Soil classification: a proposal for a structural approach, with reference to existing European and international experience

Classification des sols: une proposition pour une approche structurelle, tenant compte de l'expérience Européenne et internationale

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ABSTRACT: Most soil classification schemes, used in Europe and all over the world, are of the basic type and are mainly based upon particle size distribution and Atterberg limits. Degree of harmonisation is however moderate as the classification systems are elaborated and / or adapted for typical soils related to the country or region considered. Proposals for international standardisation have not yet resulted in ready for use practical classification tools. In this paper a proposal for structural approach to soil classification is given, and a basic soil classification system is elaborated.

RÉSUMÉ: La plupart des méthodes de classification des sols, en Europe et dans le monde entier, sont du type de base et font appel à la distribution des particules et aux limites Atterberg. Le degré d'harmonisation est cependant modéré, les systèmes de classification étant élaborés et / ou adaptés aux sols qui sont typiques pour le pays ou la région considérée. Les propositions pour normalisation internationale n'ont à ce point pas encore résulté dans des outils pratiques de classification. Cette note propose une approche structurelle pour la classification et un système de classification de base est élaboré.

1 INTRODUCTION

1.1 *General versus regional soil classification*

Soil classification seems to be a topic where it is hard to find the greatest common denominator of existing national systems. Most classification systems are however based upon particle size distribution and Atterberg limits, as basic tools.

It might not prove difficult to develop a general classification scheme, which is apt to conceal the different criteria put forward for "standard" soiltypes (sand, clay, silt, ...). It is however not possible to differentiate a general classification scheme for particular differences in soils occuring in countries all over the world (e.g. coarse silt in Spain, loam in Belgium, France). Instead of creating a system that intends to include most of these particularities, or just bluntly denying their existence, one should create a multi-layered system. This system would consist of a basic international soil classification system, with a general outline of basic soil classification and an additional optional regional classification system.

1.2 *Soil classification versus soil description*

Some classification schemes (ASTM, BS) also include visual description (for organic soils).

In the author's opinion one should not mix a purely objective scheme based upon laboratory test results with the more subjective appreciation by visual description. That does not mean that visual description should be simply put aside, but instead of mixing up with the laboratory test results based classification visual description would form one more layer of the global system. As visual soil description is complementary to soil classification on a basic level, it could be put under the heading of basic soil classification.

1.3 *Basic soil classification versus extended soil classification*

Soil classification can be performed on different levels and the ongoing trend is to incorporate more and more geotechnical parameters. Therefore it's necessary to first indicate the different levels of classification to be considered.

On the one hand we have a basic soil classification, as in most existing soil classification systems, on the other hand we have an extended soil classification which goes beyond the classical approach and also takes into account geotechnical properties of the soil. Extended soil classification includes, density, watercontent, strength properties, ... and needs undisturbed samples for testing.

In the author's opinion the added value of an extended soil classification is not obvious, as appreciation of geotechnical characteristics such as shear strength is difficult to put in general rules, and should be left to engineering judgement. However in the proposal multi-layered system the extended soil classification system can be fully incorporated.

1.4 *Soil classification from field tests*

Soil description out of results of field tests (mainly CPT) is also a much covered item and one might consider it useful to incorporate soil description based upon field testing as an item in the classification system.

2 MULTI-LAYERED SOIL CLASSIFICATION SYSTEM

A multi-layered soil classification system could be subdivided in following sections

2.1 *Basic soil classification (BSC)*

Basic soil classification gives a first assessment of the nature of the soil considered, and does not need undisturbed samples. It consists of two different parts, which are complementary, but may stand on their own:

a. visual soil description (VSD)
b. basic soil classification scheme (BSCS) with a pure classificational approach, and based on the results of following soil classification tests: particle size distribution, Atterberg limits, organic content and calcareous content.

2.2 *Extended soil classification*

Soil classification based on results of soil classification tests and determination of more specific geotechnical parameters (density index, water content, strength properties, ...).

2.3 *Regional soil classification*

Optional addendum to the basic and extended soil classification; relates to national soil classification procedures in order to give information on typical aspects for classification of soils which might not be included in general soil classification.

2.4 *Soil classification from field tests*

Optional addendum to the above mentioned classification systems. Soil classification form field tests is not based on description or testing of samples, but emanates from interpretation of field test results. Well known is the soil classification from CPT-testing, using e.g. charts developed by Robertson et al.

