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Soil Classification Methodology: Critical Analysis

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Abstract: ***We know that the soil is a material that has a wide dispersion of characteristics tied, mainly to its granulometry, its mineralogical constitution, and its water percentage. For its identification, several researchers in the field, have proposed different types of classifications for several decades. The objective of the classification is to standardize the naming of soils for their identification. Hence, the relevance of a classification depends directly on the characteristics on which it was made. Many classification methods have been based on granulometric analysis and the Atterberg limits. But the ones compared to the others, present insufficiencies, being able to prove worthless, or even dangerous, if the characteristics on which they rest have not been studied precisely. The purpose of this study is to establish a critical inventory of soil classification methods most commonly used in engineering.***

Keywords: Classification method, Inventory, Characteristic, test, critical

1. Introduction

The classical data for investigation pegoligic are often presented in an uncomfortable format, so they are generally under-valued and underutilized by non-specialists in land use and management decision-making [1]. Although they have improved soil understanding and classi fi cation throughout the world, internationally recognized classi fi cation systems, such as soil taxonomy [2] and the global reference base [3] , so the systems (eg South African Working Group on Soil Classification, 1991) are of general utility. These classi fi cation systems use specialized terminology and language to classify and name soils. Their use requires considerable expertise and experience [4]. The knowledge of the field in place is the prerequisite for an adequate study of any civil engineering project (road, bridge, viaduct, dam, building ...). The best way to recognize a soil, suggests taking samples as much as possible intact for their analysis in an appropriate laboratory. However, the soil classification gives a uniform name to a group of soils, in which we find almost identical characteristics. But, whatever the concern of exactitude brought to the choice of an appellation, this one can never be enough to characterize completely the ground, it is thus essential to communicate in addition, the values of a sufficient number of characteristics. Hence the thorny issue of identification and classification of soils. The last decades have seen an increase in the importance and scope of soil science. Cataloging and taxonomic identification of soils has become a growing priority for a large number of countries. This is partly due to the recognition that soil security is as relevant a priority as issues such as water security [5]. Unfortunately, communication between these countries has not been managed in the same way as science, creating a series of soil classification systems that are sometimes niche, sometimes with similar terms that mean different things [6]. Identifying truly unique soil types in a different system is therefore a challenge because even though the globalization of soil surveys, non-standard descriptions and methodologies (eg, duplex soils in the Australian soil classification) are progressing still in smaller and regional soil classification systems. Land use requirements are becoming more complex and the demand for rational land use is increasing [7]. In the meantime, more and more conflicts and environmental risks are emerging [8]. These driving forces are making land and land management planning more and more important, which should lead to more and more reliable plans. The objective of this study is to obtain an abacus (inventory) of comparisons of soil classification methods. As Taylor has said: "A simple system of soil classification using easy identification methods and giving an approximate but fairly accurate distribution in groups or types of soils, is a great convenience for all common mechanical problems. soil. Preliminary studies of soils for the construction of motorways are an example of such problems. For practical reasons, in this study we have retained ten commonly used classification methods for the Engineer, namely the Classification of the Public Roads Administration; Atterberg classification; Massachusets Institute of Technology (MIT) classification; US HighwayResearch Road Classification; U.S.C.S. classification ; Terzaghi classification; Classification according to the Casagrande plasticity abacus; A.B.E.M. classification ; Hogentogole classification; Classification according to the Belgian name. We will thus describe and criticize each of these methods and make a comparison. Not to mention that the basis of all these classifications and granulometric analysis, as well as the knowledge of Atterberg limits. The rest of the document is organized into four sections. Section 1 is devoted to the theory on the identification technique of ... Section 2 deals with the methodology. Section 3 presents the results and discussion, while Section 4 presents the conclusion.

