International Workshop on Education of Future Geotechnical Engineers in Response to Emerging Multi-scale Soil-Environment Problems, University of Cambridge, September 5-6, 2014

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Book of Abstracts

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Workshop Description

This workshop will address the new skill set needed by Geotechnical Engineers to solve the multi-scale, multi-physics problems faced by modern technology. New research areas such as solid/fluid transition from the grain to the landslide; geological waste storage from micro-cracks to fractured reservoirs; bio-engineered geomaterials from natural bacteria to designed structures; energy piles from soil properties to geotechnical performance; geotechnical earthquake engineering: from ground motion to structural safety all require a broader range of knowledge than previously provided in the typical Geotechnical Engineering course of study. This International Workshop aims to identify key challenges for the education of new generations of geotechnical engineers, focusing on undergraduate education. The main questions that will be addressed include: What courses outside the engineering curriculum are needed? Are changes in the basic Chemistry, Physics, Biology courses desirable for engineering students? What knowledge of soil mechanics is needed for students pursuing a B.Sc. in Civil Engineering who have no intent to practice geotechnical engineering? For students who plan to become geotechnical engineers? The workshop will benefit from the participation of members of the international academic and higher-education community, involving a number of leading institutions from the European Union and the United States.

In the United States, most Civil Engineering undergraduate curricula offer only one course in Soil Mechanics. In Europe and in the United States, the first course taught to engineering students in geotechnical engineering has not changed significantly in content during the last few decades: it covers soil gradation, soil compaction, steady laminar flow and Darcy’s law, one-dimensional consolidation theory and soil shear strength. Future engineers need to master new experimental and theoretical skills that will allow them to solve multi-scale, multiphysics problems, and make recommendations for safe and sustainable design. Efforts have recently been made to make geotechnical engineering course more attractive to students, and to involve undergraduate students in research projects as part of their required coursework. However, no systematic analysis has been undertaken to date that addresses the needs of the geotechnical community to prepare future engineers to validate new standards for geomaterial characterization, experimental testing procedures, and geotechnical design. Faculty and graduate students participating in this workshop will assess strategies for training and development of graduate and undergraduate students, and identify efficient teaching methods to create an innovative skills toolkit at the undergraduate level. In addition to curricular recommendations, working groups will propose two to three options of in-class activity that could be integrated in a module at the undergraduate level. Participating Ph.D. students will be encouraged to maintain the workshop wikipage after the workshop.
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Broadening students’ perspective of geotechnical engineering using virtual tours of practice and research worldwide

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Given the broad range of topics which must be covered in undergraduate degree courses in Civil Engineering, it can be difficult to enthuse students of the economic and social value of geotechnical engineering within civil engineering projects. For many of today’s problems, which have international significance, there is also a need to think more holistically about problems to develop better solutions, and not be limited by traditional subject boundaries (e.g. structural, geotechnical, hydraulic engineering). To address these issues, this paper proposes the use of an international collection of short video presentations based on current research projects and virtual tours of innovative construction projects from around the world, in each case highlighting the importance of geotechnical engineering to the work. This collection allows students to be made aware of the latest ‘technology’ being developed within geotechnical engineering research, and provides exposure to different systems of application of such technology around the world, fostering global awareness. This is particularly important for today and tomorrow’s graduates who will increasingly be required to work across international borders. An initial set of video presentations was assembled from across US and European research and practice. These were shown to undergraduate student cohorts across the participants with pre- and post-survey questionnaires used to quantify changes in students’ perception of geotechnical engineering as a result of exposure to the videos. Changes were observed in terms of awareness of global issues, as well as student interest in seeking a career specializing in geotechnical engineering. The video archive developed within the work can be a live resource for academics worldwide, being continually updated as research and practice evolve.

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What do geotechnical and non-geotechnical engineers need to know as new graduates?

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One of the greatest challenges in revising a curriculum is to decide the relevant material which should be included in each course. Within civil engineering, each thematic group guards closely the pre-eminence of their topics and is very reluctant to agree to a holistic assessment of the curriculum. This resistance to an overall reassessment of the curriculum often results in overlaps and duplications, as well as gaps in knowledge. It also contributes to the students’ perception of subjects as a set of silos that do not communicate and reinforces the fragmentation of knowledge into unconnected pieces, seemingly based on empiricism rather than powerful theory.