3 PROPOSAL BASIC SOIL CLASSIFICATION SCHEME

3.1 *Introduction*

After a study of different European classification systems (from UK, Germany, France, Belgium, Netherlands) and the ASTM classification system a basic soil classification scheme (BSCS) was developed.

The BSCS is based on particle size distribution, Atterberg limits (including plasticity chart) and organic and calcareous matter.

3.2 *Parameters of soil classification*

3.2.1 *Particle size distribution*

3.2.1.1 Subdivision in particle size categories

For classification purposes 3 categories of soils are considered:

- coarse grained soils less than 10% particles < 60 μm
- fine grained soils more than 40% particles < 60 μm
- mixed grained soils between 10% and 40% particles < 60 μm

For coarse grained soils only particle size distribution is considered in the soil classification scheme. For fine and mixed grained soils both particle size distribution and Atterberg limits are considered.

Note: the value of 60 μm can be replaced by the corresponding value of 63 μm if only sieving was performed for particle size distribution.

3.2.1.2 Main particle size fractions and subdivisions

The main particle size fractions and subdivisions (based on the internationally accepted 2,6 system) are as follows:

Table 1. Main particle size fractions.

soil fraction	qualifying term	particle size (mm)
boulders	–	d > 200
cobbles	–	60 < d ≤ 200
gravel	coarse	20 < d ≤ 60
	medium	6 < d ≤ 20
	fine	2 < d ≤ 6
sand	coarse	0,6 < d ≤ 2
	medium	0,2 < d ≤ 0,6
	fine	0,06 < d ≤ 0,2
silt	coarse	0,02 < d ≤ 0,06
	medium	0,006 < d ≤ 0,02
	fine	0,002 < d ≤ 0,006
clay	–	d < 0,002

3.2.1.3 Grading of the soil

Criteria for appreciation of the grading of the soil are expressed as limiting values of coefficient of uniformity

$$C_u \left(C_u = \frac{D_{60}}{D_{10}}\right) \tag{1}$$

and coefficient of curvature

$$C_c \left(C_c = \frac{{D_{30}}^2}{D_{10} - D_{60}}\right) \tag{2}$$

If however D_{10} is less than 2 μm the coefficient of uniformity and of curvature will not be calculated, and no evaluation of the grading of the particle size distribution will be given:

gravel

- well graded $C_u > 4$ and $1 < C_c < 3$
- poorly graded $C_u \leq 4$ and/or $C_c < 1, C_c > 3$

sand

- well graded $C_u > 6$ and $1 < C_c < 3$
- poorly graded $C_u \leq 6$ and/or $C_c \leq 1, C_c \geq 3$

3.2.2 *Atterberg limits*

3.2.2.1 Plasticity chart

The division of fine soils is made on basis of the relation between liquid limit and plasticity index, as proposed by Casagrande. On the extended plasticity chart the A-line represents the borderline between clays and silts.

A soil is named clay when I_p is not less than 7. In the plasticity chart the soil plots on or above the A-line. A soil is named silt when I_p is less than 0,73 (w_L – 20) and / or less than 4. In the plasticity chart the soil plots under the A-line.

In the hatched area – for I_p values between 4 and 7 – the soil is given a double name, clay or silt.

3.2.2.2 Liquid limit

Degree of plasticity of fine grained soils is given in function of liquid limit value:

- low plasticity $w_L < 35\%$
- intermediate plasticity $35\% \leq w_L < 50\%$
- high plasticity $50\% \leq w_L < 70\%$
- very high plasticity $70\% \leq w_L < 90\%$
- extremely high plasticity $w_L \geq 90\%$

3.2.3 *Organic content*

Determination of organic content is not harmonised and different methods exist, resulting in a wide scatter of adopted limiting values. Moreover the appreciation of organic content in different countries is relative to the maximum values of organic content encountered in those regions. The French practice to distinct 4 classes, with addition of a fifth class for peat soils is adopted:

- inorganic OC ≤ 3%
- slightly organic 3% < OC ≤ 10%
- moderately organic 10% < OC ≤ 30%
- highly organic 30% < OC ≤ 50%
- peat OC > 50%

3.2.4 *Calcareous content*

The remark formulated in § 3.2.3 for determination and appreciation of organic content is also valid for calcareous content.