2. Theory of Identification Technique

Soil classification is carried out from the soil identification tests which make it possible to recognize them and to have an idea of their behavior. Nevertheless, in order to improve the local relevance and impact of soil survey data, the knowledge of local land users should be taken into account [10]. Local knowledge of soils is widely recognized for its practical value and contribution to the rational and sustainable management of soils [11]. It has been demonstrated in many countries and many that the integration of local soil knowledge into participatory soil surveys can solve practical problems and provide culturally acceptable solutions adapted to local contexts [12]. Some studies have found weak correlations between local and scientific classi fi cations [13], while others have reported good correlations [14]. This variation has often been attributed to differences in landscape structure in the areas studied. Many rural people are soil scientists [15] in the sense that their knowledge and understanding of the soil's morphological properties has proved to be a solid foundation for land use and management, at least on the scale of the soil. ground. The taxonomies of local vernacular classi fi cation systems are developed on the basis of descriptive soil morphological characteristics important to the user [16]. The main morphological properties of the soil, such as color and texture, are the main criteria for classification [17]. Distinctions between soils are determined by the perceptions, assumptions and needs of the workbook, as they are often not hierarchical diagrams [18]. This allows people to link the soils together in a way that they feel is appropriate for their needs [10]. For a scientific study these tests are, granulometric analysis and determination of Atterberg limits. We give below the principles. The interested reader may refer to the appropriate works.

2.1. Particle size analysis

When we observe a soil closely, we immediately notice that it is formed of particles of very varied sizes, ranging from pebbles of 10 cm and more, to ultra-clays of less than one micron. The purpose of the particle size analysis is to study the size of these particles and to measure the relative importance of each of the well-defined soil fractions: large elements, gravel, sand, silt, clay, etc. represents the grain size curve in semi-logarithmic coordinates whose abscissa is proportional to the logarithm of diameters of the particles and the ordinate proportional to the percentage of cumulative passers-by. (Figure 1). The family in which the curve is the most, gives the name of the soil. This semi-logarithmic representation offers the advantage of having families of uniform curves for soils having the same grain size distribution but different mean diameters of the grains. Granulometric analysis can be done either by sedimentation or by mechanical sieve analysis. In civil engineering, the use of mono-diameter grain size is very rare. The presence of particles of different sizes and often at different proportions plays an important role in the mechanical behavior of granular materials in the sense that the presence of different orders of grain size variables radically changes the arrangement of particles [19]. The macroscopic behavior being dependent on the network of contacts that is established between the grains, a modification of the arrangement of the latter also modifies the characteristics, both local and macroscopic, of a granular material.

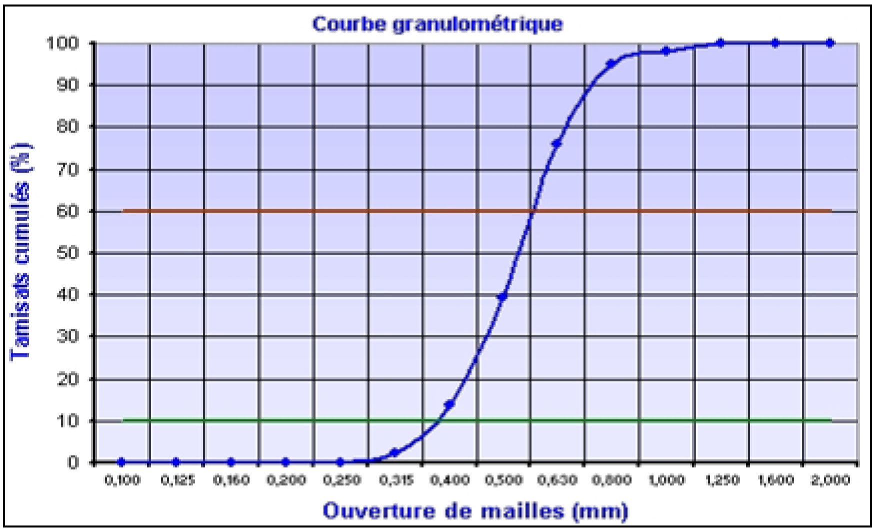

Figure 1: Granulometric curve (Degoutte, et al., 2009, pp17)

2.2. Atterberg limits

Plasticity, the value of which is preponderant in the appreciation of external forces, varies with the degree of humidity of the mixture. It is known that by gradually varying the water content, a clay may be in the solid, liquid, or plastic state. These various states of consistency are separated by very characteristic water contents. We use the Atterberg limits which are:

