Refining geotechnical education to reflect modern engineering practice

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ABSTRACT
The practice of geotechnical engineering has changed and broadened, yet in comparison, education of geotechnical engineers has not. Undergraduate programs face severe time constraints if the range of subjects needed by generalist civil engineers is to be covered at an introductory level. Pruning produces renewed vigour – 4-year engineering programs should be capable of completion in four years. With limited time available to cover core geotechnical fundamentals in undergraduate programs, there is a need to recognize that the modern geotechnical specialist will require practice-oriented postgraduate courses or their equivalent

RÉSUMÉ
La pratique de génie géotechnique a changé et élargi, pourtant en comparaison, l'éducation des ingénieurs géotechniques ne l'a pas. Les programmes de premier cycle font face à de sérieuses contraintes de temps si la gamme des sujets requis par les ingénieurs civils généralistes doit être couverte à un niveau d'introduction. La taille des arbres produit une vigueur renouvelée – les programmes de quatre ans de génie devraient pouvoir être complété en quatre ans. Avec du temps limité disponible pour couvrir les principes fondamentaux de géotechnique dans les programmes de premier cycle, il y a un besoin d'accepter que le spécialiste en géotechnique moderne aura besoin de cours de cycles supérieurs orientés vers la pratique ou de leurs équivalents.

1. INTRODUCTION

There is a shortage of geotechnical engineers and geoscientists in Canada. Workloads are high. Despite sharp rises in starting salaries, many companies and government departments have difficulty in finding sufficient staff to meet the growing demand. In response, and following large decreases in student numbers in the 1990s, student numbers are again increasing in undergraduate civil engineering programs. Some programs in geology, engineering geology and mining engineering are experiencing reduced support from their university administrations.

How should universities and industry manage the development of professionals for practice? Are the universities producing enough graduates with the right abilities? What abilities are needed? What is the correct relationship between education and training in geotechnical engineering? Who should do what? How should the roles of the university and the employer be defined? Why do our four-year undergraduate courses take an average of five years to complete? These are questions that need to be examined.

The title of this paper uses three phrases: 1) *'refining',* 2) *'geotechnical education',* and 3) *'modern practice'.* 'Refining' suggests that much of what is needed is currently being done but needs to be reworked to provide better outcomes. 'Geotechnical education' implies the paper will concentrate on education, not training, though both will be considered. We deal mostly with geotechnical engineering, although similar discussions can apply to the many branches of the geosciences used in geotechnical practice. 'Modern practice' relates to the broadened scope of current practice and the wide range of tools and techniques that are now available.

2. REGULATORY FRAMEWORK

To become licensed, professional geotechnical engineers and geoscientists require a Bachelors degree and some years of experience in practice. They are licensed to practice by provincial associations (or ordre) of professional engineers (and increasingly geoscientists) who assess the quality of candidates' undergraduate programs and subsequent supervised experience. Engineering programs are inspected by the Canadian Engineering Accreditation Board (CEAB). Completion of an accredited program is taken as an acceptable level of academic training. Requirements for geoscience programs have been established by the Canadian Geoscience Standards Board (CGSB). Additional information about CEAB and CGSB is available from the respective websites of the two Boards.

There are accredited programs in mining engineering and geological engineering programs in Canada but none in geotechnical engineering. Most geotechnical engineers graduate from a civil engineering program.
It is useful to review some objectives of the CEAB accreditation process (Engineers Canada 2007).

- *'Accredited engineering programs must contain not only adequate mathematics, science and engineering, but they must also develop communication skills and an understanding of the environmental, cultural, economic and social impacts of engineering on society and of the concept of sustainable development.'*
- *'The criteria* (used by CEAB) *are intended to identify those programs that develop an individual's ability to use appropriate knowledge and information to convert, utilize and manage resources optimally through effective analysis, interpretation and*

decision-making. This ability is essential to the design process that characterizes the practice of engineering.'

