Theme lecture: Geotechnical education towards 2000

Exposé sur le thème: La formation eu geotechnique pour l'année 2000*

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ABSTRACT: This paper summarizes the work carried out by ISSMFE Technical Committee TC31. In particular, it addresses the issues of educational objectives, geotechnical curricula, computer-added instruction, demonstrations and experiments, and case histories for teaching. It is concluded that ISSMFE should continue to be actively involved in education matters, and that, through its various Technical Committees, it should focus on bridging the gap between design practice and current research.

RESUME: Ce papier fait le sommaire des travaux du Comité Technique TC31 ISSMFE. Spécifiquement, il s'adresse aux donneés des objectifs pédagogiques, aux programmes géotechniques, à l'instruction supportée de l'informatique, aux demonstrations et expériences, et aux cas examples pour l'instruction. Il est conclu que ISSMFE devrait poursuivre activement les matières pédagogiques, et à l'aide de ses comités techniques, devrait se concentrer sur les moyens de combler la lacune entre la recherche et la pratique.

1 INTRODUCTION

Geotechnical engineering education was re-established on the agenda of the International Society of Soil Mechanics and Foundation Engineering (ISSMFE) in 1989 by the then Board of the Society. The impetus has continued via the establishment of a Technical Committee of the Society (TC31) in 1994, with widespread international representation, and the inclusion of sessions on education at a number of regional conferences, notably the European regional conference in Copenhagen in 1995.

TC31 had the following terms of reference for the 1994 – 1997 period:

1. development of detailed curricula for undergraduate courses, recognizing that these could vary from region to region and country to country
2. collection and development of demonstrations, experiments and models which illustrate the fundamentals of soil mechanics
3. the assessment and development of techniques for computer-aided instruction
4. the collection of suitable case histories for use by instructors in their courses. Such case histories should be properly documented and emphasise various facets of the subject e.g. shallow foundations, deep foundations, retaining structures, slope stability, groundwater problems. It would be aimed at students in more advanced courses.

This report is presented on behalf of TC31, and summarizes some of the results of their efforts, together with relevant contribution from the previous ISSMFE Task Force and other sources. It also addresses, in a preliminary manner, some of the issues related to postgraduate education and professional training.

2 EDUCATIONAL OBJECTIVES

The objectives of undergraduate education in geotechnics depend to a significant extent on the overall degree course which the student is pursuing. Degree courses in which one or more courses in geotechnics would be given include:

1. civil engineering, specializing in geotechnical engineering
2. general civil engineering, not specializing in geotechnical engineering
3. mining engineering
4. environmental engineering.

The amount and nature of the geotechnical courses will generally differ in each case, but there will nevertheless be a series of desirable objectives, which will include the following (Poulos, 1994):

1. a proper understanding of the principles of soil mechanics, and of the effective stress principle in particular
2. an appreciation of the process of application of theory to practice
3. an understanding of the shortcomings of both theoretical and practical design methods
4. an appreciation of the means by which soil parameters may be assessed i.e. laboratory tests, in-situ tests, empirical correlations.

It has been suggested that an undergraduate course should ideally contain three courses in geotechnical engineering:

1. basic soil mechanics (SM)
2. soil and foundation engineering (SFE)
3. geotechnical engineering (GE).

Depending on the degree course being undertaken, and the career path of the student, it may not be feasible to include all three courses in the undergraduate degree structure. Table 1 outlines the possible combination of geotechnical courses for the various degree programs. Given the likely time constraints of contemporary undergraduate degree programs, only those students in civil engineering who specialize in geotechnical engineering are likely to be able to take all three courses. In mining and environmental engineering degree programs, it will generally be appropriate to develop special courses (perhaps as components of other courses) which focus on the special courses in each discipline. For example, Adler and Neumann (1985) contrast geotechnical courses for civil and mining engineering and emphasize that the subject needs to be handled differently in each case. Table 2 summarizes some of the contrasting features in civil and mining engineering programs.

3 FUNDAMENTAL PRE-REQUISITES

Prior to undertaking courses in geotechnics, it is essential for students to have taken courses in a number of more fundamental subjects, including the following:

1. mathematics
2. numerical methods
3. engineering mechanics, including both statics and dynamics

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4. engineering geology
5. chemistry
6. computer programming, including the use of programs such as EXCEL, MATHCAD, MATHEMATICA and MATLAB.