- The liquidity limit WL which separates the liquid state from the plastic state;
- The plasticity limit WP which separates the plastic state from the solid state;
- The withdrawal limit S.

a) Liquidity limit WL

This test makes it possible to terminate the resistance to soil flow, in terms of the relative volume of capillary pore size that it possesses. The liquidity limit WL is the water content (expressed in%) above which the soil behaves like a semi-liquid and flows under its own weight. It is determined by means of a cup, where a layer of clay is placed, and by repeated beating, a previously marked groove is closed, the number of strokes is counted, and the quantity of water is measured. The details are included in the appropriate books. The results of these measurements are also represented by a semi-logarithmic curve, whose numbers of strokes are in logarithmic scale and the water content in arithmetic scale. (Figure 2).

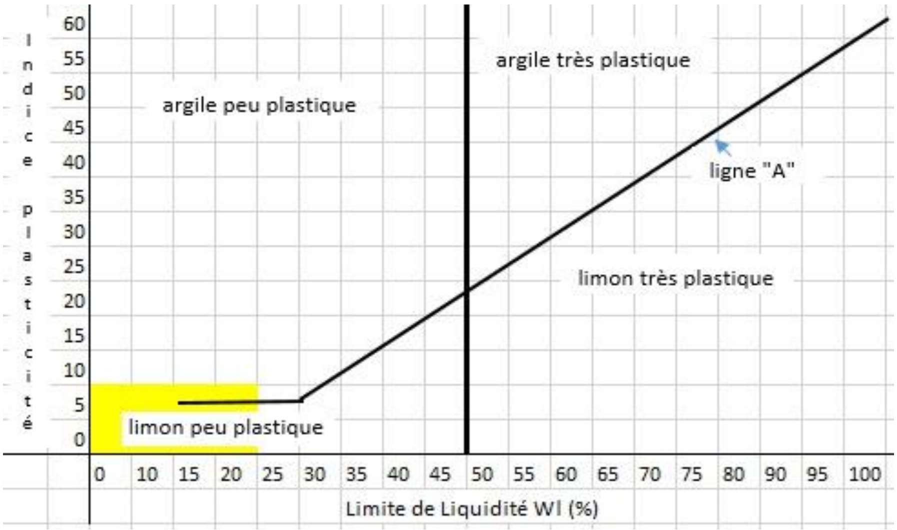

Figure 2: Liquidity Limit (Degoutte, et al., 2009, pp22)

b) WP plasticity limit

By definition, the plasticity limit WP is the water content (expressed in%) from which the soil is in the plastic state, for any content below this limit, the soil is either friable and powdery. To determine the plasticity limit, the spindle-shaped sample is rolled out and gradually thinned. The limit of plasticity WP is the water content (expressed in%) of the spindle which breaks into small sections of 1 to 2 cm in length.

c) Limit of withdrawal S (Serinage limita)

The shrinkage limit is the moisture content, expressed as a percentage by weight of dry matter weight, from which the volume of the earth's mass ceases to decrease when the moisture content decreases, and as to increase when the moisture content believes. Experience has shown that during the dissociation of a sufficiently moistened clay, this mass initially decreases exactly in proportion to the volume of the evaporated water, but that from a certain moment it keeps a constant volume while its weight continues to decrease. Its determination is made in a porcelain capsule of standardized dimensions. Of the two notions of limit of liquidity and limit of plasticity, one defines:

- **The plasticity index**

The IP plasticity index is the difference between the liquid limit WL and the limit of plasticity WP. It measures the extent of the field of plasticity of the soil and is of great importance in all the problems of road geotechnics. It is calculated by the relation: IP = WL – WP. Recall that Casagrande showed in studying American soils that there was a relation of form: IP = al-b Where for all soils with the same geological formation, we have $0.7 \leq a \leq 0.8$ and $13 \leq b \leq 17$. And for French and Spanish soils: $IP = 0.7W_L - 9$. The sands, in principle without cohesion, are free from plasticity index because IP = 0. Soils with strong cohesion have high values of plasticity index. Overall according to Atterberg; if IP <7: low plasticity; <IP <15: average plasticity and IP> 15: high plasticity.