It should also be noted that in existing classification schemes criteria for calcareous content result in a denomination with a more descriptive background (limestone, marl), rather than a comparative denomination (slightly, moderately). It seems however more appropriate to stick to the comparative approach in the pure classificational approach:

- not calcareous CC ≤ 3%
- slightly calcareous 3% < CC ≤ 10%
- moderately calcareous 10% < CC ≤ 30%
- highly calcareous CC > 30%

The denomination with a more descriptive background, which is often linked with geological features, will in most cases be covered by the regional soil classification.

4 PROCEDURE FOR CLASSIFICATION

4.1 *Preliminary classification*

Classify the soil as coarse grained, fine grained or mixed grained according to § 3.2.1.1. Identify whether the soil is organic and / or calcareous.

4.2 *Classification of coarse grained soils*

Classify the soil as sand, gravel, cobbles or boulders on basis of the main particle size fractions according to § 3.2.1.2.

For distinction between the main fractions the relative dominancy principle may be adopted. This means that when a soil is differentiated between two main particle size fractions, the dominancy of either of these fractions shall be regarded in terms of the particle size range covered by the fractions considered. For distinction between gravel and sand e.g. the dominancy of the gravel or sand fraction shall be investigated in the particle size range 0,060 mm – 60 mm, using the appropriate criteria.

For selecting appropriate criteria a dominancy ratio is introduced: a soil fraction A is considered dominant with respect to a fraction B, when the ratio of these fractions is greater than 2:

- ratio $\frac{A}{B} > 2$ soil is classified as A (principal name)
- $0,5 \le$ ratio $\frac{A}{B} \le 2$ soil is classified as A-B mixture
- ratio $\frac{A}{B} < 0,5$ soil is classified as B

The same principle is to be adopted for attributing the qualifying terms coarse, medium and fine within each fraction. The fraction accompanying the dominant fraction will be included in the classification scheme according to the percentage present; following descriptive terms are to be added:

- gravely/sandy/silty/clayey if the relevant fraction is greater or equal to 15 %
- very gravely/sandy/silty/clayey if the relevant fraction is greater or equal to 30%

The grading of the soil is qualified according to the values of C_u and C_c given in § 3.2.1.3.

4.3 *Classification of fine grained soils*

Fine grained soils are classified as silts or clays according to the plasticity chart (§ 3.2.2.1). The degree of plasticity of fine grained soils is based of liquid limit values (§ 3.2.2.2).

Silts or clays may be qualified as sandy or gravely, depending on the importance of the coarse present. Following descriptive terms are to be added:

- gravely/sandy if the relevant fraction is greater or equal to 15%
- very gravely/sandy if the relevant fraction is greater or equal to 30%.

4.4 *Classification of mixed grained soils*

Mixed grained soils are classified according to main particle size fractions for the coarse grained fractions, and plasticity chart for the fine grained fractions.

Classification of coarse grained and fine grained portion of the soil is performed according to § 4.2 en 4.3, joined in a double name. The way the names are joined is depending on the dominancy ratio of coarse versus fine fractions:

- ratio $\frac{\text{coarsefraction}}{\text{finefraction}} > 2$

  denomination coarse fraction with denomination fine fraction

- $2 \le$ ratio $\frac{\text{coarsefraction}}{\text{finefraction}} \le 0,5$

  → greater coarse fraction

  denomination coarse fraction and denomination fine fraction

  → greater fine fraction

  denomination fine fraction and denomination coarse fraction

- ratio $\frac{\text{coarsefraction}}{\text{finefraction}} > 0,5$

  denomination fine fraction with denomination coarse fraction

  e.g. poorly graded coarse sand with clay of low plasticity

5 WORKED EXAMPLES

Examples are given of soil classification of coarse, mixed and fine grained soils, including 2 typical examples where regional soil classification is complementary to general soil classification.

Classification is performed according to the Belgian classification scheme (based upon grading, plasticity index, organic and calcareous content) as an example of regional soil classification, and the proposed basic international soil classification system BSCS.

As a reference also the ASTM classification is given. For each example results of particle sizing, Atterberg limits and organic (OC) and calcareous content (CC) are given. When one or more of the soil characteristics could not be determined, the summary of test results indicates ND (not determined). The tables with the results of particle sizing refer to the main particle size fractions and subdivisions given in § 3.2.1.2.