The first four of the above subjects require little discussion, and are part of any proper University engineering course. However, chemistry became a minor part of many courses in the 1960's and 1970's, and it is only in the past 15 – 20 years that its importance in relation to environmental engineering and soil behaviour has been re-discovered. Modern computing tools, such as those mentioned in (6) above, have become an indispensable part of engineering practice, not only with respect to computation, but also with respect to portrayal and graphical representation of numerical or analytical calculations. A person not intimately familiar with these tools is likely to be at a severe disadvantage in tomorrow's engineering world.

Table 1.

Degree Course	Geotechnical Courses Taken	Remarks
Civil Engineering specializing in Geotechnical	SM SFE GE	
Civil Engineering General	SM SFE	
Mining Engineering	SM MGE	MGE=mining geotechnical engineering
Environmental Engineering	SM EGE	EGE=environmental geotechnical engineering

Note: SM = Basic Soil Mechanics
SFE = Soil and Foundation Engineering
GE = Geotechnical Engineering

Table 2. Contrasting Geotechnical Structures for Civil and Mining

Element	Civil Engineering	Mining Engineering
Materials	Soil, intact rock	Altered, fractured rock
Loads	Vertical boundary, hydrostatic	Body and tectonic
Structures	Linear, limited extent, foundations, cuts, tunnels, shafts, cavities	Vast, major disturbances, mines, shafts, tunnels
Time	Static	Dynamic (expanding, contracting, deteriorating)
Purpose	Access-opening	Extraction-Bulk solid material

4 CURRICULA FOR UNDERGRADUATE COURSES

A valuable framework for geotechnical education was proposed by Burland (1987), in which he introduced the concept of the "Soil Mechanics Triangle". The apexes of this triangle represented:
1. the ground profile
2. soil behaviour
3. applied mechanics.

Linked to these is empiricism and "well-winnowed experience", as shown in Figure 1. Components of all three aspects should pervade all geotechnical courses, together with the recognition that empiricism is an inevitable and essential aspect of soil mechanics.

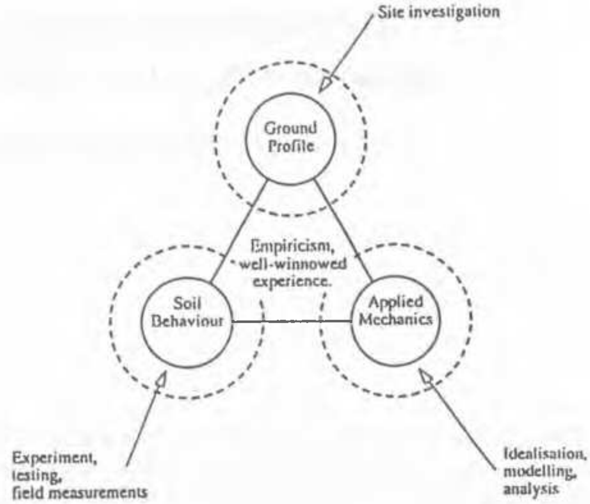

Fig. 1:The soil mechanics triangle (Burland, 1987)

It has been suggested above that there should be three main courses in geotechnical engineering at an undergraduate level, basic soil mechanics, soil and foundation engineering, and geotechnical engineering. Detailed curricula have been outlined for these courses by Poulos (1994).

No attempt is made have to suggest appropriate curricula for geotechnical courses for mining and environmental engineers (as mentioned in Section 2), not because these courses are unimportant, but because TC31 has not given the matter detailed consideration.

It is neither practical nor desirable to attempt to prescribe universal curricula for the three basic courses. Different countries, and different institutions within a country, may adopt a different approach which reflects their own historical and cultural attitude towards engineering education. Nevertheless, a limited review of geotechnical courses from a number of countries reveals considerable similarity in the basic course. Table 3, adapted from Poulos (1994), gives lecture and demonstration/experimental topics which are reasonably common in many countries.

Tables 4 and 5 summarize the main components of the courses on Soil and Foundation Engineering, and Applied Geotechnical Engineering, as proposed by Poulos (1994). Differences in curriculum tend to become more pronounced in relation to the courses dealing with applications of principles and applications to practice. For example, in contrast to the two courses indicated in Tables 4 and 5, Schlosser et al. (1995) reveal that at the École Nationale des Ponts et Chaussées (ENPC), there are four courses, in addition to a basic course in soil and rock mechanics:
a) foundations and retaining structures
b) mechanical behaviour of soils
c) in-situ geotechnics
d) soil and water: interactions.

Course (a) is an obligatory course for civil engineering and building science and covers the following aspects:
• in-situ testing
• design of shallow and deep foundations
• design of retaining walls
• design of sheet piles and cast in situ walls
• tunnels in soft ground
• soil reinforcement.