- **Consistency and liquidity index**

The determination of the Atterberg limits makes it possible to get an idea of the structure of a natural soil of water content W by calculating its consistency index IC and its liquidity index IL given by the formulas: $IC = (W_L-W) / (W_L-WP)$; IL = (W-WP) / IP = 1- IC. Depending on the value of the consistency index IC, we have: 0 <IC <0.25 (pasty soil);0.5 <IC <0.75 (dull soil); 0.75 <IC <1 (medium hard soil) and IC> 1 (hard soil).

- **Compressibility Index**

It is empirically determined using SKEMPTON's formula $C_C = 0.0091 (W_L-10)$

- **Group Index**

It makes it possible to qualify a soil of very good when, IG is weak, of good enough and bad and that according to the formula: IG = 0.2a + 0.0005 ac + 0.01 bd .Where a, b, c, and d are defined as follows: If X, is the percentage of soil passing through the 80 micron sieve, we will have: If X <35 → a = 0; <X <75 → a = X - 35; X> 75 → a = 10. If X <15 → b = 0; <X <55 → b = X - 15; X> 55 → b = 10. If WL <40 → c = 0; 40 <WL <60 → c = WL -10; WL> 60 → c = 20If IP <10 → d = 0; <IP <30 → d = 20.

3. Soil classification methods and their criticisms

3.1 Inventory of some classifications

We give below the ten classification methods selected for this study.

a) Classification of the Public Roads Administration
b) Atterberg classification
c) Massachusetts Institute of Technology Classification (MIT)
d) US HighwayResearch Road Classification
e) U.S.C.S.
f) Terzaghi classification
g) Classification according to the Casagrande plasticity abacus
h) A.B.E.M. classification
i) Hogentogole Classification
j) Classification according to the Belgian name

3.2. Descriptions of classification methods and their criticisms

a) Classification of the Public Roads Administration

The Public Road Administration has adopted a ternary diagram to facilitate the designation of soils by the names of their main constituents. In this diagram, each of the three coordinate axes is relative to one of the grain size fractions referred to as sand, silt or clay. The diagram is divided into regions that each receive the name of a soil type. The three coordinates of a point represent the respective percentages of three fractions in a given soil and determine the type to which that soil belongs. For example, a soil with a complex granulometry of 20% of sand, 30% of silt and 50% of clay is represented by the point S. and classified as clay.

Criticism of the method

The diagram of the Public Roads Administration easily allows a classification, but it is not at all adapted to the case of gravels. Moreover, such a system based solely on the different proportions of sand, clay and silt, can lead to misunderstandings, because in a soil there is also the quantity of water (humidity) which is also a non-negligible factor; in addition there are ultra-clays of very small particle size as well as stones. So this classification system is very basic.

b) Atterberg classification

The classification of the Swedish agronomist Atterberg, is based essentially on the granulometry. It follows a geometric progression of reason 1/10. (Table 1)

Table 1: Atterberg classification based on granulometry.

Floor type	Dimensions	Floor type	Dimensions
Rockfill	More than 200 mm	Fine sand	From 0.2 mm to 0.02 mm
Pebbles	From 200 mm to 20 mm	Silt	From 20µ to 2µ
Gravel	From 20 mm to 2 mm	Clay	2µ to 0.2µ
Big Sand	from 2 mm to 0.2 mm	Ultra-clay	less than 0.2µ

Criticism of the method

This classification is older and deserves to be revisited nowadays as regards the definition of silt. Indeed below 6mm, grains are no longer visible to the naked eye and already has most of the time, properties that bring them closer to silt than sand. This analysis is very basic and does not take into account the physical properties of the very fine elements of soils that depend on many factors other than grain size.

c) MIT classification (Massachusets Institute of Technology)

Adopted by German standards, this classification follows a geometric progression of reason√ (10 & 10). (Table 2).

