Computers & Geosciences 37 (2011) 1192–1204

Contents lists available at ScienceDirect

Computers & Geosciences

journal homepage: www.elsevier.com/locate/cageo

A relational rock mechanics database scheme with a hierarchical structure

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ARTICLE INFO

Article history:
Received 11 February 2010
Received in revised form
9 November 2010
Accepted 11 November 2010
Available online 12 March 2011

Keywords:
Relational database
Rock mechanics
Uniaxial compression test
Triaxial compression test
Tension test
Shear test

ABSTRACT

In this work a hierarchical rock mechanics database scheme is presented. The aim of this database is to store and represent rock mechanics test data in a standardized and "transparent" manner (format) that includes as much information as possible regarding rocks, sampling location and orientation, testing procedures, experimental results, data reduction and model calibration methods. For brevity, in the first presentation of the database only the first two hierarchical levels of analysis are presented. Initially, the database structure is described and subsequently, the relations between different components of the database are illustrated. A short description of each parameter stored for each type of test is also given. Finally, a Web application scheme for the management of the database is proposed.

1. Introduction

Nowadays numerical simulation codes are indispensable tools for the predesign and design of underground and surface excavations in rocks. However, the constitutive models used in these numerical codes usually require a large number of elastic, plastic, and strength parameters of rocks. In many cases, there are few experimental data available in the predesign phase, which can be used to estimate only a few of the required model parameters. These parameters are usually derived from several-element rock mechanics or index tests on rock cores extracted from exploratory boreholes. Nowadays, some of these lab experiments are considered to be standardized (e.g., uniaxial and triaxial compression tests, shear and cylindrical disc tests), while other have been proposed in order to overcome the weaknesses or disadvantages of the standard ones (e.g., fracture mechanics, Schmidt hammer). Furthermore, the large number of laboratories performing rock mechanics testing on a routine basis, in conjunction with the large number of parameters that affect each test (e.g., size of specimen, rate of loading, boundary conditions, size and shape of specimens) and the different empirical models used to infer rock parameters from index tests, frequently lead to large dispersion of the data for the same rock types. Furthermore, some laboratories may perform monotonic loading tests, while others conduct unloading–reloading loops until the specimen fails and so forth. The International Society for Rock Mechanics (ISRM) has published suggested methods for standardizing the testing methodology, at least for the classical tests (Brown, 1981). However, a detailed description of the parameters that affect the experiment results is often not given, and thus the data cannot be harmonized.

Several relational databases have been developed in an effort to collect the available mechanical and physical data on materials. However, most of these cases focus on engineering materials such as polymers, ceramics, and metals. MatWEB,[1] NIMS Materials Database,[2] and MATBASE[3] are some examples of such databases. Databases for natural materials such as rocks usually focus on geological and mineralogical information (e.g., petrographic data, mineral composition, microstructure). Mindat[4] is an example of such a database. Some engineering databases for rocks have been developed. For example, the program RockPro, developed by ESG Solutions[5] in Canada, is a rock mechanics database tool for recording and reporting underground observations. This program is dedicated to data recording for specific projects, including support evaluations, rockbursts, and pillar performance. A more general rock mechanics database that stores mechanical parameters for rocks is the RocProp Properties Database developed by RocScience.[6] This database contains over 700 test records. Each record includes basic information about the rock (rock type, country, location, unit weight, etc.), reference information, and the actual test data. The test data are divided into four categories,

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[1] http://www.matweb.com.
[2] http://mits.nims.go.jp.
[3] http://www.matbase.com.
[4] http://www.mindat.org.
[5] http://www.esg.ca.
[6] http://www.rocscience.com.

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doi:10.1016/j.cageo.2011.02.014

namely compressive data, tensile data, Hoek data, and velocity data. Compressive data are information about uniaxial/triaxial compression tests. Tensile data refer to direct uniaxial and indirect tension tests. Hoek data store the constants of the Hoek and Brown failure criterion (Hoek and Brown, 1980; Hoek et al., 2002). Finally, velocity data contain information on compression and shear wave velocities. RocProp does not contain the raw data of each experiment, which could be very useful for further analysis (e.g., calculation of damage or plasticity parameters). Furthermore, information referring to the microstructure and the mineral composition of each rock is not stored. Hence, the user cannot correlate the mechanical parameters with the rock's microstructure, and furthermore he or she cannot retrieve mechanical parameters for rocks with similar composition and microstructure to his or her case.

