A concept of a database for results of laboratory tests on soil and rock

Résultats des tests en laboratoire pour des sols et des roches

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ABSTRACT

An important element of geotechnical calculations are parameters for the quantification of the mechanical and hydraulic properties of soil and rock. To establish the ground properties it is not only necessary to perform field and laboratory tests for the actual site but also to take into account experience gathered with similar projects and ground conditions. This is also stressed in Eurocode 7 *Geotechnical design* in which the term "comparable experience" has particular significance and in which it is stated that "the selection of characteristic values for geotechnical parameters shall be based on results and derived values from laboratory and field tests, complemented by well-established experience". Therefore a database for the results of laboratory tests is a useful and highly necessary tool. This paper gives an overview of a concept for a database of common mechanical data for soil and rock. The aim of the proposed concept is the standardization of the database and the consideration of all important information so that the data can be used for a variety of purposes. The most important feature of the database is the introduction of reliability classes which will enable future users to assess the data objectively.

RÉSUMÉ

Les paramètres de quantification des propriétés méchaniques et hydrauliques des soles et des roches sont des éléments importants pour les calculs géotechniques. Afin d'établir les propriétés du sous-sol du site en question, il ne suffit pas de faire des tests en laboratoire et in-situ, mais de prendre aussi en compte l'expérience faite dans des projets semblables présentant les mêmes conditions de sous-sol. C'est aussi ce que demande l'Eurocode 7 "Geotechnical design" dans lequel le terme d'expérience comparable, revêt une signification particulière et dans lequel est stipulé que la séléction des valeurs caractéristiques pour les paramètres géotechniques doit être basée sur des résultats et des valeurs acquises en laboratiore et in-situ, le tout enrichi par une expérience fondée. C'est pourquoi une banque de données des résultats obtenus lors des tests en laboratoire, est un outil practique et indispensable. Cet article donne un aperçu d'une conception de banque de données générale des soles et des roches. L'intention du projet proposé est la standardisation de la base des données et la prise en considération de toutes les informations importantes dans l'utilisation des données, quels que soit leurs buts. La caracteristique innovante de la banque de données est l'introduction des classes de fiabilité, lesquelles offriront à ses futurs utilisateurs une classification objective des données.

Keywords: Database, laboratory tests

1 INTRODUCTION

A realistic evaluation of the properties of soil and rock forms the basis of the economic and safe design of any structure. A variety of information needs to be considered in order to obtain the required parameters of the different soil and rock layers. Some of the most important information is listed below.

- Area: geographical location, topology, hydrology and geology
- Structure: type of structure (building, dam, slope, etc.), function, main dimensions, loads, foundation depth
- Subsoil layers: description of soil and rock layers, results of site investigations, geological cross-sections
- Laboratory tests: classification, compaction, permeability, compressibility, shear strength
- Interaction: simulation and monitoring of the interaction between subsoil and structure.

The results of laboratory tests play an important role in the process of evaluating subsoil parameters. A typical feature of many geotechnical projects is that only very small number of samples of the subsoil can be tested in the geotechnical laboratory. That is why the data basis is often not large enough for a statistical evaluation and it is subsequently necessary to compare the results with the values of similar subsoil samples. A collection of test results can be very useful for this purpose.

Practice in Germany is characterized by the use of separate data pools by different institutions and companies. There is no common standard available to provide a framework for sharing and collating the values of soil and rock parameters. The various concepts for databases that have been developed depend on a particular corporate structure and the objective of the data pool.

A further motivation for the development of the database comes from Eurocode 7 *Geotechnical design* - Part 1 *General rules* (EC 7-1). The term "comparable experience" has

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particular significance in EC 7-1. It is defined as “documented or other clearly established information related to the ground being considered in design, involving the same types of soil and rock and for which similar geotechnical behaviour is expected, and involving similar structures. Information gained locally is considered to be particularly relevant”. The term is to be found in each section as comparable experience must be taken into account in all geotechnical designs. Comparable experience has a particular part to play in the specification of the characteristic ground parameters used in calculations. It is stated in EC 7-1 that “the selection of characteristic values for geotechnical parameters shall be based on results and derived values from laboratory and field tests, complemented by well-established experience”.

While a great deal of experience on the geology of different locations in Germany is available in the form of geological maps which have been compiled over many decades owing to legal regulations, no such pool of data has yet been compiled from laboratory tests on soil and rock. Ground investigations and laboratory tests on soil and rock are expensive so that only the minimum number of investigations stipulated is ever performed. In such situations geotechnical engineering consultants will try to check the few test results available for a project against comparable experience when specifying soil parameters.