Table 2: MIT classification

Floor type	Dimensions	Floor type	Dimensions	Floor type	Dimensions
Stones	more than 63mm	Big Sand	2mm à 0.6mm	Clayey silt	20µ à 6µ
Gravel wholesale	63mm at 20mm	Medium sand	0.6mm à 0.2mm	Fine silt	6µ à 2µ
Medium gravel	20mm à 6mm	Fine sand	0.2mm at 0.006mm	Clay	2µ à 0.6µ
Fine gravel	6mm à 2mm	Silt	60µ à 20µ		

Criticism of the method

This classification is much more precise and more explicit than that of Atterberg because it contains several subgroups. It is very basic, it is only based on particle size without taking into account other factors.

d) US Highway Research Board Classification

It is based both on granulometry and plasticity and may seem a priori more interesting than the previous ones. It uses a simplified particle size analysis (2mm sieve, 0, 40mm and 80µ) as well as the liquidity limit and the plasticity index. 80µ sieving makes it possible to distinguish between fine soils (category A4 and A7) from grained soils (category A1, A2, A3) depending on whether the sieve is greater or less than 35% for clay soils (IP≥11, group A6 and A7). The value of the liquidity limit separates A1 (pebbles, gravel and sand) and A3 (fine sand), which are devoid of plasticity or nearly so, from group A2, which includes mixtures of gravel and silty or clayey sand. Group A2 is also divided into four (from A2-4 to A2-7) according to the same criterion as fine soils.

Criticism of the method

Apart from the particle size, this system gives details of the resistance to the flow of a soil (liquid limit) and the extent of the plasticity field of a soil (plasticity index). However, this classification is rather poorly applied to road soils that are very unequally distributed among the different categories.

e) Classification of the U.S.C.S (Unified soil classification system)

Inspired by the previous one, this classification is an improvement and was proposed in 1965 by the central laboratory of the bridges and roads of Paris (France). It is designated by a symbol whose first letter indicates the nature of the soil and the second its quality. Symbol indicating the nature of the soil (first letter of the total symbol)

G: soil whose main fraction consists of gravel; S: soil whose main fraction consists of sand; M: soil whose main fraction consists of silt; C: soil whose main fraction consists of clay; O: soil with a high organic matter content and Pt: soil whose main fraction consists of peat. Quality symbol (2nd letter of the total symbol)

It is :W: well graduated, that is of extended particle size, with a uniformity coefficient of less than 0. 25; containing grains of all sizes, none of which predominates. P: poorly graded, that is to say that the soil is relatively uniform, it contains grains of all sizes, but a group of grains of series

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size predominates or the soil has significant grain size gaps. H: high liquidity limit, high compressibility L: low liquidity, low compressibility; M: indicates a large silty fraction in coarse soil; C: indicates a large fraction in coarse soil.For further details refer to specific works.

Criticism of the method
This classification is the most explicit of all, it gives information on the granulometry, the content in fines while insisting on the plasticity, but it has the disadvantage of not deepening on the humidity.

f) Terzaghi classification

Terzaghi proposed the following classification based on liquidity limits. (Table 3).

Table 3: Terzaghi classification

Class	Limits of liquidity	
	Lower value	Higher value
0	10	14.2
1	14.2	20
2	20	28.4
3	28.4	40
4	40	56.8
5	56.8	80
6	80	113.6

The values of the liquidity limits are deduced from each other by multiplication by 2. Terzaghi characterizes the land by the simultaneous consideration of three limits (liquidity, plasticity and withdrawal) and the classes by decreasing order of liquidity limits. He draws a diagram.