- *'The criteria are intended to provide a broad basis for identifying acceptable engineering programs, to prevent over-specialization in curricula, to provide sufficient freedom to accommodate innovative educational development, to allow adaptation to different regional factors and to permit the expression of the institution's individual qualities and ideals.'*

In sum, CEAB accredits programs that are a) broadly based in science, mathematics and complementary studies, b) design oriented, and c) generalist rather than specialist. We see merit in this approach.

Typically, civil engineering programs in Canada contain only two or three geotechnical term courses. The programs must provide a broad introduction to structures, hydraulics, environmental engineering, and transportation, as well as geotechnics. Some universities provide optional 'streams' in their undergraduate programs (Sparling and Kells 2008). It can be questioned whether streams can produce either the breadth required by CEAB or the specialization required by employers. It is unlikely that such streams will produce specialist geotechnical engineers. Increasingly, introductory geology is being deleted (Graham and Hachich 2002).

If undergraduate programs are designed to provide the broad education required for CEAB accreditation, then geotechnical specialists will have to be trained through a combination of work experience, professional development short courses, and master's programs (or an agreed equivalent) that are aimed at employability. Increasingly, licensing associations require evidence of ongoing professional development activities.

3. MODERN GEOTECHNICAL PRACTICE

Geotechnical engineering is broader than just soil mechanics. Practice now involves consideration of soils, rocks, hydrogeology, engineering geology, engineered materials, ground improvement, cold regions and various geosciences such as geophysics and geochemistry. Site characterization through sampling, in-situ testing, and remote sensing is common, as is field instrumentation. Older closed-form solutions are limited in their capabilities, so there is increasing use of numerical modeling with commercial software. Laboratory testing and engineering geology seem to be receiving less attention than before.

The changes appear to be structural in nature and not temporary. Educational programs need to be modified – 'refined' – in response to the requirements from the Accreditation Board and the needs of professionals who choose to practice geotechnical engineering.

4. THE UNDERGRADUATE CURRICULUM

Course loads in Canada are typically higher than in comparable programs in the United States, where required credit hours have been dropping since 1925 (Sparling and Kells, 2008). Most undergraduate engineering programs in Canada are nominally 4 years in duration, yet the average completion time is close to 5 years. For a discipline that prides itself on good planning, this lack of agreement between 'demand' and 'performance' should be cause for concern.

A tightly packed curriculum that requires large numbers of Academic Units (AU, Engineers Canada 2007) does not necessarily improve the quality of the educational experience. The required minimum is 1800 AU. 'More' is not necessarily 'better': 'better' is 'better'. As with apple trees and rose bushes, pruning can produce renewed vigour. The objective of pruning would be two-fold. It would remove deadwood from courses and allow growth of new materials that we can consider 'basics'. The principal objective in refining present programs should be to reduce the average duration of batchelor's programs from five years to four, thus allowing specialization in subsequent master's programs.

Employers regularly ask for more specific technical skills without fully understanding the framework of accreditation or the relatively limited freedom that universities have in rebalancing their professoriat. As well, adding courses to undergraduate programs to permit specialization is contrary to the broad objectives that CEAB seeks in accrediting programs. For example:

- *Engineering design integrates mathematics, basic sciences, engineering sciences and complementary studies in developing elements, systems and processes to meet specific needs. It is a creative, iterative and often open-ended process subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may relate to economic, health, safety, environmental, social or other pertinent interdisciplinary factors.*
- *The engineering curriculum must culminate in a significant design experience which ….. gives students an exposure to the concepts of team work and project management.*
- *A research project may be interpreted as engineering design provided it can be clearly shown that the elements of design, as noted in the definition, are fulfilled in the completion of the project.*
- *Appropriate content requiring the application of computers must be included in the engineering sciences and engineering design components of the curriculum.*
- *Complementary Studies: minimum of 225 AU of studies in humanities, social sciences, arts, management, engineering economics and communication that complement the technical content of the curriculum. The curriculum must include studies in engineering economics and on the impact of technology on society, and subject matter that deals*

with central issues, methodologies and thought processes of the humanities and social sciences.