The other three courses are "experimental courses", in that they involve primarily laboratory and field work. While the ENPC courses are packaged and presented in a particular way, the overall content is not markedly different from that outlined in Table 4. Clearly, there is considerable room for flexibility in the way in which the courses are organized and run, but it would appear that the basic educational objectives are similar to those outlined in Section 2.

Table 3. Basic Soil Mechanics – Main Course Topics

Lecture and Tutorial
• Soil formation and geomorphology • Phase relationship and basic definitions • Soil classification • Effective stress principle • Soil permeability • Seepage analysis • Stress paths, Mohr circles • In-situ stress, preconsolidation pressure • Soil compressibility and stress-strain • Soil strength • Critical state concepts • Undrained and drained strength
Demonstrations and Laboratory work
• Effective stress principle (Demo) • Seepage/quicksand (Demo) • Soil classification (Lab) • Seepage model (Lab) • Direct shear test on clay (Lab) • Direct shear test on sand (Lab)

Table 4. Soil and Foundation Engineering – Main Course Topics

Lectures and Tutorials
• Principles of stability analysis; short-term and long-term conditions • Principles of settlement analysis • Laboratory testing procedures • Design of shallow foundations • Design of deep foundations • Earth pressures and retaining wall design • Stability of slopes and excavations
Demonstrations and Laboratory work
• Consolidated undrained triaxial test on clay* • Oedometer test* • Model footing test • Model laterally loaded pile test • Retaining wall model • Computer analysis of slope stability

* Video or demonstration preferable

5. COMPUTER-AIDED INSTRUCTION

Very significant advances have been made in the past few years in computer-aided instruction. Computer programs now go far beyond tools to analyze engineering problems, and cover almost the entire range of geotechnical education, including theory, laboratory test simulation and foundation design. As examples of these developments, four computer-aided teaching suites will be described below.

5.1 CATIGE - Computer-Aided Teaching and Instruction for Geotechnical Education

Jaksa, Kaggwa, and Gamble (1996) have described a suite of 11 computer programs which have been written to assist with the teaching of elementary geotechnical engineering principles to university undergraduates. They describe the philosophy underlying the development of the programs, and outline the main principles they have attempted to follow. These principles include:

Table 5. Applied Geotechnical Engineering - Main Course Topics

Lectures and Tutorial
• Site investigations • In-situ testing • Soil compaction • Soil improvement techniques • Soil reinforcement • Support of excavations • Dewatering and groundwater control • Problem soils: expansive and collapsing soils, frost susceptibility • Approaches to solution of practical geotechnical problems
Laboratory and Field Demonstrations, and Projects
• Site investigation (Field) • In-situ testing techniques (Field) • Soil reinforcement (Lab) • Case study (Project) • Foundation design (Project) • Retaining structure design (Project)

• the software should be easy to use and user-friendly
• the programs should have adequate Help facilities
• the main aim is to enhance understanding of the fundamental geotechnical engineering principles, rather than to provide experience in computer-aided design
• the software should be user-interactive.

The programs in the CATIGE Suite are as follows:

1. CLASS4W - Soil Classification
2. EFFECT4W - Vertical Effective Stress
3. MOHR4W - Mohr Circle of Stress
4. DSAND4W - Direct Shear Test in Sand
5. TRIAX4W - Triaxial Test
6. FALLINGW- -Falling Head Test
7. CONSOL4W - Consolidation Processes
8. PROCTORW - Proctor Compaction Test
9. RETAIN4W - Sheet Pile Retaining Wall Analysis
10. DAMS4W - 2D Seepage Analysis
11. EXPANSIV - Expansive Soil Heave.

Figures 2 and 3 show typical screens from two of these programs, DSAND4W and RETAIN4W.

The authors discuss the benefits of computer-aided teaching, but at the same time, recognize and point out the limitations. In particular, students do not see or handle real soils on the computer, nor do they become familiar with the equipment or apparatus involved. Therefore, computer-aided instruction is only an adjunct to a broader range of teaching methods.

5.2 GeotechniCal - Computer Assisted Learning in Geotechnical Engineering

Davison (1996) has described the software suite developed by a consortium of 23 universities in the UK via a large grant from the Government Teaching and Learning Technology Programme.