Instead, the task should start with the assessment of the needs of new graduates entering the industry, balanced with a grounding in basic principles and theory.

It is important to recognize that every field will develop dramatically within the working life of these new engineers and it is imperative for them to develop their understanding and mastery of concepts within a sound theoretical framework that will allow them to process and absorb new developments easily. This study presented in this paper focuses on the field of geotechnical engineering. Its goal is to identify the technical knowledge and skills that industry desires for new graduates in civil engineering, for students specializing in geotechnical engineering, as well as other civil engineering disciplines. The survey is to be administered to a variety of firms, to capture a broad range of practitioners, and academics in the United States and the European Union. The results of the survey will then be used to develop sample curricula that address the needs of industry, while relying on basic principles and theory and providing opportunity to connect with other subjects. A small sub-group of the survey respondents will be invited to comment on the proposed curricula, potentially leading to revisions.

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New challenges within geotechnical engineering rely upon concepts that are not necessarily taught in our traditional undergraduate soil mechanics course. However, our societal needs call upon geotechnical engineers to respond to issues in parallel industries, such as environmental remediation, energy and petroleum, and carbon sequestration, in addition to traditional geotechnical and foundation related work. These emerging multi-scale soil issues rely on fundamentals in thermal-hydro-chemical-biological-mechanical couplings. Our students are the engineers that will address these societal challenges, whether or not they specialize in geotechnical engineering. They can be better served by including these fundamental concepts in our introductory geotechnical engineering courses while encouraging them to develop transferable skills.

An assessment of the current topics taught in the introductory geotechnical course across the US and EU will be performed. The survey will be designed in conjunction with engineering education researchers. Professors will be asked to indicate which topics they currently teach, how many hours are spent on covering each topic, and which topics they wish they could teach but find they do not have the time to cover. For each course topic (currently taught or not) the instructors will be asked to rate the importance of the topic. This survey will provide an appraisal of our collective priorities within the introductory geotechnical course in addition to a current instructional summary.

Based on the results of the survey, recommendations will be proposed to broaden the scope of our current introductory geotechnical engineering course. Succinct modules will be developed for selected concepts to introduce students to the fundamentals of thermal-hydro-chemical-biological-mechanical couplings. The goal of the modules is to provide effective tools for instructors to efficiently discuss a broader scope of concepts in the course and allow students to develop transferable skills that they can apply to interdisciplinary challenges society currently faces.
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Efficient Integrated Coursework for Coupled processes in Engineering

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Increasing pressure on natural resources is stretching engineering capabilities to its maximum. More than ever, underground resources are offering new perspectives in terms of development and require advanced knowledge and skills in geotechnical engineering. In the past decade, there has been an increasing need to put into place new facilities for nuclear waste storage, carbon dioxide geological sequestration and energy production (e.g. geothermal, compressed air storage or oil and gas extraction). New technologies are currently being developed and allow engineers to increase the efficiencies of their designs such as biological, chemical and mechanical self-healing buildings, bridges, dams and even roads. However, such developments require knowledge in coupling effects and inter-disciplinary collaboration. The current engineering teaching curricula in the US and Europe do not promote, and in some cases even allow, the knowledge of coupled processes to be transferred to freshly trained engineers who will have to face tomorrows challenges. This paper suggests a new approach, curricula and coursework of geotechnical engineering teaching which will promote a better understanding and application of soil mechanics and especially multi-physics coupling problems.

The first aspect in teaching geotechnical engineering with coupled processes would be to address the necessity of knowledge in fundamental sciences such as biology, chemistry and mechanics. A review of the current American and European curricula in civil engineering will be performed. A preliminary investigation showed that physics, chemistry, geology, mechanics and many more are generally taught in America and Europe in the early stage, but they do not currently cover the needs for teaching coupled processes. Furthermore, the teaching of basic soil mechanics aspects in a time-constrained framework do not currently allow freeing up time for teaching coupled processes. Finally, the absence of teaching material devoted to coupled problems hampers the teaching process due to a lack of experience in training young engineers.