Criticism of the method
This classification has a major flaw to give no indication of the grain size, being limited only to the state of liquidity of the soil.

g) Classification according to the Casagrande plasticity abacus

Casagrande (Casagrande, 1948) has, according to the limits of liquidity and plasticity of soils, given a nomenclature whose use gives precision on the different groups of soils. (Figure 3)

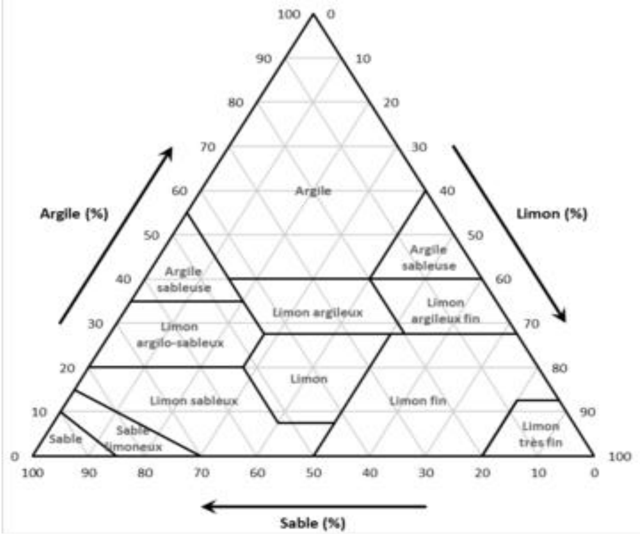

Figure 3: Abacus of Casagrande (Degoutte, et al., 2009, pp23)

In fact, we can classify cohesive soils, according to their general characteristics and their physical characteristics, into three large groups: organic clays of high, medium or low compressibility; organic clays and organic silts. In the Casagrande plasticity abacus, the ordinates represent the plasticity index IP and the abscissae the corresponding liquidity limit. It is divided into six regions, three above line A and three below. The group to which a given soil belongs is determined by the name of the region which contains the representative point of the ground of IP and WL coordinates.

Criticism of the method
This classification is rather weak and more incomplete than the previous ones, it is insufficient in most cases, because the natural soils are heterogeneous mixtures. Also the limits of Atterberg are directly influenced.

h) Soil classification according to A.B.E.M

The soil mechanics commission of the A.B.E.M (Belgian Association for the Study of Materials) has adopted a simple classification directly indicated by the plasticity index. (Table 4).

Table 4: Soil classification according to A.B.E.M

Dominant character	Plasticity index
Sandy	I_P <15%
Slimy	5% <I_P<25%
Clayey	I_P >15%

Criticism of the method
Very basic classification because the plasticity index only indicates the range of water content for which a coherent soil has plastic properties.

i) Hogentogle Classification

This classification defines a clay soil according to the place it occupies according to its limit of liquidity and the index of plasticity. It should be noted, however, that the lines corresponding to the various control soils used by Hogentogle are in line with the zones.

Table 5: Hogentogle Classification

CLASSE	Définition	Caractéristique	Sous-classe
A	Sols fins	$D_{max} \leq 50$ mm et passant à 80 µm > 35 %	A1 à A4 selon VBS ou Ip
B	Sols sableux et graveleux avec fines	$D_{max} \leq 50$ mm et passant à 80 µm ≤ 35 %	B1 à B6 selon VBS ou Ip et tamisat
C	Sols comportant des fines et des gros éléments	$D_{max} > 50$ mm et passant à 80 µm > 12 % ou passant à 80 µm ≤ 12 % + VBS > 0,1	30 sous-classes selon VBS, Ip et tamisat à 50 mm
D	Sols insensibles à l'eau avec fines	VBS ≤ 0,1 et passant à 80 µm ≤ 12%	D1 à D3
R	Matériaux rocheux	voir la norme NF P 11-300	
F	Sols organiques et sous-produits industriels	voir la norme NF P 11-300	

D_{max} = diamètre pour lequel 95 % des grains du sol ont une dimension inférieure (soit D_{95} si la courbe granulométrique est disponible, sinon appréciation visuelle de la dimension des plus gros éléments).

Zone I: Powdery soil, zero or negative relative plasticity; Zone II: Friable soil, very weak relative plastic; Zone III: Soil little plastic, low relative plasticity; Zone IV: Moderately plastic soil, average relative plasticity; Zone V: Very plastic soil, strong relative plasticity; Zone VI: indeterminacy.