There are 5 components or strands to the project, each addressing a different aspect of geotechnical teaching and learning. In summary, the 5 strands are as follows:

1. Geotutor - an exploration of some of the important concepts in geotechnical engineering by manipulating simple models and observing the effect. A total of 25 models have been produced to date, including strength, compression, permeability, walls, foundations and slopes.
2. Soil-Structure Interaction - illustrations of the dependence of sol-

DSAND4W

Direct Shear Testing of Sands

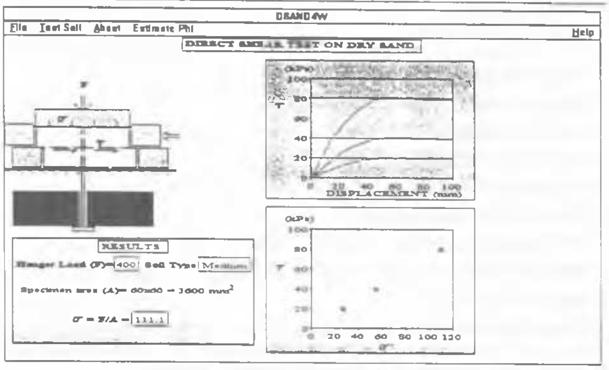

Fig. 2:Typical screen from CATIGE program DSAND4W

RETAIN4W

Sheet Pile Retaining Wall Analysis

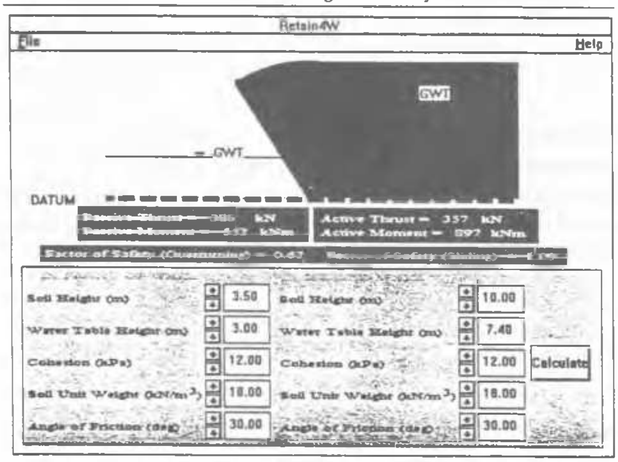

Fig. 3:Typical screen from CATIGE program RETAIN4W

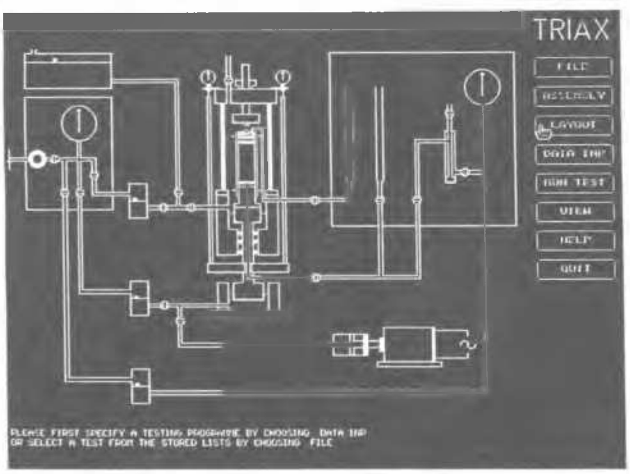

Fig. 4:Typical screen from TRIAX, showing completed Test Assembly

structure systems on the stiffnesses of the soil and the structure, as well as the applied loads. Examples include pile and slab foundations, tunnels, retaining walls, and reinforced structures.

3. CONFOUND - a knowledge-based system for the preliminary conceptual design of foundations. It operates in two modes, browse mode and decision mode, and can offer the user a hierarchy of foundation types together with an indication of the circumstances for applicability.

4. Site Investigation - this comprises a game supported by a series of tutorial models. It provides a simulation of a number of situations and enables the students to explore some of the consequences of decisions taken about costs, information assembly, and exploratory techniques.

5. LABSIM - computer simulation of the triaxial test, allowing students to carry out a "test" on the computer screen and observe the behaviour of soil types which can be user-defined.

Once again, it is emphasized that computer-aided instruction is a most valuable component of an overall teaching strategy. Trial demonstration versions are available on CD, and students and instructors are now able to access the system via the Internet.

5.3 TRIAX - Triaxial Test Simulation

Fung and Kay (1994) have described an interactive computer graphics simulation package for triaxial testing of soils. In the TRIAX package, the user may chose any or all of the following options:

a) participate in the assembly process in preparation for the test

b) define the detailed nature of the test and proceed with its execution

c) observe and study, on the screen, the physical response of the sample and the appropriately timed test paths of the various parameters in graphical form.

Figure 4 shows a typical screen from the program, illustrating the completed text setup prior to testing.