The aim of this work is to create a relational rock mechanics database scheme of standard, as well as nonstandard tests, which could be used in a transparent manner for the collection, harmonization, and representation of the data among laboratories and for the calibration of elastic-damage-plasticity constitutive models for brittle rocks. By design the database includes as many parameters of the tested rocks as possible, as well as information concerning the experimental procedure. In its present state the database scheme proposed is able to store five different types of tests, namely uniaxial/triaxial compression tests, direct tension tests, indirect (Brazilian) tension tests, direct shear tests, and the relative new and nonstandard microdrilling test (Exadaktylos et al., 2000; Stavropoulou, 2006). For these tests, a hierarchical bottom-up data reduction methodology is proposed.

Rock mechanics experiments produce a certain number of raw data. In order to extract the rock mechanics parameters from these data, a calculation process must be performed for each test. In the current form of the database, data are processed at two levels, namely Level I and Level II. At Level I the direct experimental results are extracted from the raw data (e.g., failure stress, failure strain). At Level II, calculations are performed to evaluate basic parameters such as the elastic moduli. The concept followed at Levels I and II is to use generic equations that correspond to the physics of each test so they are not dependent on the specific rock type. The plasticity parameters of the rock, as well as more advanced calculations (e.g., reproduction of test results through particle or distinct element modeling), can be performed subsequently at higher levels of analysis (e.g., Levels III, IV, V). For brevity, only Levels I and II will be presented here. Raw data and all the parameters that are subsequently calculated are stored in the database. Moreover, spreadsheet files containing the above data are also included in the database.

The proposed rock mechanics database (RMDB) may be used by practitioners and researchers as a tool in rock mechanics and rock engineering. It is worth noting that it could be connected to data mining software for the extraction of relations between rock microstructure (grain size and shape, porosity, density, fabric and orientation of microcracks, etc.) and basic rock constitutive parameters (i.e., elastic modulus, cohesion, internal friction angle, etc.). That is, even at the predesign stage of a given project, where exploration data are scarce, one can use the stored data in the database to infer additional rock mechanical parameters necessary for subsequent numerical simulations.

The ultimate aim of this work, which is currently out of the scope of this paper, is to create a framework to derive a phenomenological constitutive model for rocks from their microstructural and mineral composition characteristics. The innovative feature of this work is that it is the first time a rock mechanics database has been organized in a hierarchical manner (i.e., various levels of bottom-up analysis) with a clear methodology of data reduction and modeling at each level. It should be noticed that the database is flexible, since it can handle a variety of rock mechanics data through the spreadsheets and queries, and it is extendable to more test types. It could have a large impact in the rock engineering community, since it is Web-driven.

Section 2 presents the structure of the proposed database scheme in detail. In the same section, theoretical aspects pertaining to the stored parameters are also briefly presented. In Section 3 the basic principles of the proposed Web application are described. Output reports and dynamic queries are also briefly presented. Finally, concluding remarks are presented in Section 4.

2. Structure of the database

In this work, an effort has been made to combine and store the results of four types of standard tests, namely uniaxial/triaxial compression (UCTC), direct uniaxial tension (UT), Brazilian test (BT), and direct shear (ST), as well as one nonstandard drilling test (DT), into a single rock mechanics database. Besides the experiments, the database also includes detailed information about each geomaterial tested, as well as information about the laboratories responsible for the execution of these tests. These features allow

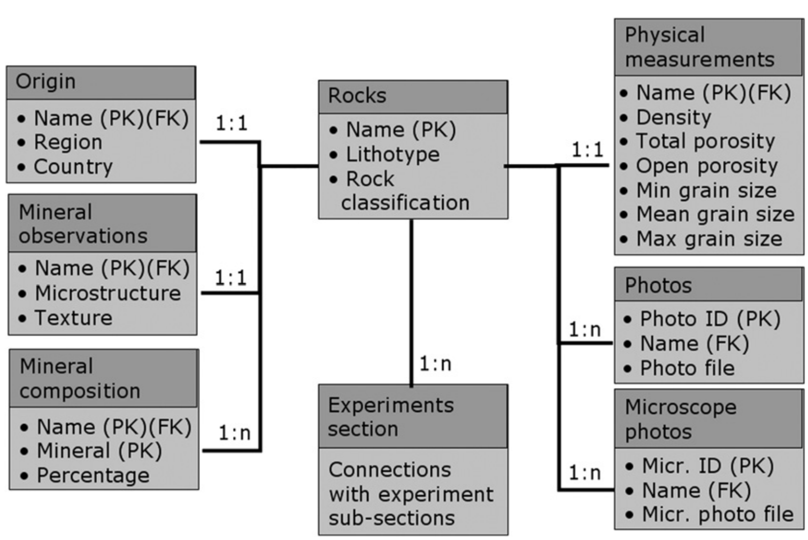

Fig. 1. Part of the relational diagram of the database showing the rocks section.