.05 > g$	: very poor distribution of equal sized particles ; very well graded. It nearly means a ganssian distribution.

The poorer the uniformity the better the soil is graded and hence the easier compaction will occur. See fig. 1.3. were a $g < \frac{1}{20}$ is indicated by W, meaning well graded. The soil is good to make a solid body with high resistance against froces (high bulk density) e.g. when building dikes. It is the opposite which is needed to make a good soil structure meaning a more uniform sized particle distribution is needed $g > 0,2$.

2.3. Pressure resistance at different moisture contents

Atterberg was the first to recognize that the soil behavior is not only a function of its texture alone but also of the cations present, the kind of clays, the organic matter, the soil treatment before, etc. He recognized for a soil with the same or almost the same soil texture sometimes a different plasticity behaviour.

As this topic will be elaborated more extensively in another chapter it suffices to recall the essentials. Atterberg defined the transition of the plastic behaviour in terms of the moisture content at which a given soil showed a well defined strength.

liquid limit : W_l; boundary between the plastic state (the soi' can take and keep a given shape) and the liquid state (the shape vanishes through excess of water). Technically : the liquid limit is the water content at which the soil has such a small shear strenght that it flows to close a groove of standard width when jarred in a specified manner.

plastic limit : W_l; boundary between the plastic and semi-solid state (soil can crumble) . Technically the plastic limit is the water content at which the soil begins to crumble when rolled into threads of a given size.

The amount of water which must be added to change a soil from its plastic limit to its liquid limit is an indication of the plasticity of the soil. The plasticity is measured by the plasticity index "Ip". It is equal to the difference between the liquid limit minus the plastic limit.

$$I_p = W_l - W_p \qquad (1)$$

3. Interpretation of the grain-size distribution in function of the plasticity

It has been the merit of Casagrande (1948) to indicate that the comparaison of the soil texture and I_p is a very helpfull way to predict the soil behavior when subjected to pressure. The impact of agricultural machinery on soil can be predicted this way. The method escaped the attention of the agriculturists but was mainly used for the classification of soils for airport constructions. The "AC Method" standing for "Airfield Classification Method" is represented in fig. 1.4.

Casagrande subdivided the diagram using three lines A - B - C. The lines B an d C are crossing the line A.

Line A : indicates the upper limit of I_p for organic soils. When W_l increases I_p will increase only gradually ; the change is comming from the Wp that increases see formula (1).
When Ip increase. more the organic matter has a substantial amount of clay or loam and is highly sensitive for compactions.

Line B : indicates the lower limit for soils howing a Wp > 50 %. It means one is dealing with fine textured soil: meaning heavy soil having at the same time a high Ip. These are mineral soils highly sensitive to compaction.

Line C : indicates the upper limit for soils having a W_l < 30 %. These soils have a sandy behavior. To cultivate such soils a light tractor suffices. When I_p is < 20 % one can cultivate the soil at a wide range of moisture content. These soils are not very sensitive to compaction.

The chart of Casagrande (fig. 1.4.) has been made still more explanatory by adding a few letters (see fig. 1.3.) such as : S = sandy ; M = medium (silt) ; C = clay ; O = organic ; F = fine sandy ; indicating at the same time with a L or H if they are L = little or H = highly sensitive to compaction. So 6 characterities could be introduced : CH ; OH ; MH ; CL ; OL ; ML. An other two also were added SF and SC for two kinds of soil. They are very highly resistant to compaction.

4. Assessment for soil mechanical purposes

In soil mechanics the necessary has been felt to make a much finer distinction in textural classes than ordinary done in soil science. The influence of an increasein size and in clay fraction in the lower percentage is much more important than a linear progress indicates.