An efficient way to overcome the issue of teaching coupled processes in geotechnical engineering is to review the current teaching program. First there is a necessity to introduce biological, chemical and physical knowledge at an early stage which would facilitate the introduction of multi-physics coupling in geotechnical engineering. The actual little emphasis of these courses on engineering needs could be easily overcome by integrating engineering aspects in those fundamental courses. It will stress the need of such knowledge in engineering and motivate students in learning those fundamentals.

Second, we propose curricular adjustment to overcome the limitations noted in current undergraduate geotechnical coursework. The main idea is to incorporate all the contents devoted to elementary processes and shared by different engineering departments in preliminary courses (e.g., physics, mathematics, material science, transport phenomena, geology, etc.). Those elementary processes are meant to become prerequisites for the soil mechanics courses. Consequently, time will be spared in current soil mechanics courses, which will allow the introduction to these coupled problems.
This analysis will allow establishing an optimal teaching program which could be used as a reference point for any university. Reviewing the current curricula in engineering will not only enhance the teaching of soil mechanics to civil engineers but will also broaden the knowledge of young students in other fields of engineering.

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This paper proposes a framework for establishing a project-based learning system for undergraduate level civil engineering students in United States of America, European Union and other countries. The aim of the study is to explore project-based options and challenges for introducing and exposing undergraduate students to emerging challenges associated with Thermo-Hydro-Chemo-Bio-Mechanical (THCBM) coupled processes in geostructures. THCBM coupled processes are encountered in geostructures, such as nuclear waste disposals, carbon dioxide capture systems, geothermal foundations and power plants, natural gas storage facilities.

Educational goals of the proposed project-based approach are to improve creativity, self-learning, critical thinking, and integrating existing knowledge from interdisciplinary areas, integrate tools from different subjects and develop teamwork skills. Towards these goals, we propose to assign open-ended geotechnical projects to undergraduate civil engineering students. During their work on the project, students will gain fundamental knowledge on heat transfer, water transfer and coupled thermo-mechanical soil and rock properties. A companion paper on the current challenges in related education on needed knowledge on fundamentals THCBM coupled processes will further complement this paper.

First, we review project assignments focused on coupled processes and geostructures that are currently offered in our universities. A special attention is given to several different important features, such as the period of the project, time at which the project comes in the curriculum, number of earned credits, involvement of industry and deliverables on which students are evaluated. Next, we discuss the level and quality of the existing projects with respect to the educational goals stated above.

Based on these analyses, we propose a model of project-based learning for THCBM coupled processes in geostructures. The proposed length of the project is at least a year. We suggest a mentoring strategy to involve industry partners, in order to provide students with up-to-date information and technologies, and to include site and plant visits as part of the project experience. We propose a plan to rotate project topics to ensure continuity for the students and for the industry partners. Optional features in the project-based learning method include collaborations amongst students across departments and across generations (e.g. first-year, second-year students, etc.). The project will require splitting problems into partially coupled problems. Students will be asked to propose a time-frame to achieve projects, in order to promote critical thinking and self-learning.

Lastly, we develop an assessment method, including: metrics, ways to adapt the model depending on the curricular constraints: compare two populations of students (with and without project): exit interview of students (ask them if they perceive they have learnt xyz, if they feel they can do xyz); interview of industry mentors (ask about progress made by the students and ask about the final product: would you hire our students? If you have already, are they effective?); after curriculum: what do our students do? (Leadership in students associations and in professional life); to monitor enrollment in geotechnical engineering.
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The importance and future of educational geotechnical engineering laboratories in undergraduate civil and environmental engineering education

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An active learning approach and hands-on laboratory experience in geotechnical engineering is a key component to reinforce geotechnical engineering concepts taught as part of lectures for undergraduate civil and environmental engineering education. This greatly enhances the understanding and application of the theory, as well as the knowledge retention of the students. This practical experience also generates interest in the field of geotechnical engineering and encourages students to pursue further studies and/or a career in the field.

Challenges such as large classes, limited teaching resources, onerous health and safety requirements, lack of suitable laboratory space & equipment and ineffective use of laboratory sessions make it difficult or economically unfeasible to provide an appropriate practical and hands-on experience to supplement theoretical class time learning.

