Some thoughts on the interplay between theory and practice in geotechnical engineering education within the frame of the new modularized university education system

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ABSTRACT: The splitting of the long-cycle first degree offered by universities in continental Europe into two components has significant consequences in civil engineering education. Key features of the traditional curriculum with respect to the knowledge area of geotechnical engineering are summarized. A curriculum is then proposed aiming to meet the challenge of maintaining the high standards of the traditional system while offering labour-market relevant qualifications at two different degree levels. The importance of combining a solid theoretical background with technical specialization and practice-oriented thinking is emphasized.

1 BACKGROUND

The Diplom-Ingenieur (Dipl.-Ing.) degree, first established as a university certificate in 1899 after an extensive struggle against the almost exclusively humanistic educational ideal, is in the process of disappearing.

The vast majority of the German universities will not be awarding this degree in the near future. Some of the technical universities (TU) intend to continue offering the degree in parallel with the new bachelor's and master's degrees due to its reputation as a trademark of quality engineering education. However, this double-track has practically little chances of surviving.

The abolishment of this traditional and extremely successful educational system started in 1998 when European politicians signed a declaration intending to harmonize the European educational system. The main task was the international acceptance of the European university degrees. Some were concerned about the value of their national certificates abroad, others were interested in shortening the duration of studies that were long particularly in Germany. In the meantime the so-called Bologna Accord signed by 45 countries aims to create a European higher education area by making the academic degree and quality assurance standards more comparable and compatible throughout Europe.

In the traditional Diplom-Ingenieur curriculum an interim-exam (Vordiplom) recognized only intra-university was required after the first two years of study. However, since the respective courses were in their majority the civil engineering fundamentals that were common to all national technical universities, the Vordiplom enabled students to change their place of studies with minor additional examination effort. The politicians' intention was to substitute this system by a shorter self-contained program of studies with a bachelor's degree that was expected to enable the graduate to directly enter the primary labour market early on.

Civil engineers were suddenly faced with the necessity to define new course structures leading to the hitherto unknown bachelor's and master's degrees with ETCS credits. Whereas in the traditional diploma the first years of study were dedicated to the fundamentals such as mathematics, mechanics, material behaviour, structural analysis etc., the new system requires the consideration of engineering applications already in the first semesters.

Whether or not the skills and abilities of the graduates of the bachelor's degree fit into the requirements posed by recruiters in the challenging environment of a global economy is not of prime importance to the promoters of the new model. Even for occupational fields for which the primary educational objective is routine engineering, and not innovation, the bachelor's degree is considered insufficient by universities. By classifying the graduates as "employable but not professional" companies are advised of the need to further educate the graduates in-house so as to attain the level of the former graduates of the German polytechnics (Fachhochschulen).

For a master's degree, German technical universities (TU) are expected to require a four-semester education with an explicit recommendation that all civil engineering students pursue this higher degree. The bureaucratic standard of prescribed "workload" (5400 course and home work hours for a bachelor's degree) that was introduced for the sake of degree comparability can not equally be applied to all disciplines: It may be acceptable for economics or literature studies, but it is not sufficient for engineering.

Instead of homogenization each university department is debating about the appropriate duration of studies, and various combinations are being reviewed, e.g. six plus four, seven plus three, eight plus two. In fact, the decade-long equivalence of engineering diplomas -even within the country- is in danger. It should be noted that the vast majority of continental European countries had traditionally a five-year program for the education of their engineers.

2 GEOTECHNICAL ENGINEERING EDUCATION IN THE TRADITIONAL MODEL

In the traditional five-year university diploma, courses in geotechnical engineering were offered in the third or fourth semester. Students first came to know about its importance during the first year of study as part of a course that provided in short an overview on engineered structures. The basic courses were on soil mechanics and foundation engineering, respectively, accompanied by laboratory exercises. The courses in Soil Mechanics addressed the following topics:

- Soil classification and soil properties
- Methods of subsoil investigation
- Effects of groundwater - permeability
- Stresses is soils
- Deformation properties - settlements
- Consolidation
- Shear strength
- Earth pressure
- Slope stability
- Bearing capacity of footings

The courses in Foundation Engineering included:

- Methods of ground improvement
- Surface foundations
- Retaining walls
- Supported excavations
- Groundwater control
- Piles

These courses were mandatory for all students, irrespective of their specialization after the interim-exam (Vordiplom). After the interim-exam students were asked to decide by themselves on the field of specialization. In most universities students were free to combine two fields or even three (for example geotechnics, reinforced concrete structures, and construction management). Only few universities decided to put a stronger focus by prescribing a single field of specialization. The latter concept is inevitably related with the ability of the department to offer a variety of courses covering a broad range of subjects. This in turn can only be realized if the respective human resources in terms of qualified teaching personnel are provided by the state. This is not automatically given, since in the German system the overall teaching responsibility is assigned to the chair person. Nowadays, with a few exemptions, the field of soil mechanics and foundation engineering is represented by a single chair person at each university. Even after adding the small number of permanently employed senior research associates with a qualification for autonomous teaching, the number of courses that can be offered is limited. Additional specialized subjects are entrusted to external adjunct faculty members that are employed full-time in consulting offices, authorities, or construction companies. Concurrently, this concept enhances the exchange of experience with practicing engineers and provides an up-to-date education in these specialization fields.