In simulating the execution of a test, the user observes the complete circuit arrangement and then specifies the detailed nature of the test, including the applied stresses, the consolidation phase, and the shearing phase. The progress of the test is tracked by various test paths (e.g. deviator stress versus mean effective stress; specific volume versus mean effective stress). Finally, in order to increase the concept of realism, pictures showing a triaxial testing apparatus and various failed soil samples have been incorporated in the program. There are activated intelligently, according to the soil and the test nature.

Such a program provides an instructive and entertaining means of simulating a test which, in practice, can be both time-consuming and frustrating.

5.4 GEO-SIM - Laboratory Test Simulation

An approach which is similar in principle, but different in execution, to the above system is described by Penumadu et al (1997). They discuss the implementation of computed-aided teaching methods via the development of a Geotechnical Test Simulator (Geo-Sim) for virtual laboratory experiments. Its application to triaxial tests is discussed in detail. During simulation of the test, appropriate commands are sent to locate and play the pertinent track of a laser disc, thus displaying the video image of a previously taped physical test on the monitor. At the same time, the soil model predicts and displays appropriate graphic output for a given set of input test parameters.

5.5. The Role of the Internet

The meteoric rise of the Internet over the last two years has resulted in a vast amount of geotechnical information being available on the World Wide Web. A cursory search revealed 10560 matches for the key words "geotechnical and teaching" and 60500 for "piles and foundations". Clearly, not all of the items will be of enduring value. Useful guides to some of the available sites are given by

Table 6. Some Web Sites with Geotechnical Content

Organisation	Web Site	Remarks
Virtual Library of Geotechical Eng.	www.geotech.civen. okstatc.ed/wwwvl	Elec. journal of geot. eng., lists of computer programs; consultants; research labs; conferences; magazines
Geotechnical and Geo-Environmental Software Directory	www.lbmpcug.co. uk/nbedrock/gsd	Catalogue of hundreds of computer programs for geotechnical engineering
Edinburgh Eng. Virtual Library	www.eevl.ac.uk	Database of eng. resources, offshore eng. information, 40 day archive of articles
Pile Buck	www.pilebuck.com	Pile driving, foundation and marine contractors' newspaper; specifications for sheet piling
Geotechnical Project	cl24.uwe.ac.uk/geo cal/geocal.htm	News and information on project
UK Building Research Establishment	www.bre.co.uk	List of research programmes; promotional material
CIRIA	www.gold.net/ciria/ groupub.html	Summaries of research publications
SGI	www.sgi.geotek.se	Literature database (requires subscription)

Bond (1996, 1997).

Table 6 summarizes some current web sites of geotechnical interest.

6 DEMONSTRATIONS AND EXPERIMENTS

There is little doubt that some of the principles of soil mechanics and foundation engineering can be communicated effectively via suitable demonstrations and experiments. Sparks (1997) describes a series of conceptual and physical models involving partly saturated soils, slope stability, deflections, seepage problems and soil strength. Simple and innovative models and soil compressibility are also described in detail. A summary of some other examples is given in Table 7.

The geotechnical centrifuge is a powerful demonstration tool which provides a most instructive means of examining mechanisms of failure, both qualitatively and quantitatively. Barker at al (1997) describe the use of a drum centrifuge to model embankment construction on soft clay. Students have an opportunity not only to see the mechanism of failure, but also to compare the measured behaviour with theoretical predictions. Henderikus (1997) describes the use of a small centrifuge to carry out a variety of instructive experiments.

Of course, only a few teaching institutions around the world have a centrifuge available. It would therefore appear that an opportunity