Therefore following limits and percentages are dealt with :

Fraction I : d < 2 µm
IIa : 2 µm < d < 20 µm
II : 2 µm < d < 60 µm
III : 60 µm < d < 200 µm (also called filler fraction)
IV : 200 µ < d < 2 mm
V : 2 mm < d < 20 mm
VI : 20 mm < d

Coarse texture : fractions I + II < 10 % ($CaCO_3$ + O.M. < 1 %)
Fine texture : fractions I + II > 10 %
Fine sand : fraction III > 50 %

Medium coarse sand : fraction III + IV > 50 % and fraction IV < 50 %.
Coarse sand : fraction V > 50 %.
Fine gravel : fraction V > 50 %.

To distinguish between fine texture soils attention is paid to the I_p value. The denominations are as follows :

0← Ip = 5	Ip = 15		Ip = 25→
Clayey sand with little loam	III + IV + V > 50 % clayey sand loamy sand	III + IV + V > 50 % sandy clay	C y
	III + IV + V < 50 % loam	III + IV + V < 50 % loamy clay; III > 50 % loam	

To distinguish a clayey from a loamy sand one looks at the ratio of the fraction IIa/I

clayey sand : IIa/I < 1
loamy sand : IIa/I > 1.

To stress the mechaniccal behavior one looks at the ratio I_p versus W_l

strong clayey $I_p / W_l > 0,5$ (very poor soil)
loam or clay sandy $I_p/W_l < 0,2 - 0,5$ (medium soil)
loam or sand clayey $I_p / W_l \approx 0.5$ (poor soil)

<u>Practical example</u> :

Sand for draining purposes : no I_p (it means W_p could not be determined as no soil tread could be made)

Sand for foundations : no I_p
particles < 74 µm is < 12 %
particles < 20 µm is < 3 %
$CaCO_3$ or O.M. < 4 %

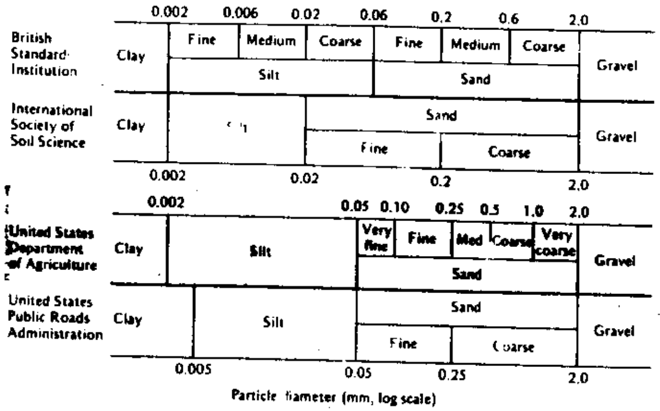
5. <u>Soil texture and sensitivity to erosion</u>

For a given soil no direct relation could be found to assess its sensitivity to erosion when looking at the soil texture alone.

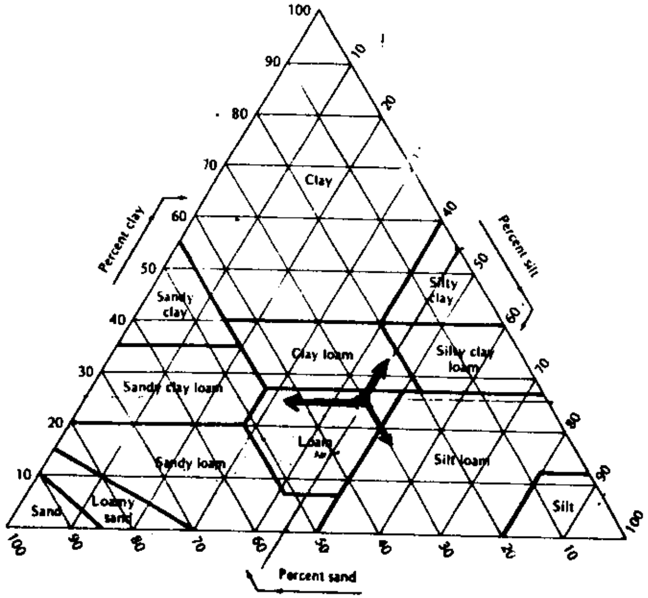
In general it was remarked that loamy soils were sensitive but a clear distinction could not be made even when looking at I_p/W_p ratio's.

