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CONSISTENCE OF SOIL

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Consistence of Soil

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1. Introduction: What is consistency?
   . Not just Atterberg
2. Field observations: Feeling when walking
   Observation of footpath and wheeltrail
   Observation of slip of wheels etc
3. Forces influencing consisteny:
   Force systems
   what is stability: consistence
   Reduction to one plane of contact
   4 forces-simplified
   Details to those forces
   . direction -amount- point of action
   . Change of these properties
4. Consistence in situ:
   Change of forces in situ in soil profile
   The role of waterfilms and menisci
   The role of compaction
5. Measuring consistence:
   Classical Atterberg limits
   liquid limit, upper plastic limit
   Compression tests
   Proctor as example
   in situ probing - penetration resistence
   influence of cohesion
   . influence of compaction
6. Conclusions:

Introduction

When soil consistence is mentioned, usually one thinks of Atterberg-limits. There are several of them, but the most widely known ones are upper and lower plastic limit. The first of these is frequently called liquid limit.
It is generally known as well, that these limits give the water content of a soil at a specified consistence. These specified consistences are determined empirically and the procedure employed is extremely simple. This last fact may be the reason, why sometime the question comes up: what is the use of these Atterberg values?
The answer to this question is, that the Atterberg limits are just one measurement to formulate a rather complex property of the soil. The property "consistence" is as complex as the property "fertility" and so one should not try to describe the whole complex with but one figure.
The original latin meaning of the word consistence is ability of a man or a thing to keep his or its place or its form in relation to his or its immediate environment. As all environment in most parts of soil is soil again, this definition is almost the same as that comonly given for "stability" of structure of aggregates.
So consistence turns out to be one aspect of the wide object of structure, its changes, the ability of soil to withstand these changes and the way in which a change of the active forces will influence the soil.

Field observations

Consistence of soil can be felt quite obviously if one walks over it. The difference of feeling when walking on the walking path between two freshly prepared seedbeds and the feeling when accidentally stepping on the bed itself, is obvious.
The attentive observer may as well feel the difference between the hard consistence of a soil of a park-lawn and the softer consistence of a meadow soil. Even the fact that cattle is treading a soil strongly and regularly can be distinguished from cases, where cattle just occasionally treads the soil.
One feature of consistence can even be seen as well: The soil surface of pathway is generally lower as the one from the soil left and right of it. It can be observed quite generally that soil in the deep trails of heavy vehicles is harder than that besides these trails. There is a third observation easily made: If one watches the wheels of a tractor the behavior of the soil under a driving wheel is obviously different from the one of a passively rolling wheel. Furthermore the soil under these wheels gives way to a certain extent. Sometimes the result is a hardbottomed trail, sometimes the soil would not become hard and the wheels will sink down puddling it.

All these observations have to do with consistence and its effect under various stresses.

Forces influencing consistence

If we consider the relative movement of particles to each other to be a question of consistence, then we can reduce the system to be observed to just one point or plane of contact.
The simplification is possible, if we consider the rules of addition and combination of forces in forcesystems of several kinds - i.e. planar-central, planar-general, spacial-general. As in the latter case all momenta and forces can be reduced to give one resulting force and a momentum in a plane, rectangular to that force, one can conclude that for a given particle there is just one contact, where only a normal stress is activ. On all other contacts there is some force "not normal" and in contact planes normal to that of the momentum there is no normal force at all. Now we consider one arbitrarily chosen point resp. plane of contact of one soil particle on some other.
We can reduce all forces active at that plane to four of them, if we sum up vectorially all those of equal mechanisms to give one resultant.
These four forces are:
- weight of particle in consideration
- resultant of all weight components from other particles transmitted over the solid phase to the contact in consideration
- resultant of all force components transmitted from the liquid phase
- cohesion and adhesion at the contact.

Fig.1 If we for simplicity let these four forces give a planar-centric force system, they can be summarized to give one resultant force. This resultant will in most cases not be normal to the plane of contact. So it can be split up to a component normal and a conponent tangential to that contact plane or surface.

Fig. 2 If now the soil withstands these both components the structure is said to be "stable" or - the consistence is "hard" or "stiff".
As this situation can be described as well in terms of the Coulomb-equation, we can reduce one aspect of the term "consistence" to basic physical properties at a contact.
If we accept this statement, we must take into account the fact that a change of any of these four forces will change the resultant and hence the equilibrium situation of the whole system. Therefore we should look a little bit closer to the possibilities to change each of them !

Weight force. This force is practically unchangeable. An apparent change will come about when the whole soil is submersed and the weight of the soil particles is counteracted by the weight of the displaced water.