Table 7. Summary of Available Demonstrations and Experiments

Principle Illustrated	Method	Typical References
Stoke's Law	Settling rate in hydrometer	Barber and Krizek (1967) Casagrande (1996)
Deposition of granular soil	Base friction model	Burland (1987)
Effective stress	Cotton ball experiment Rubber glove with dry sand and vacuum Liquefaction via upward flow	Casagrande (1996) Poulos (1994) Poulos (1994)
Capillary rise	Different size tubes filled with water Tube of fine silty sand Excavation in moist sand	Casagrande (1996) Casagrande (1996) Casagrande (1996)
Physio-chemical effects	Mix dry clay with various pore fluids-observe plasticity differences	Elton (1997)
Friction	Angle of repose	Holtz and Kovacs (1981)
Quicksand, liquefaction	Upward flow in container with sand	Holtz and Kovacs (1981), Poulos (1994), Elton (1997)
Arching effects	Coarse sand in transparent tube with trapdoor	Casagrande (1996), Biarez and Taibi (1995)
Lateral earth pressure and retaining walls	Base friction model Model wall with rods as "soil"	Burland (1987) Biarez and Taibi (1995)
Reinforced soil structures	Fine sand backfill with paper sheets as reinforcement	Biarez and Taibi (1995) Elton (1997)
Settlement of cohesive soil	Terzaghi spring models. Banded clay layers in transparent container	Casagrande (1996) Barber and Krizek (1967)
Bearing capacity	Base friction model. Banded clay layers in transparent container. Gelatine poured into sand after footing failure on slope.	Burland (1987) Barber and Krizek (1967) Sparks (1997)
Slope stability	Granular soil at angle of repose: add soil to show that catastrophic failure does not occur. Tilting slope model with sand layer.	Casagrande (1996) Sparks (1997)
Seepage	Flow tank with sand; dye injection and piezometer tappings	Barber and Krizek (1967), Poulos (1994), Elton (1997)

exists for some carefully planned stability experiments to be conducted and videotaped, and then distributed for teaching purposes.

7 CASE HISTORIES

The use of case histories in geotechnical education may serve several useful purposes including:

1. illustration of the behaviour of real soil and foundation systems
2. the opportunity to compare measured behaviour with that predicted theoretically
3. a demonstration of how even experienced engineers can often overlook details which may result in failures.
4. demonstration of the fact that there is almost invariably a lack of data available in real projects.

Various approaches can be adopted in using case histories for teaching purposes. An interactive approach has been described by Peck and Ireland (1974) and involves interaction between the instructor and groups of students who act as a board of specialist consultants. To be successful, such an approach requires an instructor with considerable practical experience and an intimate knowledge of the case history being considered. In the absence of such a person, it may be necessary for an instructor to adopt a more passive approach in which the details of a published case history are presented, and the students are asked to provide a substantiated opinion on the reasons for the behaviour observed in that case history.

To be useful for teaching purposes, a case history should include at least some of the following features:

a) a description of the geological setting
b) details of the subsurface and groundwater
c) quantitative information on the appropriate soil parameters and a description of how these were derived
d) details of the design/analysis method used and the design loadings
e) construction details
f) details of performance, including appropriate measurements
g) description of any incidents or failures which occurred
h) details of the subsequent assessment of reasons for the incident or failure
i) details of any remedial works undertaken to alleviate or remedial the problem
j) the case should not be excessively complex so that a quantitative assessment can be made without a sophisticated computer analysis.

The text book by Anderson and Trigg (1976) provides a useful summary of case histories involving dams and reservoirs, tunnels, shafts and underground chambers, bridges, cuttings, road rail and runway foundations, building foundations, harbours and coastal works, and tip failures in South Wales. While instructive, most of the cases are described rather concisely, and lack the quantitative detail to enable the student to make an assessment of the problem.

Table 8 gives a few examples of some published case histories which possess a reasonable number of the desirable attributes listed previously. There are doubtless many more available in the vast geotechnical literature.

8 POSTGRADUATE AND CONTINUING EDUCATION

In many countries, the traditional undergraduate courses cannot provide the necessary depth and breadth for a student to become a competent geotechnical engineer. The primary aim of the undergraduate courses should be to assist the student to understand the fundamentals of geotechnical engineering. Depth and breadth of knowledge require further education, either via a formal postgraduate degree course, or via short courses for practising professionals.

Table 8. Examples of Published Case Histories Useful for Teaching Purposes

Subject Matters	Details	Reference
Shallow foundation settlement	Auditorium, Chicago: measured and calculated settlements on clay	Skempton et al (1995)
	Leaning tower of Pisa; settlement and tilting, and remedial measures	Kerisel (1975), Jamiolkowski (1994, 1997)
Shallow foundation failure	Transcona Elevator, Canada; rigid foundation failure of clay	Peck and Bryant (1953)
	Footings on sand, Texas, USA. "Class A" predictions	Briaud and Gibbons (1994)
Pile foundation settlement	Hotel Sao Paulo, Brazil/ group settlement greater than single pile	Vargas (1948)
	Furnace foundation, Quebec. Group settlement affected by soft layers at depth	Golder and Olsen (1968)
Sheet pile wall	Anchored bulkhead, Houston, Texas; failure of wall; short-term analysis only used, but long-term case more critical	Daniel and Olsen (1983)
Highway embankment settlement and failure	I-95 Boston, USA. Test embankment loaded to failure, "Class A" predictions	Davis and Poulos (1975)

Formal postgraduate courses vary very widely throughout the world, and in many cases, may emphasize the particular research and professional interests of the faculty members giving the courses. Poulos (1994) suggests that such courses may be classified into "in-depth" courses, which build upon and extend topics which have been covered in the undergraduate courses, and "added-breadth" courses, which address topics which may not have been covered previously. A number of course topics are suggested in each category. Courses involving environmental geotechnics are an example of this latter type of course.