- **Criticism of the method**

Hogentogle seems to solve the problems encountered during the previous classification but introduces a zone of indeterminacy that brings us to new difficulties.

c) Classification of soils according to the Belgian name

In this classification, the nomenclature of the different soils is based on the particle size composition, the plasticity index, the calcareous and organic contents. The organic and calcareous content implies a designation qualifier. As shown in Tables 5 and 6.

Table 6: Granulometric fractions

Fraction	Lower limit mm	Grain diameter	Upper limit mm
I		Dg	≤0.002
II	0.002 <	dg	≤0.06
III	0.06 <	dg	≤0.2
IV	0.2 <	dg	≤2
V	2 <	dg	≤20
VI	20 <	dg	

- **Criticism of the method**

This classification is close to the U.S.C.S. In fact, it is in view of its insufficiency as regards the water content that the Belgian engineers were brought to the U.S.C.S. classification

Table 7: Determination of organic and calcareous soils

% Organic matter content	Qualification
50 à 10 10 à 5 5 à 1	Very peaty Peaty Little peaty or unorganized
% Of calcareous matter	Qualification
25 à 10 10 à 5 5 à 2	Very calcareous-marly (clay soil) Calcareous Little calcareous

Table 8: Summary of typological strengths and limitations of different methods

Classification methods	The advantages of the classification	Limitations on soil typology
Classification of the Public Roads Administration	The designation of soils by the names of their main constituents, namely: sand, silt or clay.	It allows easy classification, but it is not at all suitable for the case of gravel.
Atterberg classification	It is based essentially on particle size.	She has a problem regarding the definition of silt. Indeed below 6mm, grains are no longer visible to the naked eye and already has most of the time, properties that bring them closer to silt than sand.
Massachusetts Institute of Technology (MIT) Classification	It is much more precise and more explicit than that of Atterberg, because it contains several subgroups.	It is very basic, it is only based on particle size without taking into account other factors.
US HighwayResearch Road Classification	It is based both on granulometry and plasticity and may seem a priori more interesting than the previous ones.	It is rather badly applied to road soils that are very unequally distributed among the different categories.
U.S.C.S. classification	It is the most explicit of all, it gives information on the granulometry, the content in fines by insisting on the plasticity.	It has the disadvantage of not deepening on the soil moisture.
Terzaghi classification	It is based on liquidity limits namely: liquidity, plasticity and withdrawal.	It gives no indication of the particle size,
Classification according to the Casagrande	It is based on the limits of liquidity and plasticity of the soil. It groups soils	It is rather weak and more incomplete than the previous

plasticity abacus	into three major groups: organic clays of high, medium or low compressibility; organic clays and organic silts.	ones, it is insufficient in most cases, because the natural soils are heterogeneous mixtures.
A.B.E.M. classification	It is based on a direct indication of the plasticity index.	It is very basic because the plasticity index only indicates the range of water content for which a coherent soil has plastic properties.
Hogentogole classification	It defines a clay soil according to the place it occupies according to its limit of liquidity and the index of plasticity.	It seems to solve the problems encountered during the previous classification but introduces a zone of indeterminacy of the soil which brings us to new difficulties.
Classification according to the Belgian name	In this classification, the nomenclature of the different soils is based on the particle size composition, the plasticity index, the calcareous and organic contents.	It is close to the U.S.C.S. In fact, it is in view of its insufficiency as regards the water content that the Belgian engineers were brought to the U.S.C.S. classification

4. Conclusion

All soil classification systems that are based solely on grain diameter are capable of misunderstanding because the physical properties of very fine soil elements depend on many factors other than grain size. This is why an additional indication of the limits of liquidity, plasticity, organic matter content and hardness is essential. Not to mention that the suggested names (such as silt or clay) refer only to the particle size and not the mineralogy, geology ... Hence, the classification of the soil based solely on particle size is suitable for gravel and sand. It is insufficient for clays and silts etc. It is inadequate for peat and marl because there is no relation between their grain size and their properties. The undisputed U.S.C.S. (UnifiedSoil Classification System) classification to date takes into account several factors at once. It is the newest and most used because it is the improved form of all others.

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