- *Provision must also be made to develop each student's capability to communicate adequately, both orally and in writing.*
- *Appropriate laboratory experience must be an integral component of the engineering curriculum.*
- *Instruction in safety procedures must be included in students' laboratory experience.*
- *Each program must ensure that students are made aware of the role and responsibilities of the professional engineer in society. Appropriate exposure to ethics, equity, public and worker safety and health considerations and concepts of sustainable development and environmental stewardship must be an integral component of the engineering curriculum.*
- *The curriculum must prepare students to learn independently and must appropriately expose them to engineering research and development or other innovative engineering activities.*

The question is frequently raised if undergraduates are better served by greater breadth or greater depth. Intellectual challenge can be equally high in both approaches, though different in nature. The CEAB requirements are perceptive and serve the long-term needs of the profession. During discussions on revising the Civil Engineering program in Manitoba in 1995, senior engineers from major employers agreed that the curriculum should be broadly based and non-specialist. The Canadian Academy of Engineering (CAE 1999), reported that employers prefer students with breadth and a fundamental (basic) knowledge of the modern discipline. Specialization can come later. As we have seen, programs accredited by CEAB have to be broadly based and focused towards the design process that is the essence of engineering. This approach emphasizes understanding rather than specific training. It can be considered *'education'* rather than *'training'.*

'Almost all the information from my college science courses is hopelessly out-of-date, inaccurate and irrelevant. Yet I still use skills I learned then. That's because the emphasis was on process, not nickel-knowledge facts.' David Suzuki (1987)

5. UNDERGRADUATE GEOTECHNICAL COURSES

Following the CEAB guidelines, undergraduate programs should be generalist in nature – they will educate civil engineers, not geotechnical engineers. This section deals with a 'general' geotechnical component in an undergraduate Civil Engineering program; that is, the geotechnical component that all civil engineers should know. Postgraduate specialization will be dealt with later.

It is important that geotechnical courses become 'high tech' and not concentrate on 'low tech' material such as Atterberg limits, compaction tests, unconfined compression tests, Boussinesq stress distributions and 'ϕ_u = 0' analysis for slopes. Better testing and computer modeling with commercial software provide an improved understanding of the capabilities and opportunities of modern practice.

Anecdotally, the numbers of geotechnical courses in Civil Engineering in Canadian universities vary from one to three term courses, each with about 40 – 50 hours of total contact and involving laboratory projects, tutorials and assignment classes. This compares well with undergraduate geotechnical programs in Europe where the majority have 150 - 200 hours of compulsory geotechnical courses (Manoliu 1999). Commonly, courses deal mainly with soil mechanics, foundations, laboratory, and earth structures. Some programs also include an introductory geology course (for example Program A in Table 1), a hydrogeology course, or elective courses. Bearing in mind the systemic constraints outlined in previous sections, core geotechnical programs at undergraduate level will likely continue to contain three core courses with perhaps some additional electives. The core courses could include:

i) Introductory geology, with an emphasis on geomorphology,
ii) Geotechnical materials and analysis, and
iii) Geotechnical design.

This is similar to Program B in Table 1 (from the authors' university), which has the added benefit of a core course in hydrogeology.

<u>Program A:</u>	
Geology for Engineers	Core
Geotechnical Materials	Core
Geotechnical Analysis	Core
Geotechnical Design	Core
Soil-Structure Interaction	Elective
<u>Program B:</u>	
Geology for Engineers	Core
Geotechnical Materials and Analysis	Core
Hydrogeology	Core
Geotechnical Design	Core
Geotechnical Engineering	Elective

Table 1. Two approaches to Geotechnics courses in an undergraduate Civil Engineering program.

If modern geotechnical courses are to reflect the scope of modern geotechnical practice, all of the core courses should include some coverage of soils, rock, water, geoenvironmental issues and geosynthetics. Additional elective courses would depend on the interests of the academic staff and the influence of local geology on practice. They could include, for example, some additional treatment of hydrogeology, geoenvironmental engineering and ground improvement.

In Table 1, Programs A and B are former and current programs at the University of Manitoba. Differences between the two programs are larger than appear simply from the course titles. The earlier Program A provided a modernized approach to specifically soil mechanics, for example by teaching elasto-plasticity. Commercial software was used for stress, seepage and slope analysis in both the Analysis and the Design courses.