Following symbols are used in the tables:

- Fraction IVa : coarse gravel
- Fraction IVb : medium gravel
- Fraction IVc : fine gravel
- Fraction IIIa : coarse sand
- Fraction IIIb : medium sand
- Fraction IIIc : fine sand
- Fraction IIa : coarse silt
- Fraction IIb : medium silt
- Fraction IIc : fine silt
- Fraction I : clay

5.1 *Example of coarse grained soil*

5.1.1 *Test results*

Results of particle sizing (percentages per fraction, and uniformity indexes), Atterberg limits and organic and calcareous content:

Table 2. Fractions coarse grained soil.

IVa	IVb	IVc	IIIa	IIIb	IIIc	IIa	IIb	IIc	I
-	-	-	1.2	37.7	58.6		2.5 < 63 µm		

$C_u = 1.7$ $C_c = 1.1$
w_L = ND w_P = ND I_P = ND
OC = 0.1% CC = 8.7%

5.1.2 *Classification*

- ASTM poorly graded sand
- Belgian CS slightly calcareous sand
- BSCS slightly calcareous, poorly graded medium to fine sand

5.2 *Example of mixed grained soil*

5.2.1 *Test results*

Results of particle sizing (percentages per fraction, and uniformity indexes), Atterberg limits and organic and calcareous content:

Table 3. Fractions mixed grained soil.

IVa	IVb	IVc	IIIa	IIIb	IIIc	IIa	IIb	IIc	I
-	-	-	1.0	40.2	29.7	0.8	4.3	2.6	21.4

C_u = ND C_c = ND
$w_L = 32.3\%$ $w_P = 15.6\%$ $I_P = 16.7\%$
OC = 0.8% CC = 29.2%

5.2.2 *Classification*

- ASTM clayey sand
- Belgian CS marl
- BSCS moderately calcareous, medium to fine sand with clay of low plasticity

5.3 *Example of fine grained soil*

5.3.1 *Test results*

Results of particle sizing (percentages per fraction, and uniformity indexes), Atterberg limits and organic and calcareous content:

Table 4. Fractions fine grained soil.

IVa	IVb	IVc	IIIa	IIIb	IIIc	IIa	IIb	IIc	I
-	-	-	-	0.9	36.2	43.8	5.5	1.3	12.3

C_u = ND C_c = ND
w_L = 35.8% w_P = 22.3% I_P = 13.5%
OC = 2.2% CC = 10.7%

5.3.2 *Classification*

- ASTM lean clay with sand
- Belgian CS calcareous, slightly organic sandy loam
- BSCS moderately calcareous very sandy clay of intermediate plasticity

6 SOIL CLASSIFICATION FILE

For practical application of the proposed multi-layered soil classification system the creation of soil classification files is proposed.

An example of such a classification file is given in the table below:

Table 5. Example of classification file.

classification type	reference	classification
soil classification from field tests	CPT Roberson (1886)	sandy silt to clayey silt
a) basic soil classification – visual description	ISO (1996)	silt with clay seams
b) basic soil elastification – BSCS	Van Alboom (2001)	slightly organic sandy clay of intermediate plasticity
extended soil classification	ISO (1996)	not performed
regional soil classification	Belgium - BGGG (1998)	sandy loam

7 CONCLUSIONS

In this note a structural approach to soil classification is proposed. The multi-layered system gives the opportunity to combine one internationally acknowledged basic soil classification scheme (BSCS) with regional classifications systems, which may draw the attention to typical soils which may not be covered by the BSCS.

In the examples of §5 e.g. loam and marl are soils which are not covered as such by the BSCS, and may need some further investigation by the engineer.

The multi-layered system also (optionally) includes soil classification from field tests, visual soil description and extended soil classification, so that by reading the soil classification file one gets an overview of different approaches of soil classification. For implementation of the multi-layered system is needed:

- a reference international basic soil classification system; the ISSMGE might taken herefore the necessary initiative (as for reference test procedure for CPT)
- a reference procedure for visual soil description (eventually taken from ISO or ASTM)
- a reference procedure for extended soil classification
- registration of regional soil classification systems by ISSMGE; national members could provide full documentation of these regional systems, which can be validated by ISSMGE and put into a general classification date base.

There is still a way to go to meet the requirements for providing practical tools for international soil classification. This note is merely a first attempt for creating a classification system that might be of practical use for engineers and soils all over the world.

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