Geotechnical engineering education and training in Switzerland

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ABSTRACT: The geotechnical engineering education in Switzerland at a university level is based on BSc and MSc programmes at the Swiss Federal Institute of Technology in Zurich (ETHZ) and in Lausanne (EPFL), according to the 'Bologna Declaration'. Admission requirements for ETH are the general qualification for university entrance, and this paper discusses solely the university level. The geotechnical unit at the ETHZ is the Institute for Geotechnical Engineering (IGT), which is part of the Department of Civil Engineering, carries out teaching and research in the areas of geomechanics, geotechnical engineering, tunneling and environmental geotechnics, with a strong emphasis on natural hazards. The rock and soils laboratories (LMR & LMS) at EPFL are part of the Institute of Infrastructure, Resources and Environment (ICARE), located within the School of Architecture, Civil and Environmental Engineering. They conduct courses of a similar nature to IGT within their Bachelor and Master programmes. It is a strong national theme from both institutions that they strive to prepare students for their future careers in civil engineering, in close collaboration with industry, through obtaining access to many interesting and current practical applications in Switzerland. Relevant knowledge from current research feeds into teaching at all levels.

1 GENERAL

The geotechnical engineering education in Switzerland is made available to students either through the practical route within advanced technical colleges, or at a more conceptual level through technical universities. Entry to the technical colleges is based on professional experience, with courses of 3 years duration offered currently up to Bachelor level. Each major region of Switzerland boasts such a college and masters courses with a geotechnical component may be developed in a minority of them in the future.

University level education may be accessed at the two Swiss Federal Institutes of Technology. ETH Zurich (ETHZ) is over 150 years old, whereas EPF Lausanne (EPFL) was established from the former Polytechnical School University of Lausanne, less than 40 years ago, although both of the older institutions founded soil laboratories in 1935. Admission requirements for ETH are the general qualification for university entrance (the 'matura' in Switzerland).

The geotechnical unit at ETHZ is the Institute for Geotechnical Engineering (IGT), which is a part of the Department of Civil Engineering (D-BAUG). IGT carries out teaching and research in the areas of geomechanics, geotechnical engineering and modelling, tunnelling and environmental geotechnics, with a strong emphasis on natural hazards. The IGT has three Professorships: Geotechnics (Prof. Dr. Sarah Springman); Geomechanics (Prof. Dr. Alexander Puzrin) and Underground Construction (Prof. Dr. Georg Anagnostou). In addition, there is an Environmental Geotechnics unit.

The rock and soils laboratories (LMR & LMS) at EPFL are led by Prof. Dr. Jian Zhao and Prof. Dr. Laurent Vulliet at present, although LMS will be taken over by Prof. Dr. Lyesse Laloui from 2008. The Laboratories are located within the Institute of Infrastructure, Resources and Environment (ICARE), from the School of Architecture, Civil and Environmental Engineering. LMR / LMS also conduct undergraduate courses in geotechnical engineering, geomechanics, groundwater flows and geotechnical aspects of risk, safety and reliability.

Despite the international nature of the university Professors, most of whom came to Switzerland to take up their chairs, all of them are fully committed to the Swiss approach of developing rounded civil engineers, capable of balancing fundamental theory with applied solutions, from their first day in practice. Postgraduate education is offered through individual chairs, Institutes and Departments, sometime within a more formal graduate school. Doctoral students are encouraged to take courses from without civil engineering, to benefit from the range of geotechnical opportunities available within their own, and other, national universities.

Lifelong learning has also been a key focus for all educational Institutions engaged in geotechnical engineering in Switzerland. IGT, LMS and LMR all

present regular colloquia, during semester periods, on a range of technical, applied and theoretical topics. Both proffer more specific further education courses and organise international seminars and conferences. IGT further education courses were held on 'piles' in 1995, 'the observational method' in 1997 and 'clay in geotechnics' in 1999.

Furthermore, the Swiss Society for Soil and Rock Mechanics is hosted from IGT, supported by academics and practitioners alike, and runs biannual seminars on a variety of themes.