The current Program B reflects a broader view that geotechnical engineering must also include rocks, ground water, and geoenvironmental topics. For example, when dealing with ground water and seepage, Program A handled seepage problems in the usual way in soil mechanics, except that finite element analysis was introduced through a computer laboratory session. In Program B, seepage is introduced through regional hydrogeology. The course then proceeds to include seepage problems usually covered in soil mechanics courses, plus studies of ground water supply, contaminant migration and contaminant mitigation.

Table 2 shows further examples of the differences between the A and B programs. The table lists course contents for the Geotechnical Design courses in Table 1. Both courses emphasize design principles and give students experience with interpreting test results, borehole logs, nonhomogeneous site conditions, site characterization, and open-ended problem solving. Extra topics in B mean that they are dealt with in a broader way, with more attention being given to socially and economically important issues such as environmental impact, transportation, community concerns, etc., and less to technical details of the analyses themselves.

Geotechnical Design,
Course Content A:

Site characterization (soils)
Surface footings on sands and clays using both laboratory and *in situ* results: stability and settlement
Deep foundations in sands and clays
Braced and gravity retaining walls
Slope design in clays: riverbanks, dams, remediation

Course Content B:

Site characterization (soils and rocks)
Surface footings on sands, clays and rocks using both laboratory and *in situ* results: stability and settlement
Deep foundations in soils and rocks
Tied-back and gravity retaining walls, excavations in rock.
Natural and engineered slopes in clays and rocks: dams; planar, circular, and wedge slides; remediation
Geosynthetics and geofabrics
Underground openings, tunnels, rock anchors
Introductory geoenvironmental problems, tailings ponds, remediation, etc.

Table 2. Alternatives for Geotechnical Design in a Civil Engineering program: Program A - traditional, soils only; Program B - representing the increased breadth of modern geotechnical engineering

It was suggested earlier that programs should include material relevant to geotechnical problems in the surrounding region. This can be done, in part, in core courses, but it also provides a good learning strategy if there are only a limited number of elective courses. Table 1 shows that the planners of Program A and Program B felt they could support just one elective course with their available resources. The two approaches taken were quite different. In Program A, Soil-Structure Interaction was essentially an analysis course based on classical elasticity, and emphasizing Winkler theory for beams on elastic foundations. It also included the use of finite elements for modelling foundations, walls and slopes and some geotechnical modeling. That is, it was a 'deepening' or 'specialization' course. In contrast, Geotechnical Engineering in Program B is a 'broadening' course. It addresses students' questions about the effectiveness of the techniques they have learned. The course uses a case studies approach similar to the one used widely in medical education. The course takes a series of well-documented construction projects from journals and conference proceedings, examines the soil or rock conditions, reviews the analyses that were undertaken using modern modeling tools, and compares predicted performance with field measurements. The principal emphasis is on comparing *performance* with *prediction*.

The awkward question remains, however, why professors who are themselves engineers would design four year programs of study that require five years to complete.

6. TEXTBOOKS FOR UNDERGRADUATE PROGRAMS

Teaching geotechnical engineering has often been based on fairly traditional presentations of long-established solutions and ideas (Graham 2000). For example, Tables 3a,b,c list the principal subject headings, essentially chapter headings, in three introductory textbooks (Taylor 1948, Budhu 2007 and Coduto 1999). Other recent textbooks have been presented by Das (1998) and Craig (1997).

While newer books introduce some new ideas and concepts – critical states, in situ testing, landfills, liners, and reinforced walls, for example - they are broadly similar in structure and the order in which topics are presented. More importantly, all of these books deal exclusively with soils and do not reflect the breadth of modern geotechnical practice. Many new textbooks provide 'training' of technological facts rather than an 'education' in the sense outlined by CEAB. When new 'flavours of the month' arrive, narrowly defined factual knowledge is added; no topics are deleted or re-thought. 'Pruning' has not been undertaken.