Each department emphasizes selected subjects, such as rock mechanics, tunnelling, soil dynamics, or sanitary landfill engineering.

During the beginning of the 1990's when civil engineering was very popular among students, departments offered a variety of specialized courses. A typical example are courses on design and operation of landfills that where at that time an expanding field. Today, due to the decrease in civil engineering students and the associated reduction of the permanently employed academic personnel there is a tendency to shrink such courses.

The interplay of theory and practice is a key issue in the civil engineering educational system. To guarantee the proper consideration of practical aspects in engineering education, practical skills and also the ability to communicate them to the students is a pre-requisite for most of the appointments of geotechnical chair persons.

It should be noted that geotechnical engineering is composed of a number of sub-disciplines dealing with a variety of material classes and structure types unified under one single roof: soil mechanics, rock mechanics, foundation engineering, tunnelling, soil dynamics and earthquake engineering, dam engineering, environmental soil engineering, to name the most important. Compare the traditional water engineering that is split into hydromechanics, hydrology, waterways engineering, or the traditional breakdown of structural engineering into material-specific sub-disciplines for concrete, steel, and light-metal structures. Furthermore, geotechnical engineering introduces students to the need in considering the concepts of continuum mechanics in the analysis, in addition to the complexity arising from the inherent nonlinearity and time-dependency of soil behaviour.

Hence, it becomes obvious that an integrated consideration of theoretical and practical aspects is the key in the formation of a capable geotechnical engineer, who is requested to understand in depth the complex soil behaviour in order to interpret the observations made and successfully realize new difficult projects. The study of soil mechanics is very fruitful in furnishing concepts which form the solid background for his intuition. Practical experience in construction is also valuable in this respect, but it is not the main task of a university education to provide this. Technical know-how can be gathered much faster than knowledge of mechanical and physical properties of soil and on the concepts underlying high-end geotechnical design.

The aspects outlined above have to be considered in the tight requirements of the modularized system that most probably will survive the undoubtedly successful five-year diploma model that aimed at forming -even at a cost of prolonged studies- engineers with a solid education having the capability to gain fast insight into a problem, able to take initiative and responsibility, and to provide appropriate solutions in a short time.

3 GEOTECHNICAL ENGINEERING EDUCATION IN THE MODULARIZED SYSTEM: A PROPOSAL

3.1 *First-degree courses*

The subject matter of the fundamental courses in soil mechanics and foundation engineering, respectively, as outlined above are considered as a minimum of knowledge for any bachelor's level civil engineering school graduate.

The first contact with the role and importance of geotechnics in civil engineering is offered in an introductory course on Principles of Structural Engineering. This course is jointly offered in the second and third semester by the structural analysis, reinforced concrete, steel structures, and geotechnical engineering chairs. An equivalent of 2 Credit Points (CP) is assigned to geotechnical engineering within this course. Each CP corresponds to 30 hours of work load (courses, home work, and examinations). The students get acquainted with the basic physical and mechanical properties of soil and rock and their determination in the laboratory, and the set-up of exploration programs. Basic foundation systems like footings, rafts, and piles are described and the interaction between superstructure and foundation is elucidated. This course is mandatory for all students.

Courses on Soil Mechanics and Foundation Engineering as outlined above for the traditional five-year course are offered in the fourth and fifth semester. It is mandatory for all students irrespective of their focus area, i.e. structural engineering or infrastructure and environmental planning. 5 CP for Soil Mechanics including practical laboratory exercises and 3 CP for Foundation Engineering are assigned.

Foundation Engineering includes also an introduction to numerical methods as applied to the solution of standard geotechnical boundary value problems, such as soil-structure interaction for shallow and deep foundations as well as for excavation design. Well-documented codes that do not require expert knowledge in finite-element methods already exist. The importance of selecting appropriate constitutive models for the soil is accentuated in this course.