2 EDUCATION AT ETH ZURICH

2.1 *Institute for Geotechnical Engineering ETH Zurich*

Currently, IGT (http://www.igt.ethz.ch) is responsible for teaching obligatory geotechnics courses in soil and rock mechanics, geotechnical engineering, and tunnelling to civil engineering students from the 4th to 6th semesters (Bachelor), and from the 1st to 4th semesters to those who select geotechnics as one of their two specialisations in the Masters (http://www.vvz.ethz.ch/Vorlesungsverzeichnis/sucheLerneinheitenPre.do?lang=en) in Civil Engineering. This includes supervision of their design projects, leading to publication of semester- and master-theses; these may be on current design projects from practice, supervised in conjunction with contributors from industry, or on more research focused topics.

The implementation of the general 3-year Bachelor course, followed by a 2-year specialised Masters course to replace the 9 semester long Diploma course, has led to a small reduction in the contact hours for the obligatory courses. Additionally, there was a transfer of significant quotas of the more advanced material out of the 5th & 6th semesters in the diploma to the Masters course (1st-3rd semesters).

The Bachelors provides the basic geotechnical knowledge in soil and rock mechanics, geotechnical engineering and tunnelling for practitioners, supported by the essential theoretical background in mechanics. More specialist and research-oriented material at the Masters level requires more advanced analytical skills and techniques (including simple computational approaches, and their use and limitations) and offers opportunities for those hoping to follow a career in geotechnical engineering, or indeed to take a higher degree as a researcher.

In-depth study and analysis of case histories is adopted to teach problem evaluation and application of mechanics in practice. Emphasis is placed on the integration between design and analysis, on the design process, as well as on the interactions between planning, design and execution, in order to prepare students optimally for their eventual role in civil engineering practice.

2.2 *Professorship for Geotechnical Engineering*

The group of Prof. Sarah Springman is responsible for teaching primarily in the field of soil mechanics, (basic principles, experimental aspects, modelling), soil dynamics, design and construction, soil structure-interaction and geotechnical natural hazards. The team combines both national and international aspects, nourished by research in these areas, to help students initially to solve simple and then more advanced, multidisciplinary problems related to geotechnical engineering.

The group embraces the current opportunities offered by modern teaching approaches, respecting the pedagogical demands of each course, by using a mixture of embedded or multi-threaded Computer Aided Learning CAL (lectures, virtual and real laboratories, quizzes, animations, simulations and challenges), more traditional teaching styles and with partial adoption of 'Problem Based Learning' (e.g. Sharma et al., 2001; Davison et al., 2002; Springman et al., 2003).

Some freedom of choice is important from the student's point of view. In the early courses, this was achieved by offering freedom in the style and pace of learning (from lectures, video streaming, books, website), while remaining very specific about the material to be covered and the eventual end date by which work must be completed. Latterly, the students have been given broad guidelines and encouraged to select their own material for investigations and exercises in a specific area.

The group has organised several further education courses for industry. These were on Critical State Programs in 1997, in conjunction with the Cambridge Programme for Industry, on Advanced Geotechnical Analysis using the Finite Element Method in 2002, on Ground Improvement in 2005 and on Geotechnical Finite Element Analysis in 2006.

Prof. Sarah Springman is joined by Dr. Jan Laue, Pierre Mayor and Ralf Herzog from IGT and external lecturers from industry, Dr. Jost Studer and Rudolf Rueegger, to contribute to the geotechnical education and training as listed below. Dr. Rita Hermanns and Dr. Michael Ploetze share delivery of the course on Environmental Geotechnics. New initiatives include a course on 'Soil Mechanics for Geophysics' within the IDEA League International Masters (http://www.idealeague.org/geophysics) in Applied Geophysics and contributions towards a new Master of Advanced Studies in Natural Hazards. This will be managed by the Department of Civil, Environmental and Geomatic Engineering on behalf of the ETHZ Network for Natural Hazards (HazNETH; http://www.hazneth.ethz.ch), which is coordinated by Sarah Springman.

(1) BSc, 4th Semester, "Soil mechanics": 4 hours/week

The course introduces key processes such as:
- classification, site investigation;
- stresses and their distribution in soils;
- influence of groundwater in soils and on structures;
- piping, erosion and filters;
- stress-strain relationships, stress history;
- stiffness, settlement calculations, consolidation;
- strength, slope stability;
- mechanical compaction.

These fundamentals in soil mechanics and geotechnics are presented in order to:
- understand soil as a multi-phase hydro-mechanical system;
- obtain parameters essential for classification and description of soil;
- recognise key aspects of soil behaviour and the implications of this for obtaining and characterising the stress-strain response and deriving associated parameters (stiffness and strength).