The following objectives were focused on during the development of a model for a database:

1.) Development in the first phase is limited to the results of laboratory tests.
2.) The emphasis is on testing soil samples.
3.) The data model should enable comprehensive storage of the results of routine tests.
4.) The model should also be sufficiently detailed to enable the boundary conditions in sophisticated specialized tests to be taken into account to an adequate extent.
5.) The data model must ensure that it is possible to deal with practical projects and to evaluate the data scientifically.
6.) A standard should be defined to facilitate the exchange of data.
7.) Reliability Classes should be introduced, which will enable future users to assess the data objectively.

As a first step, the data structure for selected types of test were developed and tested. Rules for the structure of the data model as a whole were then derived on the basis of the results of discussions on the implementation of the pilot examples. It is intended for the data models to be made publicly available for discussion. The first results are reported in this paper.

2 CONCEPT OF THE DATABASE

2.1 *Fundamental considerations*

Each laboratory test is characterized by a series of steps, each of which can be described in terms of the instruments used and the test results. Laboratory test results are generally documented in logs and are recorded in the units in which they are displayed by the instrument. In addition, descriptive information such as the date, time, operator etc. are also recorded.

- Information on the test method used that cannot be described numerically is documented in the form of written information on the test method, device and test procedure.
- Measurements or readings are taken and recorded during the test.
- The test results subsequently used in diagrams and other evaluations are calculated from the measurements or readings by means of an algorithm (translation).
- Coefficients are obtained by evaluating each test. These are the test parameters used to numerically describe a test or a stage in a test.
- Finally, the geotechnical parameters are obtained by interpreting several tests or the individual stages of tests.

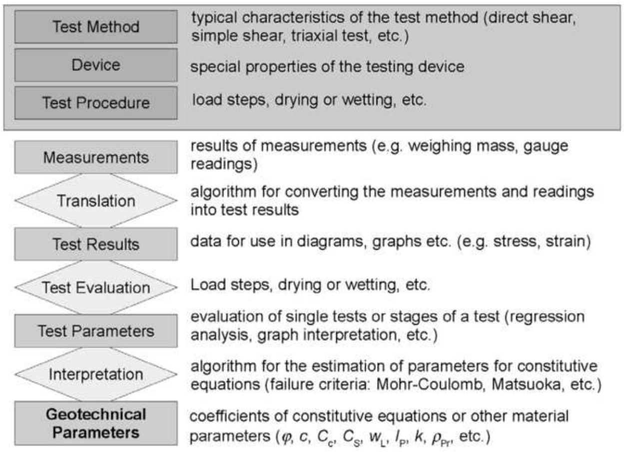

Figure 1: Data and information on laboratory tests

Possible applications are the representation of tests in diagrams, in publications and reports on experiments. Parameters of special test stages - e.g. the maximum shear stress coefficients of constitutive relations, classification or compaction values may also be calculated.

Each geotechnical laboratory test can be described by means of the systematic approach shown in fig. 1. The approach is explained below, using direct shear tests by way of an example.

- Test method: Several direct shear tests are performed at different normal stresses.
- Device: There are different types of shear box or annular shear apparatus. The test result can be affected above all by the way in which the load is generated (stress- or strain-controlled) and the way in which the shear cells are supported.
- Test procedure: Rate of shear deformation, degree of preliminary loading, information on wetting, etc.
- Measurements and readings: Output of the devices measuring force and distance.
- Translation of readings: Algorithms for calculating the shear stress (shear force divided by total area of specimen), etc.
- Test results: Normal and shear stress, shear displacement, settlement.
- Test evaluation: Representation in diagrams, mathematical rules for interpretation, e.g. regression equation (Kondner’s hyperbolic law, etc.), algorithms to calculate the failure value, the critical shear stress and the residual shear stress.
- Test parameters: Shear stress in the failure state, in the critical state and at the residual shear strength, coefficients of the mobilization function, angle of dilatancy, void ratio and degree of saturation.
- Interpretation: Failure criteria.
- Geotechnical parameters: Angle of shearing resistance, cohesion.

2.2 *Reliability classes*

Geotechnical parameters cannot be compared with other results without further information on the testing conditions.

For example, the values of the shear parameters obtained in direct shear tests differ from those obtained in triaxial tests. That is why it is necessary to incorporate information about boundary and testing conditions. Often it is not possible to quantify all influences. A description of the test device and the boundary conditions within the laboratory (climate, date, time, stuff, etc.) can give interesting hints for further interpretations.