This paper highlights the importance of incorporating practical education sessions and laboratory experience for geotechnical engineering in an undergraduate civil engineering curriculum. Suggestions are provided for incorporating open-ended design-based experiments in the laboratories, with examples of geotechnical concepts that are well suited to laboratory experiments. Potential ways that the identified challenges can be overcome and opportunities to include technology into the geotechnical engineering laboratory for an enhanced student experience are discussed.

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The geotechnical engineering world is expanding to encompass far more than the classical geotechnical structures and simplistic strength, stiffness, and porous media concepts summarized by Terzaghi, Peck, Holtz, Kovacs, and other notables of the 20th century. Today, geotechnical engineering is at the heart of subsurface environmental protection, ground improvement, engineered barriers, sustainability, energy production, and of course, multi-scale and coupled processes. As the issues become more complex, the approach to education in the geotechnical arena must also adapt. The question is, therefore, is a classical geotechnical education on the undergraduate level is too limiting? If so, how would it change? In response to these questions, we propose modifications to the current undergraduate geotechnical engineering course. This paper summarizes the opinions presented by the authors above (a combination of PhD students, mid-level professors, and full-professors) for improving the undergraduate geotechnical experience. The majority of the discussion focuses on the introductory geotechnical engineering experience, typically a 40 hour required course for undergraduate civil engineering students. This extended abstract will outline the proposed class format, necessary prerequisites, fundamental content to be included in the introductory soils course, and curriculum changes to be addressed.

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I. **CLASSROOM FORMAT**

- Length: 40 hour introductory geotechnical engineering class completed in one semester
- Target group: Third or fourth undergraduate year
- Class sizes: 40-100 students
- Lecture content: traditional soil mechanics with some introduction to geotechnical structures and foundation systems
- Laboratory section: 2-3 hours per week
- Interactive activities
  - At least one site visit per semester
  - Some demonstrations (e.g., shake tables to show liquefaction and electrically-conductive paper to simulate water flow through soil)
  - **For reference:** ‘Hands-On Undergraduate Geotechnical Engineering Modules…’ (Dewoolkar et al. 2009)

II. **PREQUISISTES**

<table>
<thead>
<tr>
<th>General Subject</th>
<th>Courses</th>
<th>Comments</th>
</tr>
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| Math                    | • Calculus I, II, III  
                           • Linear Algebra  
                           • Differential Equations | NOT NEEDED AT THIS LEVEL: Statistics and Probability |
| Sciences                | • Physics I, II  
                           • General Chemistry | NOT NEEDED AT THIS LEVEL: Biology, Geochemistry |
| General Engineering     | • Statics  
                           • Deformable Bodies (Continuum Mechanics)  
                           • Dynamics  
                           • Thermodynamics |                                           |
| General Civil Engineering | • Fluid Mechanics  
                           • Strength of Materials  
                           • Introduction to Civil Engineering  
                           • Geology | NOT NEEDED AT THIS LEVEL: AutoCAD or similar design software |

- An ‘Introduction to Civil Engineering’ perquisite, a course which would introduce the various disciples of civil engineering to first and second year undergraduates
  - Sustainability concepts introduced
  - **For reference:** ‘Integrating Fundamental Science and Engineering Concepts into a Civil Engineering Sustainability Course’ (Seagren and Davis 2011)
III. FUNDAMENTAL CONTENT AND APPROACH