Theory is related to aspects of earth and rockfill dam engineering to provide practical examples of why the theory is necessary and how the processes work. Laboratory exercises are organised in groups of 3-4 students, with 2 groups supervised per teaching assistant, to gain hands-on experience of classification, groundwater and shear strength. Virtual exercises are offered as computer aided learning within the Geotechnical Information Platform (GEOTip, http://geotip.igt.ethz.ch) in German and English, together with a course management system, notes, pictures, linked animations, challenges and exercises, worked examples, a glossary and a search machine.

(2) MSc, 1st Semester, "Theoretical and Experimental Soil Mechanics": 4 hours/week

The course extends the knowledge of theoretical approaches that can be used to describe soil behaviour to enable students to carry out more advanced geotechnical design and to plan the appropriate laboratory tests to obtain relevant parameters for coupled plasticity models of soil behaviour, based in Critical State Soil Mechanics (e.g. Schofield & Wroth, 1968). A further key goal is to give students the wherewithal to be able to select an appropriate constitutive model and set up insitu stress conditions in preparation for subsequent numerical modelling (e.g. with finite elements).

Lectures are conducted with reference to the framework of an embankment constructed on soft ground, such that students carry out oedometer and triaxial tests in the laboratory on sands as well as their 'virtual' equivalents on clay.

Recent contributions from a pedagogical study of this course by Thielen (2007), has led to more clarity in the presentation of complex material, and notably improved understanding by students. At the time of writing, 2/3rds of the annual oral examinations have been completed, and even better performance has been observed. Students answer more quickly and effectively, demonstrating deeper understanding of the underlying theoretical concepts.

(3) MSc, 1st Semester, "Design and Construction in Geotechnical Engineering": 2 hours/week

This course offers geotechnical design and construction of geosystems and structures, including more advanced analysis of the Ultimate and Serviceability Limit States. Particular themes covered include:
- introduction to Swisscode SIA 267 (2003);
- advanced pile design;
- design and construction for reinforced geosystems, (walls, natural slopes, soil nailing);
- landslides, case histories, stabilisation measures, influence of unsaturated conditions;
- measures to improve stability of embankments and river levees (ground improvement).

(4) MSc, 2nd Semester, "Soil Dynamics": 2 hours/week

The course delivers basic knowledge on soil dynamics, to solve simple problems and to be able to specify the tasks for multi-disciplinary specialists working on more complex systems. Contents include:
- differences between soil mechanics, dynamics,
- application of spring - mass - damping systems,
- wave propagation in ideal and non-ideal soil conditions,
- constitutive modelling, and relevant soil parameters for different soil types, determination of soil parameters in field and laboratory investigations,
- applications: machine foundations, vibration calculation, isolation, geotechnical earthquake engineering from geophysical background, seismic design and microzonation.

Studer et al. (2007) provides course documentation.

(5) MSc, 3rd Semester, "Physical Modelling in Geotechnics": 2 hours/week

Aspects of physical modelling in geotechnical engineering are presented to enhance an appreciation of typical mechanisms pertaining to the Ultimate & Serviceability Limit States for various geostructures (foundations (shallow, deep), bridge abutments, reinforced soils, soil nailing, anchorages, tunnels, deep excavations, earthquakes and dynamic problems, environmental geomechanics, transport processes, dams, embankments & slopes, cold regions engineering) and influence on resulting design methods.

Centrifuge modelling (Schofield, 1980; Taylor, 1995) forms a significant part of the course including calibration and validation of various types of models. The ETHZ Geotechnical Centrifuge (Springman et al., 2001) offers opportunities for providing physical data from a test carried out during the course.

2.3 *Professorship for Geomechanics*

Prof. Dr. Alexander Puzrin teaches (together with Ivo Sterba, Dr. Sophie Messerklinger and Dr. Markus Caprez) the following courses in the area of Geotechnical Engineering, Constitutive and Numerical Modeling in Geotechnics:

(1) BSc, 5th Semester, "Geotechnical Engineering": 4 hours/week

The course explores the fundamental principles of Geomechanics and Geotechnical Engineering, (Lang et al., 2007) with the following objectives:
- Recognition of the basic consequences of the ground construction;
- Understanding of the important fundamental concepts of Soil Mechanics and Geotechnical Engineering;
- Independent analysis of the basic geotechnical problems.