Geotechnical parameters are stored in the database not the test parameters or all information about the tests. However, to enable the quality of the data to be evaluated and detailed interpretations to be performed in spite of this, each set of data is assigned to a reliability class. There is no generally valid, objective criterion for assessing the reliability of geotechnical test results. To establish such a criterion, the quality of the test procedure and the design of the test devices would need to be taken into consideration. However, the technology and measuring instruments in particular are continuously being developed and refined.

A criterion for specifying the reliability classes is therefore the completeness of the information on the various parameters stored in the data pool, as shown in fig. 1. This enables the original data to be used for detailed interpretations. The parameters stored in the database are sufficient for simple inquiries.

The inclusion of reliability classes is the key to being able to use the data for a wide variety of applications. Several examples are listed below:

- In practice, a parameter for a material may in some circumstances be specified solely on the basis of an assessment by an expert. The parameter concerned may also be stored in the database. The assessment by an expert is stated as the test method and the parameter is assigned to reliability class VII.
- There are only a few data available for very unusual materials. In cases where a material is very rare, the few available data should also be stored in the database. This is allowed for in the model.
- Data on experimental paths or other detailed information on materials that have been thoroughly investigated are required. If the data set is assigned to reliability class I to III, the data can be supplied by the institution that performed the tests.

The following rules apply for assigning data sets to reliability classes (see fig. 2 and table 1):

1. Reliability class I: The original test records with all test data are available.
2. Reliability class II: The original readings are no longer available. The translation rule for calculating the stress, for example, is known.
3. Reliability class III: The test results for the interpretation of individual tests are available. It is not known how they were calculated.
4. Reliability class IV: The algorithm for calculating the parameters of an individual test from the test results is known, e.g. the determination of the coefficients of consolidation and creep for a load increment in a compression test.
5. Reliability class V: The parameters of the different stages of a test or of individual tests are known, but the method with which they were determined is not.
6. Reliability class VI: The interpretation rule, e.g. the regression equation, for determining the geotechnical parameters is known.
7. Reliability class VII: Only the geotechnical parameter is known.

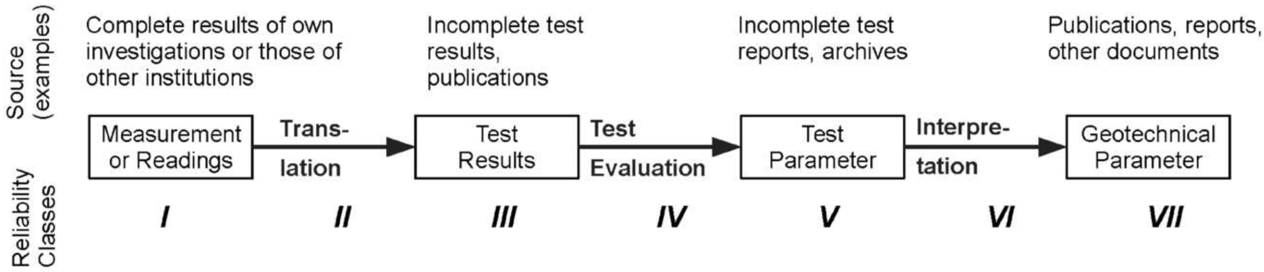

Figure 2: Definitions of the reliability classes

2.3 *Contents and applications*

It was decided that the database should include the following (see fig. 3):

- Sample description: This includes the location coordinates and the orientation of the sample. A problem is the consideration of raw information, e. g. an old address. This information needs to be converted into coordinates. Furthermore, information on the sample quality and the sample type is useful.
- Geological description: Geological descriptions can be very complex and have so far not been harmonized. Information on the history and the genesis of soil and rock may be important.
- Classification parameters: The soil and rock classification is the basis for the evaluation of the soil properties. All classification systems are based on parameters that can be determined by simple means. The terms used to classify soil or rock samples must be converted into a format that can be interpreted for the database. The rules required for this purpose have not yet been developed.

Table 1: Reliability classes for direct shear tests

Data and information	Reliability classes						
	1	2	3	4	5	6	7
Measurement (force, length)	x	x	x	x	x	x	x
Idealization of the shear area	x	x	x	x	x	x	
τ, σ, translation	x	x	x	x	x		
Criteria: $\tau_{max,}$, 20 % translation	x	x	x	x			
τ_f and σ_f	x	x	x				
Mohr-Coulomb failure criteria	x	x					
φ', c'	x						

- Shear strength: In addition to stating the shear parameters, the extent to which those parameters depend on the loading history, the void ratio and the state of stress must be taken into consideration. It is for this reason that the angle of shearing resistance used in the database is a function of the stress and the void ratio. The majority of users will only need to enter and evaluate φ‘ and c‘. This is done via the user interface.