Engineering Geology with 2 CP is offered in the second or third semester. The principles are important to geotechnical engineers helping them to understand the nature of subsurface conditions and form much of the basis for interpreting data collected from exploratory borings. The course explores fundamental principles of geology and their application to geotechnical engineering, with extra emphasis on the geological origin of soils. It addresses the following topics:

- Rock and soil
- Rock-forming minerals
- The geologic cycle
- Major categories of rock
- Elements of structural geology
- Soil formation, transport, and deposition
- Planning of site exploration and characterization programs
- Geological aspects in the design of underground structures

Site visits are helping the students to get familiar with soil and rock material and visualize the geological processes.

The soil and rock laboratory exercises cover standard classification tests, hydraulic conductivity, compression tests, and shear and triaxial tests for estimating shear strength.

The philosophy underlying modern design and construction codes such as DIN, Eurocodes, and DIN EN is explained to the students, and calculation methods pertinent to standard foundation types, retaining structures, and slopes are also covered. The application is demonstrated in the accompanying exercises.

The aim of engineering education in the first three years should be two-fold: i) Provide insight into the variable and complex nature of soil arising from the complicated stress-strain relationships of soils, which will enable the students to follow the advanced geotechnical courses offered in the master's program, ii) provide an adequate expertise level on geotechnical engineering for students that either focus on non-structural specialization fields in their advanced studies or discontinue the university to join construction industry, authorities, or design offices.

3.2 *Advanced-degree courses*

Courses in Advanced Soil Mechanics (3 CP) focus on the theoretical and quasi-theoretical approaches for solving problems in the broad soil mechanics subject areas of stress analysis and consolidation theory. Specifically, this course may include:

- Constitutive models for inelastic material behaviour
- Yield criteria and plastic flow
- Work hardening models
- Composed rigid body failure mechanisms in slope stability analysis
- Groundwater flow
- Time-dependent soil behaviour

Courses in Advanced Foundation Engineering (3 CP) may include:

- Anchoring
- Soil reinforcement
- Ground improvement by grouting
- Embankments
- Sanitary landfills
- Cofferdams

Courses in Computational Geotechnics (2 CP) focus on the application of computational mechanics, and in particular of the finite element method, on the solution of stress and flow problems in geotechnical engineering. The course offers an overview of the key features of the finite element method emphasizing the aspects on proper modelling of soil as nonlinear continuum. Application examples include simulation of deep excavations in soft soils, or the deformation prediction of settlement sensitive structures, demonstrating also common errors/pitfalls.

A course that covers more practical aspects refers to Special Foundation Works (3 CP) including:

- Laterally loaded piles and pile groups
- Piled-raft foundations for high-rise buildings
- Diaphragm wall design
- Supported excavations in soft soils
- Monitoring, and applications of the observational method
- Tunnelling in soft ground

Rock Engineering and Underground Structures (3 CP) cover:

- Characteristics of rock mass
- Testing techniques for rocks
- Rock slope stability
- Rock reinforcement
- Tunnel boring machines
- Design and analysis fundamentals for underground excavations

Soil Dynamics and Geotechnical Earthquake Engineering (3 CP) include:

- Simple structural vibrating systems
- Wave propagation in soils
- Dynamic soil properties
- Foundation vibrations
- Vibration protection
- Earthquake motions and site response analyses
- Liquefaction
- Principles of earthquake resistant design of geotechnical structures

Throughout all courses it is emphasized that, although the underlying theories are relatively straightforward, the actual difficulty in geotechnical engineering is the transfer/application of these theories to real-world problems that are often characterized by incomplete information regarding site characteristics, loading, and soil properties/behaviour. Hence, students are learning to identify the key variables governing the problem under consideration and the sources of error, to investigate the sensitivity of solutions to changes in the input data and its impact on construction costs.

Considering the fact that nowadays the tolerable response time in the decision making processes is continuously shortened, the geotechnical engineer must possess an adequate theoretical background so as to identify the implications of design changes in the overall system behaviour, and also have access to the respective tools in terms of simple theoretical solutions to complex boundary value problems.

Finally, is should be noted that in 2001 the ASCE Board of Direction adopted policy 465, which supports the concept of the master's degree or equivalent as a prerequisite for licensure and the practice of civil engineering at the professional level. In other words, the Board believed that education beyond the bachelor's degree is necessary to prepare an engineer for practice.

4 CONCLUSIONS

With emphasis on fundamentals in the first two years of study and the subsequent blend of theory and application within specialized fields, the traditional five-year diploma program ensured that civil engineers achieved a broad technical and theoretical background so as to face challenges in a demanding profession and secure their place in an increasingly global society. The curricula evolving from the split of the long-cycle degree into two components and the associated modularization of studies, as driven by the Bologna Accord, shouldn't deviate from these high standards.