The content of the course includes:
- Overview of stability problems;
- Bearing capacity of shallow and deep foundations;
- Soil-foundation interaction;
- Analysis and design of shallow and deep foundations;
- Earth pressure on retaining structures;
- Analysis and design of retaining walls;
- Excavations: dewatering, analysis and design;
- Soil improvement;
- Safety considerations.

(2) MSc, 1st Semester, "Geotechnical Engineering in Transportation": 2 hours/week

Road design criteria are presented in this course, together with technology of road construction materials and geotechnical testing methods in the laboratory and in situ. The students benefit from a series of hands-on laboratory experiments, having learnt how to plan, monitor and interprete soil field tests, particularly in soil classification for traffic construction and mechanical compaction of road structures and dams. Frost characteristics of soils and soil stabilization techniques are also covered.

(3) MSc, 2nd Semester, "Constitutive and Numerical Modelling in Geotechnics": 4 hours/week

This course targets geotechnical engineers, who face these days more often the necessity of the numerical analysis in their practice.

The purpose has been to bridge the gap between the graduate courses in Geomechanics and those in Numerical Modeling. Traditionally, in many geotechnical programs, Geomechanics is not taught within the rigorous context of Continuum Mechanics. However, when it comes to Numerical Modeling courses, these are often taught using commercially available finite element (e.g. ABAQUS, PLAXIS) or finite difference (e.g. FLAC) software, which utilize constitutive relationships within the Continuous Mechanics framework. Quite often students have to learn the challenging subject of constitutive modeling from a program manual!

Content: This course is introductory - by no means does it claim any completeness and state of the art in such a dynamically developing field as constitutive and numerical modeling of soils. Our intention is to achieve a basic understanding of conventional continuum mechanics approaches to constitutive and numerical modeling, which can serve as a foundation for exploring more advanced theories. We focus on applications of the constitutive models within the available numerical codes. The important issue of derivation of model parameters from the lab tests has also received considerable attention.

(4) MSc, 3rd Semester, "Forensic Geotechnical Engineering": 2 hours/week

In this course, selected famous geotechnical failures are investigated with the following purpose:
- to deepen understanding of the geotechnical risks and possible solutions;
- to practice design and analysis methods;
- to learn the techniques for investigation of failures;
- to learn the techniques for mitigation of the failure damage.

Content:
- Failure of retaining walls;
- Failure of dams and slopes;
- Failure of shallow and deep foundations;
- Failure due to the creeping landslides;
- Failure due to excessive settlements;
- Failure due to the leaning instability;
- Excavation failure.

2.4 *Professorship for Underground Construction*

Prof. Dr. Georg Anagnostou teaches the Rock mechanics and courses on Tunnelling in soil or rock. The BSc, 5th semester course *(„Rock Mechanics", 2 hours/week)* supplements the basic soil and structural mechanics courses. Teaching focuses on the fundamental rock mechanics principles in the context of civil engineering as well as on the design of surface structures (foundations on rock, slope stability).

The 6th semester BSc course, as well as the MSc courses, is more design-oriented. Besides providing a solid theoretical background in the geotechnical and statical aspects of underground structures, as well as of the related analysis methods (including both simple computational approaches and advanced analysis techniques, their use and limitations), emphasis is placed on the integration of design and analysis issues, on the design process and its methodology, as well as on the interactions among the several activities of planning, design and execution

of underground activities. In this respect, exercising engineering synthesis (from problem appreciation to structural detailing) on realistic underground projects is an essential part of the education. In-depth study and analysis of case histories is an additional resource applied to teach problem evaluation and application of mechanics to practice.

The contents of the tunnelling courses are:

(1) BSc, 6. Semester, "Tunneling": 2 hours/week

Introduction to planning (incl. questions of tunnel system and alignment), design and mechanics of underground structures in rock or soft ground.

(2) MSc, 1. Semester, "Underground Construction I": 2 hours/week

Basic aspects of design and analysis of underground structures. Conventional construction methods (tunnels, caverns, shafts). Auxiliary measures (ground improvement and drainage, fore poling, face reinforcement). Principles and applications of numerical analysis methods. Urban tunneling (tunnel system, alignment, design and construction).

(3) MSc, 2. Semester, "Underground Construction II": 2 hours/week

Geotechnical aspects of mechanized tunneling in soft ground or hard rock. Lining systems. Tunneling through squeezing or swelling rock.