<u>Resultant of overload components.</u> Conduction of this force at the contact area is normal to plane if there is no friction at all. If frictional resistance can be developped a tangential component comes into existence. Therefore at the differently orientated planes of contact different net movements become possible. Part of their results will persist, when the force is relaxed. The deformation that have thus been developed are called "plastic". Some rest may be reversible. Its deformation vanishes as the force is relaxed. This is known as "elastic". Wether a force will relaxe or not depends largely on the geometry of the transmission. This is easily shown by the following example: As everybody knows a soil sample will slip out of a cylindrical core sampler if it is loosely packed. It can be made to stay in the core sampler by just temporarily loading it - i.e. compressing the free soil surface at the open ends of the sample.

<u>Fig. 3 Resultant of liquid-transmitted forces.</u>
The influence of a fluid in the pore systems of a soil affects the contact at a plane in two ways. First the effect of flowing should be mentioned, because it is a unique property of the fluid medium. Here the pressure difference in direction of flow, that moves the fluid, is as well effective if in place of fluid there is a solid particle in the stream-path. The force thus implied on the particle will influence the force-system as explained before and thus also net stability as shown in Fig. 1 and 2.
Water movements or pressure differences that cause such an effect may by themselves be created by compaction of a structure so that water is forced to give way for solid particles. The other way in which water will influence the forcesystem of the contact is in principle not exclusively a consequence of water properties. Therefore it is discussed here in the subchapter on Adhesion-Cohesion.

<u>Adhesive and cohesive forces.</u> These forces that act normal to the plane of contact may be of very different origin. All classical stabilizing mechanisms are involved here, including v.d. Waals-forces, Madelungs-forces, electrostatic forces and so on. Here all organic material or synthetic stabilizing compounds are to be mentioned. Furtheron ion-effects and the effects of precipitations must be accounted for. Particularly important is it to mention the effects of water here. Water adsobed at surfaces of solid particles may act as coherent as long as the curvature of the menisci is concave seen from outside. If however the particles are forced closer to each other, a meniscus can develop that shows the existence of a pressure within the water that will force apart the particles.

<u>Consistence in situ in the profile.</u>

As is generally known, a soil can be compressed under load. The more compression is already achieved, the less further compression can be obtained by adding another unit of load.
The curve showing this is called a standard compression curve or compression curve or compression characteristic. On the abscissa of this curve pressure is plotted. On the ordinate a unit is plotted that is connected with pore space. This is because usual compression forces will only affect pore space. As this compressing force is appied uniaxially and horizontal expansion is prevented by the sampleholder the consequence of increased load can be measured as decrease in sample height as well as in void ratio.
This relation calls attention to a fact that is frequently neglected in pedology, namely the change of position of soil surface when pore volume is changed. This means in the end, that pore volume at a given level in a profile is a function of depth under surface (because of natural overburden), of shearing resistance that might develop and of "precompression" that is previous temporary higher load, for instance caused by agricultural machinery. One can say therefore, that pore volume or bulk density of a soil is strongly dependent on consistence as a material-parameter as well as consistence as a parameter of present and previous influences from outside or from geometric environment.

Every soil has its own compression characteristic for the whole profile that shows an equilibrium situation between the three factors mentioned. This can be seen from the fate of loosening or deep ploughing actions, if the same management as before this amelioration is applied again after it. It can be seen as well from curves of differently developped soils on same material. And it can finally be seen from a comparison of pore volumes and shearing resistances as related to soil development.

<u>Fig. 5 How to measure consistence.</u>

First of all the classical methods to determine Atterberg limits should be named. As wellknown <u>liquid limit</u> is mostly determined after Casagrande. This means that a brass-dish in which a moist soil is formed to give a particular form of two separate halves, is knocked in a standardized way until both halves flow together. This is done at several moisture contents. The results are plotted - moisture per centage against number of knocks. Liquid limit is the moisture content interpolated to belong to 25 knocks.

Lower plastic limit is determined by rolling a moist soil sample to form a string of ca 6 mm diameter. Rolling is performed on blotting paper, which is changed until the roll begins to break. At this moment water content is determined.

Another method to determine consistence on a somewhat comparable principle is maximum density determination using the Proctor-equipment. Here a soil sample is filled into a standard cylinder and compacted in a highly standardized way. After compaction bulk density and water content are determined. The procedure is repeated with several different water contents. Maximal density that is achieved at standard compacting action is a function of consistence of soil.

Of course the basic physical properties that describe soil consistence are those connected with the Coulombequation - as there are angle of internal friction and cohesion. There is a widespread literature on this item. So here the statement must do, that the simplest way to determine shear parameters is the socalled simple shearing test, in which the plane of failure is given by the apparatus. The triaxial method which allows the soil to break on its weakest planes is by far more complicated.
In the field first data including information on consistence might be obtained be using a shear vane. Sometimes the results of a penetrometer will be more useful if the apparatus is properly used and the evaluation of the results is done carefully.