Short courses for professionals are an important source of continuing education, and are a mandatory requirement in some countries for continued professional registration. Such courses may take a number of forms, among which are the following:

1. refresher courses on fundamental courses
2. courses on recent developments in traditional topics
3. courses on newer topics
4. courses on topics which are associated with geotechnology, but are outside the immediate scope e.g. courses on seismology for geotechnical earthquake engineers, microbiology for environmental geotechnical engineers, and wave forces for offshore geotechnical engineers.

A series of recent papers has addressed continuing education in Germany for various professional groups, including junior engineers, within the construction industry (Arz and Seitz, 1997), civil engineers involved in hazardous sectors of the construction industry (Ensinger, 1997), and coordinators and site managers carrying out work in contaminated areas (Wilhelm, 1997).

A vital function of continuing education courses is to bridge the gap between current practice and the latest research developments. Too often, instructors who have learned traditional approaches to certain problems continue to teach them to their own students, perhaps unaware that such approaches may have been superseded by more recent developments. The same comment can be applied to geotechnical designers who may persist in using design procedures which are empirical or not based on sound principles. It would appear appropriate for ISSMFE to assist in narrowing the gap between practice and research by directing the efforts of at least some of its technical committees towards defining more closely acceptable and unacceptable approaches to geotechnical education and practice.

9 CONCLUSIONS

Technical Committee TC31 has addressed four major issues over the past three years:
1. curricula for undergraduate courses
2. computer-aided instruction
3. demonstrations and experiments
4. suitable case histories for teaching purposes.

The most significant advances have occurred in the second category and there are a number of effective computer packages which cover fundamental soil behaviour, laboratory testing and foundation design. In the future, the Internet is likely to provide an abundant source of geotechnical information for both students and practising professionals.

This paper summarizes a limited number of demonstrations, experiments and case histories which may be of value in supplementing traditional lectures on principles and practice.

There seems little doubt that the ISSMFE should continue its concentration on geotechnical education. Among the areas which may benefit from future attention are:
1. considering ways in which areas such as environmental geotechnics can be introduced into existing courses
2. utilization of geotechnical centrifuges to produce videos of fundamental behavioural characteristics and failure mechanisms for various geotechnical problems
3. further consideration and exposition of case histories suitable for teaching purposes
4. further development of computer-aided instruction, including the utilization and dissemination of teaching materials via the Internet
5. bridging the gap between traditional design methods and modern research.

The latter is seen as being of fundamental importance, not only to undergraduate geotechnical education, but also to professional practice. The Society's Technical Committees should direct at least some of their attention to pursuing this objective.

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REFERENCES

Adler, L. and Neuman, E. S. 1985. "Mining and Civil Engineering, Allies or Adversaries?". *Proc. Conference on Challenges to Civil Engineering Educators and Practitioners, ASCE*, 268-275.

Allersma, H.G.B. 1997. "Possibilities of Small Geotechnical Centrifuges". *Proc. 14th International Conference S.M. & F.E.*, Hamburg.

Anderson, J.G.C. and Trigg, C.F. 1976. "*Case-Histories in Engineering Geology*". Elak Science, London.

Arz, P. and Seitz, J.M. 1997. "Training of Geotechnical Junior Engineers within the German Construction Industry". *Proc. 14th International Conference S.M. & F.E.*, Hamburg.

Barber, E.S. and Krizek, R.J. 1967. "Soil Mechanics Demonstrations". *Proc. 3rd Pan American Conference S.M. & F.E.*, Caracas, 2:375-389.

Barker, H.R., Sartain, N., Schofield, A.N. and Soga, K. 1997. "*Modelling of Embankment Construction on Soft Clay in the Mk. II Mini-Drum Centrifuge*". Tech. Rep. CUED/D - SOILS/TR 303, Department of Engineering, University of Cambridge, UK.

Biarez, J. and Taibi, S. 1995. "*Multimedia Geomeca*" Several titles, including CD-Rom and video tapes. Ecole Central Paris, Chatenay - Malabry, France.

Bond, A. 1996. "Where to Geo on the World Wide Web". *Ground Engineering,* Nov., 22-25.