A. Fundamental Concepts

<table>
<thead>
<tr>
<th>General Topics</th>
<th>Specific Content</th>
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<tbody>
<tr>
<td>Soil classification</td>
<td>• Heterogeneity, anisotropy</td>
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<tr>
<td></td>
<td>• USCS and other classification systems</td>
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<td></td>
<td>• Physical properties (shape, size, color, porosity, etc.)</td>
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<td></td>
<td>• Plasticity</td>
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<td></td>
<td>• Clay mineralogy; clay-water electrolyte system</td>
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<td>Water</td>
<td>• Hydraulic conductivity</td>
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<td></td>
<td>• Seepage</td>
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<td></td>
<td>• Effective stress</td>
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<td>Mechanical behavior</td>
<td>• Non-linearity of the stress-strain relationship</td>
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<td>• Odometer and triaxial tests</td>
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<td>• Shear strength, Mohr’s circle and friction angle</td>
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<td>• Drained and undrained response</td>
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<td>• OCR</td>
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<tr>
<td>Geostructures</td>
<td>• Retaining walls</td>
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<td></td>
<td>• Dams</td>
</tr>
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<td></td>
<td>• Shallow foundations: settlements and bearing capacity</td>
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<tr>
<td>Hydro-mechanical coupling</td>
<td>• Consolidation</td>
</tr>
<tr>
<td>Others</td>
<td>• Compaction</td>
</tr>
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<td></td>
<td>• Case studies</td>
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- Limit time spent on soil shear strength or consolidation analytical solutions
  - Use that time to introduce students to geotechnical structures and applications
- This may be the only geotechnical engineering class taken by some students
  - Must include foundations, geotechnical structures, and case studies
B. Reflecting Changes Within the Field

- Curriculum reflects the advances made in the field within the last half-century
- New technologies incorporated
  - Imagining and modeling for behavior on the micro-scale
- Soils inherently non-linear
  - Adopt new frameworks for strength, stiffness and strain
- Governing differential equations the same for:
  - Thermal
  - Hydraulic
  - Electrical
    - Students can apply these to all areas, though focus in hydraulic conductivity for this course
- Coupled processes
  - Gradients of different potentials can induce water flow, i.e. hydraulic, thermal, chemical, electrical
  - Beyond the classical Darcy Law relating hydraulic potential gradient to water flow, the role of coupled flows is fundaments for the 21st century geotechnical engineer
  - Consolidation, reinterpreted in a broader sense as a coupled phenomenon-coupled processes
    - Electro-kinetic remediation
    - Fluid flow through engineering barriers due to osmotic phenomena
    - Thermal induced flow in nuclear waste disposal facilities

IV. THE NEW INTRODUCTORY SOILS COURSE AND CURRICULUM CHANGES

A. Summary of New Geotechnical Curriculum

- Summary of geotechnical curriculum
  - Introduction to Civil Engineering and Sustainability course
  - Geotechnical Engineering I
    - See above concepts
  - Geotechnical Engineering II
    - Numerical solutions of seepage and consolidation equations
    - Critical state soil mechanics (CSSM)
    - Shallow and deep foundations: bearing capacity and settlement calculations for fine and coarse grained soils
    - In-situ testing and site analysis
    - Drilling and sampling
    - FEM/DEM concepts
  - Geotechnical Engineering III
    - Environmental geotechnics
    - Detailed laboratory testing procedures
    - Slope stability
    - Seismic design of geotechnical structures
B. Suggested Modules and Activities

• For reference: ‘Cooperative learning in a soil mechanics course at undergraduate level’ (Macedo and Bonito 2011)

C. Potential Challenges

• Adapting new curriculum to different class sizes
• Moving theoretical concepts to more advanced geotechnical courses
  o Lose some of the theoretical background
  o Often students appreciate theoretical background
    ▪ How effective is it really?
• Moving slightly away from traditional lecture format
  o Students like a “get in, get out” approach because it’s easier
  o Might take a few years to adapt to the most productive curriculum
    ▪ Incorporating activities takes time out of lecture
    ▪ How much can realistically fit into the curriculum?

D. Measuring Course Success

• Bologna Process
• ABET
• Surveys
  o Student Questionnaires
  o Teacher Perspective
• Student Performance

V. CONCLUSIONS
VI. REFERENCES
Granular mechanics is not magic: Critical analysis of classroom physical models in teaching soil mechanics

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Soil mechanics is traditionally taught at the undergraduate degree level from the perspective of soil as a continuum material. This viewpoint has stemmed from the older discipline of structural mechanics and the extension of structural concepts of material behaviour, for example, elasto-plasticity, to soil behaviour. In recent decades, however, there has been an increased appreciation by the geotechnical profession of soil and its behaviour being governed by its particulate nature. Indeed it is now recognised that the discipline of soil mechanics within civil engineering runs parallel to that of granular mechanics within physics (Soga et al, 2014). It is suggested here that the teaching of soil mechanics at undergraduate level should explicitly recognise the particulate nature of all things granular and by doing so, behaviour that may seem surprising or even “magic” from a continuum perspective of soil (Elton, 2006) will be revealed as ubiquitous in the granular world.