The solution was found when looking at the steepness of the curve relating the increase in moisture content of a soil when it flows to close a groove of standard width for 10 blows versus 5 blows. The higher the difference in moisture content the more the soil can take water before flowing (dispersing-slaking) thus sensitivity ↑ to erosion. So De Ploey 1983) called this difference in moisture the C_{5-10} index. He could establish the following table for Wester-European soils.

C_{5-10} index > 3, stable soil-nearly no slaking
C_{5-10} index < 2.5, unstable soil-severe slaking
C_{5-10} index between 2,5 - 3 ; transition sensitivity



Figuur 1.0. : Classification of soil particles according to size by four systems.

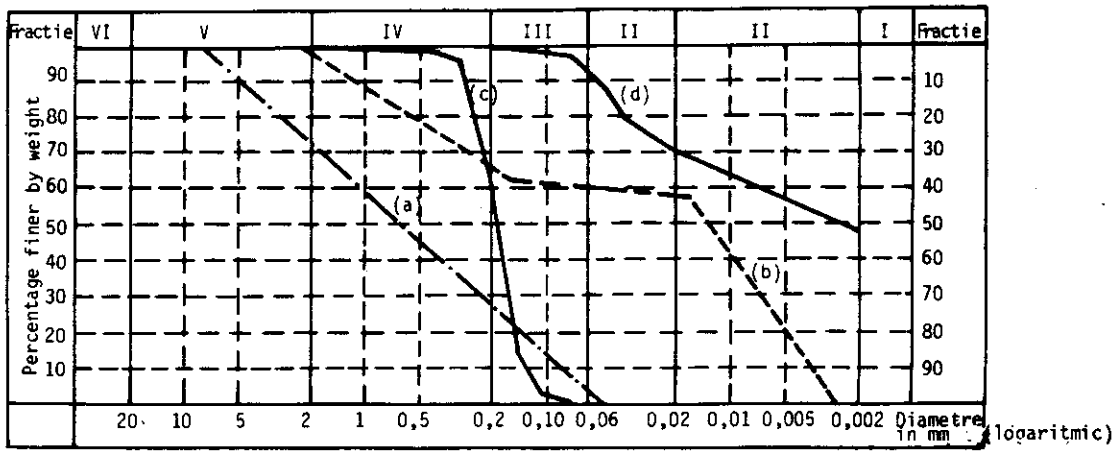


Figuur 1.2. : Percentage of sand, silt, and clay in the major soil textural classe. To use the diagram, locate the percentage of clay first and project inward as shown by the arrow. Do likewise for the percent silt (or sand). The point at which the two projections cross will identify the class name.

Fig. 1.3. : Symbols introduced by Casagrande (1948) for better interpretation of fig. 1.4.

Major symbols		
G	Gravel	
S	Sand	
M	Silt (M)	
C	Clay	
O	Organic	
Pt	Peat	
Additional symbols for coarse soils		**Remarks**
W	Well graded	Small grading index ($g < \frac{1}{20} = 0{,}05$)
P	Poorly graded	Large grading index ($g > \frac{1}{5} = 0{,}2$)
C	Clay binder with a low to medium plasticity	
F	Excess fine and or silt	
Additional symbols for fine textured soils		
L	Low to medium compressibility	
H	High compressibility	

GRAIN SIZE DISTRIBUTION DIAGRAM



a) well graded
b) poorly graded
c) sandy soil $q = \frac{0,150}{0,20}$: poorly graded soil
d) heavy clay $\frac{0}{0,007} = 0$: well graded

Figuur I.1.1. : Well graded soil particles have a gaussean distribution curve which is represented by a straight live in this diagram.
Poorly graded soil particles are represented by a broken line showing a nearly horizontal segment.

Denomination of soil according to A. Casagrane