Bond, A. 1997. "Where to Geo on the World Wide Web". *Ground Engineering*, March, 29-30.

Briaud, J.-L. and Gibbons, R.M. 1994. "*Predicted and Measured Behaviour of Five Spread Footings on Sand*". Spec. Tech. Pub. No 41, ASCE, New York.

Burland, J.B. 1987. "The Teaching of Soil Mechanics - A Personal View". Nash Lecture, *Proc. IX European Conference S. M. & F.E.* Dublin, 1427-1447.

Casagrande, A. 1966. "*Soil Mechanics*". Harvard University. Unpublished lecture notes.

Daniel, D.E. and Olsen, R.E. 1983. "Failure of an Anchored Bulkhead". *Jnl.Geotechnical Engineering Divn., ASCE*, 108, GT10, 1318-1327.

Davis, E.H. and Poulos, H.G. (1975). "Predicted and Measured Behaviour of an Embankment on Boston Blue Clay". *Aust. Geomechs. Jnl.,* Vol. G5, 1-9.

Davison, L.R. 1996. "GeotechniCal-Computer Assisted Learning in Geotechnical Engineering". *Proc. 7th Australia - New Zealand Conference on Geomechanics*, Adelaide, 957-963.

Elton, D.J. 1997. "Soils Magic Show". *ASCE Geo-Institute Specialty Conference*, Logan, Utah.

Ensinger, W. 1997. "Training for Specialized Civil Engineers". *Proc. 14th International Conference, S.M. & F.E.*, Hamburg.

Fung, H.T. and Kay J.N. 1994. "An Interactive Computer Model for Triaxial Test Simulation". *Proc. International Conference on Computer Methods in Structural and Geotechnical Engineering*, Hong Kong, 429-435.

Golder, H.Q. and Olsen, J.C. 1968. "Settlement of a Furnace Foundation, Sorel, Quebec". *Can.Geot. Jnl.*, 5:1, 46-56.

Holtz, R.D. and Kovacs, W.D. 1981. "*An Introduction to Geotechnical Engineering*". Prentice Hall, New York.

Jaksa, M.B., Kaggwa, W.S. and Gamble, S.K. 1996. "CATIGE for Windows - A Computer Aided Teaching Suite for Geotechnical Engineering". *Proc. 7th Australia - New Zealand Conference on Geomechanics*, Adelaide, 976-980.

Jamiolkowksi, M.B. 1994. "Leaning Tower of Pisa - Description of the Behaviour". Special lecture to *ASCE Specialty Conference*, Settlement 94.

Jamiolkowksi, M.B. 1994. "Leaning Tower of Pisa - A Summary of the Present Situation". *Intl. IAEG Symposium*, Athens.

Kerisel, J. 1975. Old Structures in Relation to Soil Conditions. *Géotechnique*, 25, 433-483.

Peck, R.B. and Bryant, F.G. 1953. "The Bearing Capacity Failure of the Transcona Elevator". *Géotechnique*, 3, 201-208.
Peck, R.B. and Ireland, H.O. 1974. "Experience in Teaching Engineering Judgement by Case Histories in Foundation Engineering". *Proc. ASCE Conference on Civil Engineering Education*. Ohio State University, 1:1, 187-192.
Penumadu, D., Frost, D. and Zhao, R. 1997. "Geotechnical Test Simulator". *Proc. 14th International Conference S.M. & F.E.*, Hamburg.
Poulos, H.G. 1994. "Patterns and Practices in Future Geotechnical Engineering Education". *Proc. 13th International Conference, S.M. & F.E.*, New Delhi, 5, 245-253.
Schlosser, F., Amar, S. and Canou, J. 1995. "Specific Aspects of Geotechnical Education at the École Nationale des Ponts et Chausées". Workshop on Geotechnical Engineering Education, *Proc. 10th Danube - European Conference S.M. & F.E.*, Mamaia, Romania.
Skempton, A.W., Peck, R.B. and Macdonald, D.H. 1955. "Settlement Analyses of Six Structures in Chicago and London". *Proc. Instn. Civil Engineers*, 1, [6070], 539-541.
Sparks, A.D.W. 1997. "Geotechnical Education - Conceptual and Physical Models". *Proc. 14th International Conference S.M. & F.E.*, Hamburg.
Vargas, M. 1948. "Building Settlement Observations in Sao Paulo". *Proc. 2nd International Conference S.M. & F.E.*, Rotterdam, 4, 13-21.
Wilhelm, V. 1997. "Training Programme for Coordinators and Site Managers". *Proc. 14th International Conference S.M. & F.E.*, Hamburg.