This paper discusses the use of classroom based physical models that focus on the granular nature of soil as an aid to teaching some of the fundamental principles of soil mechanics. Experiments use both soil grains and soil grain analogues – such as rice, cornflakes, coffee, and coins. Specific granular mechanics phenomena include: undrained to drained behaviour; normal compression and swelling; 1D versus 3D deformation; granular friction, strength and dilatancy. Specific geotechnical applications include: soil reinforcement; planar seepage through embankments / under retaining walls.

In order to be considered, classroom based physical experiments must be both low cost and reasonably straightforward to perform. Given that the experiments are designed as an aid to the formal teaching of soil mechanics, part of the experimental design may include prediction before the experiment, measurement (including selection of data to measure) and comparison with soil mechanics theory using short calculations related to the phenomena under consideration. Examples of such an experimental design will be given, as well as a critical assessment of the validity of the approach. Interpretation of the physical experiments also may be carried out through comparison with numerical (e.g. via discrete element) modelling or imaging (e.g. via tomographic or photoelastic methods). Again, examples of this approach will be given. Finally, it is important to consider the limitations and shortcomings of each physical model and of modelling in general. A discussion on these issues will be included.

The overall aim of the proposed approach is to enhance the student experience by giving insights into the microgeomechanisms behind macroscopic granular behaviour. In doing so, it is expected that students will be better prepared for future trends in geomechanics and to better tackle multiscale and multiphysical geotechnical problems.
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1. Introduction
   a. Brief overview / history of granular mechanics
   b. Current learning context
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3. Critical appraisal / discussion
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4. Conclusions

References

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Soil Friction: Fact or fiction

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Current understanding of soil strength amongst civil engineers is based on an assumption that the relationship between confining pressure and strength is analogous to the relationship between the normal force and the resistance to sliding of a block resting on a surface. This understanding firstly develops in undergraduate soil mechanics teaching and originates from the work of Coulomb in the 18th century. It is common in soil mechanics textbooks (e.g. Bolton, 1979) to graphically relate the sliding block mechanism to a direct shear test, or as shown in Figure 1(a), to indicate schematically that in a direct shear test failure takes place by sliding along a plane that vertically bisects the specimen (e.g. Bolton, 1979; Knappett and Craig, 2012; Holtz and Kovacs, 1981). The use of the term angle of internal friction strongly implies that it is sliding friction that drives the strength-dependant nature of soil block.

Recent research suggests that this emphasis on sliding does not accurately reflect the true origin of soil strength. Discrete element simulations have shown that the relationship between inter-particle friction and the angle of shearing resistance ($\phi'$) (often called the angle of internal friction or the friction angle) is non-linear, and that beyond a certain value increases in interparticle friction do not result in increases in $\phi'$ (e.g. Thornton, 2000; Ni et al., 2000). Photoelastic experiments (e.g. de Josselin de Jong & Verrujit, 1969), micro computed tomography images (e.g. Hasan & Alshibli, 2010), and DEM simulations (e.g. Rothenburg & Bathurst, 1989) all indicate that in a granular material a subsets of highly stressed particles, transmitting relatively high contact forces, form clusters and align to form strong force chains. As indicated in Figure 1(b), in the direct shear apparatus these strong force chains develop in a diagonal manner as deformation progresses. A number of studies have convincingly argued that failure of the soil is associated with the collapse of these strong force chains (e.g. Tordesillas, 2007).

This contribution argues that it is timely to discard the sliding block analogues when teaching the fundamentals of soil strength. Recent findings from particle-scale analysis, simulation and experiment should be acknowledged and used to engage students in a discussion on fundamental mechanisms when the idea of soil strength is introduced.

Tentative table of contents:

- Introduction
- Overview of introduction of soil strength in popular undergraduate textbooks.
- Findings from micro-scale analyses, simulation and experiment
- Proposed new section on soil strength for inclusion in a UG textbook or notes
Figure 1 Alternative perspectives on the direct shear test.

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