- Compressibility: The one dimensional stress-strain behaviour is expressed numerically by the compression and swelling index or by the compression modulus. These variables can each be converted into the other if the void ratio is known. The time-settlement behaviour is described by the Buismann index $C_{\alpha\varepsilon}$, the void ratio and the coefficient of consolidation.
- Permeability: Permeability is expressed as a function of the void ratio.
- Compaction: This category was introduced to include test results for earth works, e. g. proctor density, CBR, frost resistance and stabilization methods (lime, cement).

Each parameter is described in greater detail by additional information. This involves allocating a characteristic from a list. If no information on the characteristic is available, “unknown” is selected. This concerns the following information:

- Test method: type of test method, e.g. direct shear test, triaxial test, etc.
- Device boundary conditions: principal boundary conditions of the testing device, e.g. whether it is stress- or strain-controlled, etc.,
- Test procedure conditions: certain reproducible characteristics of the test procedure that influence the results, e.g. preliminary loading in shear tests, wetting, etc.
- Fabric, sample quality: the results of tests conducted on intact samples differ from those performed on prepared, artificially compacted samples.
- Interpretation criteria: the criterion on which the interpretation is based must be characterized, e.g. shear strength at maximum shear stress, at the maximum principal stress ratio, etc.

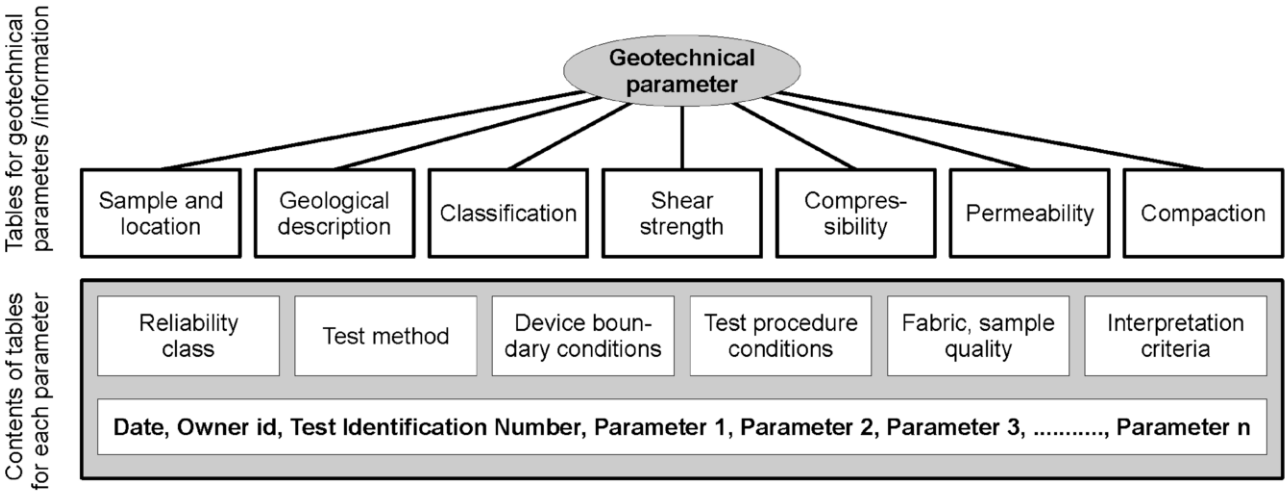

Figure 3: Structure of Geotechnical Parameter Database

3 NEXT STEPS, OUTLOOK

For the systematic collection, documentation and evaluation of geotechnical parameter obtained by laboratory tests on soil and rock samples a concept for a database has been developed which allows different kinds of applications and takes into account the most important parameter. The definition of the geotechnical parameter takes account of different constitutive laws e. g. non-linear failure criteria, complex permeability laws or different definitions of deformation moduli. At the moment this approach is implemented in a structure of a database. For selected examples a documentation of the test equipment and the test conditions is established and a management system for the data is installed. As a result a proposal for a harmonized standard for geotechnical data will be developed which will be the basis for the use of the database and for the export- and import processes.

It is planned to perform an initial trial run of the data system at the Federal Waterways Engineering and Research Institute in Karlsruhe and the University of Applied Sciences in Dresden. The “Geotechnical Database” working group is responsible for coordinating the development of the database. The further development will be reported in publications. In 2009 an internet platform for the input and output of the geotechnical parameter including their processing will be established as a pilot project to be tested among the “Geotechnical Database” working group.

It should be noted, however, that a database can never be a substitute for thorough and sufficient ground investigations in the field and in the laboratory.