European Science Foundation
Standing Committee for Physical and Engineering Sciences (PESC)

ESF PESC EXPLORATORY WORKSHOP

Fractals and Geotechnical Engineering

Innsbruck, Austria
15-17 December 2003

Convened by:
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Background:

Geotechnical engineering is part of civil engineering. It comprises the foundations, excavations, tunnelling, stability of natural and artificial slopes (landslides) etc. The behaviour of soil and rock is of central importance. Contrary to artificially manufactured materials such as steel and concrete, soils and rocks are characterized by pronounced irregularity which impedes the application of usual engineering procedures (e.g. the assessment of a structure's safety by comparing expected stresses with limit values that characterize the strength of the considered material). The irregularity of soils and rocks arises from the fact that they are not virgin materials. They are the results of fragmentation processes that impose irregularities and inhomogeneities. As a consequence, there are observed strong spatial and time scale effects which render classical approaches inapplicable. These imply, for instance, that soil and rock are not 'simple' materials (in the sense of NOLL). This inability can be illustrated with two examples:

- Bulky debris material is found adjacent to many rock slopes in mountain regions. Its stability is important for roads, dams and other structures. Loss of stability can lead to catastrophic rock debris avalanches, but the properties of bulky debris are still unaccessible to rational analysis based on laboratory tests, because of the large size of the blocks involved.
- The water inrush into an excavated tunnel is of decisive importance for the successful completion of the tunnel's construction as well as for its environmental impact. This inrush depends mainly on the number of permeable joints encountered during heading. To date we have only been able to predict this number through the intuition of the geologists involved. Therefore, water inrush is notoriously hard to predict, rendering tunnel excavation a risky operation.

The newly discovered concept of fractals could help to improve such shortcomings in the field of geotechnical engineering. It is known that fractals are appropriate in describing the results of fragmentation processes. There is, in fact, evidence that bulky debris and rock joints can be described as fractals. This brings huge possibilities to the engineering treatment of such materials, as it reveals how to deal with the underlying scale effects. We can see how the properties of bulky debris might be inferred from a small sample consisting of relatively fine grains. Equally, the joints to be encountered within a rock massive can be predicted from the analysis of, say, a small palm sized piece of the rock under examination.

[1] ESF Standing Committee for Physical and Engineering Sciences (PESC) - http://www.esf.org/pesc

True, fractals are now ubiquitous, especially in popular science. However, with regard to geotechnical engineering, the approaches available (mainly from the United States) are still insufficient to answer the aforementioned questions. One reason for this is that fractals and the underlying mathematics do not belong to the standard education of engineers. Similarly, geology is generally not taught to mathematicians and vice versa. This is a good example of how progress can only be achieved through the cooperation of three quite different disciplines: geotechnical engineering, geology and mathematics. Such a cooperation can only be established if the barriers between these disciplines can be overcome. Mathematics and Geology demand different ways of thinking. To achieve the goals described above, substantial research is necessary that includes the mathematical properties of fractals, observations from geology and mechanical analysis of fragmentation and stability, as contributed by geotechnical engineering.

The existing evidence on fractals in geological structures is mainly empirical: if the underlying distributions are rectilinear in logarithmic plots, then a fractal is assessed. The *main open problem* arises from the fact that the observations can only be made within a limited range. Consequently, obtained distributions have lower and upper limits, whereas the interesting question is how to *extrapolate* beyond the observable limits. What is missing is a theoretical explanation of the underlying processes (e.g. fragmentation). The existing attempts to provide such explanations are, as yet, unsatisfactory.

The best way to tackle this subject, exchange information in depth and motivate further research is through an informal workshop that crosses disciplines. This would open new horizons in the engineering analysis of geotechnical problems. Such an analysis would be applicable not only to engineering constructions but also would help reduce the risk from geologic environment (landslides, floods and earthquakes).

Expected benefit and outcomes

While a majority of researchers in the geotechnical and geological communities knows something about fractals, this is not sufficient to treat the problems explained above (scaling laws in space and time). The workshop is expected to help the participants to obtain more specific information into this new field and provide initial help for further research. As the theory of fractals uses very demanding mathematics, it will be beneficial to involve in this meeting interested mathematicians who will be introduced to the open problems in geotechnical engineering and contribute to their solutions. Mathematicians are capable to penetrate into the theoretical fundamentals of fractals and identify what will be their benefit for the problems of geotechnical engineering. In the longer term, the envisaged workshop is expected to act as a milestone for contemporary geotechnical engineering. In view of the European backlog (as compared with the United States) in the applications of the theory of fractals, the envisaged workshop will contribute to close a gap. The presupposed multi-disciplinarity can only be succesful within a European framework.