(4) MSc, 3. Semester, "Rock Mechanics and Tunneling - Selected Topics": 2 hours/week

Field measurements, Grouting and artificial ground freezing, tunneling in water bearing ground. Exercises: Conceptual solution of complex tunneling problems.

3 EDUCATION AT EPF LAUSANNE

3.1 *The Laboratories*

The Rock Mechanics Laboratory (LMR) and Soil Mechanics Laboratory (LMS) at EPFL cover teaching in soil and rock mechanics and related geotechnical engineering, including foundations, retaining walls, slopes and tunnels, natural hazards at the School of Architecture, Civil and Environment Engineering (http://lmr.epfl.ch/page35777.html).

EPFL has adopted the Bologna system and follows a 5 year teaching cycle. The teaching philosophy is very similar to that of ETH Zurich. In addition to the Bologna 5 Year teaching cycle, EPFL also promotes a Master of Advanced Studies (MAS) course in tunneling that runs every year. The MAS Tunneling is an advanced training programme that is jointly organised with the International Tunneling and Underground Space Association (ITA).

3.2 *Prof. Dr. Jian Zhao and LMR*

Prof. Jian Zhao and the staff of LMR teach the following courses at Bachelor and Masters level (http://people.epfl.ch/jian.zhao).

(1) BSc, 2nd Year, “Rock Mechanics”, 2 hours/week

Introduction to the principles of rock mechanics.

(2) BSc, 3rd Year, “Tunnel Design”, 2 hours/week

Introduction to planning, design and mechanics of underground structures in rock and soft ground.

(3) BSc, 3rd Year, “Foundation Engineering”, 3 hours/week

Introduction to foundation analysis, design and construction.

(4) MSc, 1st Year, “Underground Construction Technology”, 3 hours/week

Construction methods and technologies for various underground structures.

(5) MSc, 1st Year, “Geotechnical Engineering”, 3 hours/week

Advanced foundation design, slope analysis and other geotechnical topics.

(6) MSc, 2nd Year, “Soil structure interaction”, 3 hours/week

Geotechnical aspects of mechanized tunneling in soft ground or hard rock. Lining systems. Tunneling through squeezing or swelling rock.

(7) Master of Advanced Studies, “Tunneling”, Total 700 hours

This international, part-time MAS offers an advanced training programme that covers tunnel planning, design, construction, geo/investigation, analysis, modeling, construction management, safety and the environment. The course language is English. (http://lmr.epfl.ch/page64027.html?matrix=1158743307721)

3.3 *The Soil Mechanics Laboratory*

Profs. Laurent Vulliet and Lyesse Laloui (http://personnes.epfl.ch/laurent.vulliet or lyesse.laloui) and the staff of the LMS teach the following courses.

(1) BSc, 2nd Year, "Soil mechanics", 2 hours/week

Introduction to the principles of soil mechanics.

(2) BSc, 2nd Year, "Groundwater flow", 1 hour/week

Introduction to the principles of seepage in soils and rocks, leading onto analytical and numerical resolution techniques and their application to typical underground seepage problems.

(3) BSc, 2nd Year, ENAC week

This block course is focused on different themes each year.

(4) BSc, 3rd Year, Geotechnics and foundations, 2 hours/week

This course is taught for the Environmental Sciences & Engineering Section and covers identification and characterisation of soils, leading onto geomechanical solutions for geostructures.

(5) MSc, 1st Year, Geotechnical Engineering, 3 hours/week

This course covers a *Construction Project* in foundation design, slope analysis or other geotechnical topics.

(6) MSc, 3rd Year, Geomechanics 2 hours/week

Characterisation of non-linear behaviour of geomaterials leads onto constitutive and numerical modelling within an elasto-plastic framework.

(7) MSc, 1st or 2nd Year, Geotechnical testing, 5 hours/week

Students become familiar with experimental research or computation in a particular engineering field and on how to interpret and analyse data and results.

(8) MSc, 1st or 2nd Year, Safety and Reliability, 2 hours/week

Introduction to analysis in safety and reliability including mathematical theory, probabilistic methods of analysis.

(9) MSc, 1st Year, Risk management, 2 hours/week

Elements of danger and risk, leading onto the diverse mechanisms involved in hazards, global approaches and methodologies adopted to manage risk.

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