Conclusions

The most important point seems to be, that the soil property "consistence" has two aspects: The first one is a property of the material without any relation to actual soil structure. It might be assessed by Atterberg limits as well as by angle of internal friction (φ) and cohesion (c). Therefore correlations between these two sets of methods might be found. They are sometimes depicted in textbooks.
The other one is a property of soil material plus structure. It is only to be measured in situ or at "undisturbed" samples. This second aspect is the one that regulates behaviour of soil in respect to loosening and compaction by natural soil development as well as by anthropogenic influences or activities. If it is tried to define both these aspects this seems to come out to give the Coulomb-equation

$$\tau = tg \cdot \varphi \sigma_n + c$$

in which φ and **c** are properties of the first aspect. τ is one of the second aspect brought by influence of normal stress σ_n.
Overall shearing resistence (τ) seems to be a relative ample definition of the property "consistence" - but of course it is neither complete nor the only one that is possible.

Number of blows of hammer/dm
Distance from origin (cm, m)

Depth in field (cm)												
0-10												
10-20												
20-30												
30-40												
40-50												
50-60												

Fig. 1

Schema of forces acting on particle or aggregate in contact with an other

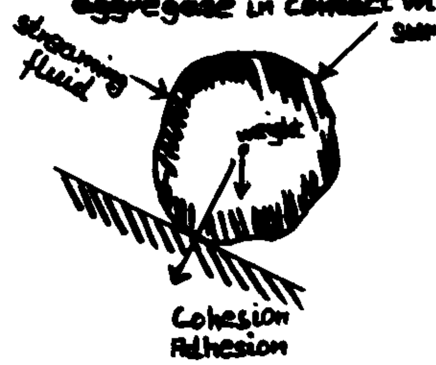

Fig. 2

Polygon of forces acting on a contact

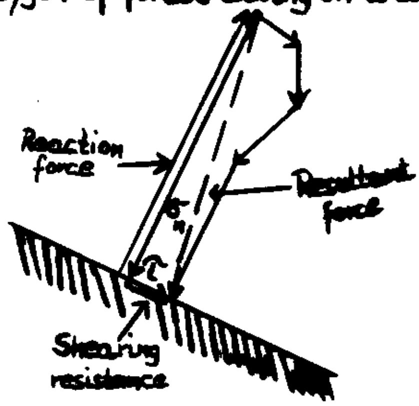

Fig. 3

Effect of surload on consistence

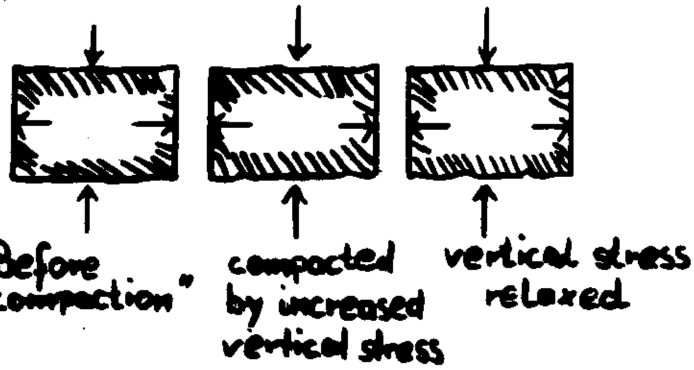

Fig. 5

Relation between pore volume and shearing resistence in sandy soils

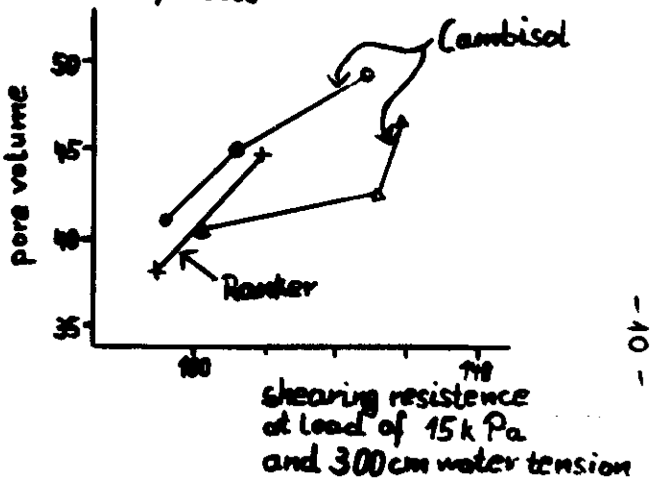

Fig. 4

compressibility characteristic