PRELIMINARY PROGRAMME

Monday 15th December 2003

09:00-09:40	Fractals in geotechnical engineering: an overview **Dimitrios Kolymbas**
09:40-10:00	Discussion
10:00-10:40	A mathematical approach to fractals in fractured multilayer sequences **Alexander Ostermann**
10:40-11:00	*Break*
11:00-11:40	3D imaging of jointed rock masses: scaling laws – are they fractal? **Alison Ord**
11:40-12:00	Discussion
12:00-14:00	*Lunch & break*
14:00-14:40	The development of fractal fabrics in deformed rocks **Bruce Hobbs**
14:40-15:00	Discussion
15:00-15:20	Break
15:20-16:00	Size effect and fractal development of multiple fracture patterns **Feodor Borodich**
16:00-16:20	Discussion
16:20-17:00	- A fractal model for permeability of clay linings - Scaling and criticality in rock mass sliding **Bernardino Chiaia**
17:00-17:30	Discussion
18:00	*Dinner*

Tuesday 16th December 2003

09:00-09:40	Fractal properties in rock fragmentation: result of a self similar process or consequence of a pure stochastic phenomenon? **Luc Empereur-Mot & Thierry Villemin**
09:40-10:00	Discussion
10:00-10:40	Scale effects of fractals in fractured multilayer sequences **Christian Hecht**
10:40-11:00	Break
11:00-11:40	Title to be announced **Andrew Palmer**
11:40-12:00	Discussion
12:00-14:00	*Lunch & break*
14:00-14:40	New modified Cantor-dust methods for evaluating the anisotropy of rock fabrics **Joern H. Kruhl**
14:40-15:00	Discussion
15:00-15:20	*Break*
15:20-16:00	Scaling properties of fracture networks and consequences on permeability models **Olivier Bour**
16:00-17:00	Discussion
18:00	*Dinner*

Wednesday 17th December 2003

09:00-09:40	Relation between fluid flow properties and scale in fractured rock – an application of multifractals **Cristian Suteanu**
09:40-10:00	Discussion
10:00-10:20	*Break*
10:20-10-40	Application of the fractal fragmentation model to the fill of natural shear zones **David Masin**
10:40-11:20	A probabilistic procedure to assess the uncertainty of fractal dimensions from measurements **Ian Lerche**
10:20-12:00	Discussion
12:00-14:00	*Lunch & break*
14:00-16:00	Discussion

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Objectives of the ESF Standing Committee for Physical and Engineering Sciences (PESC)

The **ESF Standing Committee for Physical and Engineering Sciences (PESC)** covers a broad number of fields from physics, chemistry, mathematics, informatics and computer sciences, to engineering, material and technical sciences. PESC has the following responsibilities and tasks:

- to develop scientific initiatives within the ESF operational framework;
- to make proposals for 'a la carte' scientific initiatives;
- to undertake studies on large research facilities and assist in the evaluations and assessments and other special reviews requested by Member Organisations;
- to provide specialist advice and input on a wide range of ESF actions and contribute to the development of the ESF science policy agenda and take a strategic view of the scientific area for which it has responsibility; and
- where appropriate, to work with other Committees and groups in promoting multidisciplinary and interdisciplinary activities.

PESC supports a limited number of **Exploratory Workshops** each year. These workshops allow leading European scientists to explore novel ideas at the European level with the challenging aim to "spearhead" new and preferably inter-disciplinary areas of research. (http://www.esf.org/pesc/workshops)

One outcome of an ESF Exploratory Workshop may be that participants decide to submit an ESF scientific **Programme, Network** or **Euroconference** proposal, possibly to be financed by, and coordinated through, the European Science Foundation. If this is the case, it is expected that participants of the workshop follow the relevant procedures.

In the case of **Programmes**, PESC launches (usually in September) an annual call for proposals. In the first stage of PESC's call the "programme ideas" are refereed. Those that are highly rated are invited to submit a full proposal and subsequently undergo further external refereeing and, if successful in obtaining PESC's scientific recommendation, will be submitted to ESF Member Organisations for funding on a voluntary basis. Further details are available on the internet at http://www.esf.org/pesc

In the case of a **Network** the proposal is submitted to the ESF Network Secretariat. The results of the refereeing process and PESC's scientific recommendations are provided to the Network Group. This is the body that decides whether or not to recommend a proposal for launching. More details are available at http://www.esf.org/networks .

In the case of **Euroconferences**, the proposal is submitted to the ESF Euresco Secretariat. A Committee (assisted by Advisory Panels) takes full responsibility for the selection of conference subjects and chairmen. More details are available at http://www.esf.org/euresco.