In Table 3c, Coduto (1999) includes sections on engineering geology, in situ testing, geophysics, geoenvironmental engineering, unsaturated soils, difficult soils, soil improvement and geotechnical earthquake engineering. This broader approach provides less detail but is better suited to an introductory program for undergraduate geotechnics in civil engineering practice. Further broadening and refinement of textbook contents appear to be needed.

7. POSTGRADUATE PROGRAMS - EMPLOYABILITY

Preceding sections discussed the role of geotechnical engineering in educating undergraduate civil engineers. The premise was that it should be possible to complete a

(a) Donald W. Taylor, 1948	*Order*
Classification	1
Subsurface investigation	2
Permeability	3
Capillarity, seepage	4
1-D consolidation	5
Elastic stress distributions	6
Settlement analysis	7
Strength theory, test methods	8
Shearing in sands	9
Shearing in clays	10
Stability in slopes, dams	11,13
Lateral pressures, walls	12
Shallow foundations	14
Pile foundations	15
(b) Muni Budhu, 2nd Edition 2007	
Basic characteristics of soils	2
Ground investigation	2.13
Seepage	9
Effective stresses	6
Consolidation theory	4
Stresses and displacements	3
Strength criteria, tests, strength of sands and clays	5
Stability of slopes, dams	11
Lateral earth pressures	10
Bearing capacity, shallow and deep foundations	7,8
Critical State modeling	6
In-situ testing	7.13
Reinforced earth walls	10,12
(c) Donald P. Coduto, 1999	
Introduction	1
Site exploration and characterization	3
Soil composition and classification	4,5
Excavation, grading, compaction	6
Groundwater fundamentals	7,8
Stress, compressibility, consolidation rate of settlement	10-12
Engineering Geology	2
In-situ tests, geophysical	3.3
Geoenvironmental engineering applications	9

Table 3. Subject headings in three geotechnical text-books. Shaded areas represent new topics not included in Taylor 1948. Topics are listed in largely the same order for each book. The order of appearance is numbered in the right-hand column.

4-year undergraduate program in four years with a good understanding of the role and responsibilities of geotech-nical engineers. Such programs can be expected to attract good young people into geotechnical practice. They will not, however, produce specialists.

As with other areas of civil engineering, many geotechnical engineers and geoscientists hold master's degrees and some have doctorates. Postgraduate programs provide 'training' for practice in the way that the undergraduate programs cannot. It should be noted that having a master's degree in geotechnology is not required for recognition by the licensing bodies as a Professional Engineer or Geoscientist. This may become an increasingly important issue. Some countries, notably the United States and the United Kingdom are moving towards requiring master's degrees for licensing (ASCE 2001, 2004; Townsend 2002).

What should be the nature of master's programs (Mitchell 1999)? We have argued in previous sections that batchelor's degrees should be broadly based, emphasise education and learning, and be capable of completion in four years. This leaves time and 'space' for specialization in master's programs, which are increasingly seen as stepping-stones towards employ-ability. They are no longer simply 'training in research' in preparation for a doctorate. Instead, they become the source of the detailed training in specific technologies and design procedures that are needed for practice. They should still reflect the breadth of the discipline. If this is done, master's degrees represent the first level of specialization and require a component of training (Sayão and Graham 1999). The total duration of a proper 4-year batchelor's degree plus a 1-year master's degree will be the same as the current average time for batchelor's programs but will now combine breadth and specialization.

There are two types of master's programs in Canadian universities, one based principally on coursework; and a second with less coursework and an extended project that often leads to publication. Research-based master's programs in Canada usually last 18 – 27 months of full-time study and provide some financial support. Both types of master's training are welcomed by employers. Some prefer a larger content of technical instruction, while others value a period of guided study and preparation of a research thesis.

With the current shortage of geotechnical engineers, the concept of 'employability' is important. Postgraduate courses should be arranged so that graduates can become productive shortly after entering employment. Specialist courses directed towards the needs of industry can have a high level of intellectual challenge and rigour.

Postgraduate programs tend to be less ordered than undergraduate programs and more sensitive to the interests of individual professors. For some years, employers in Manitoba criticized our program for producing master's graduates engineering who knew no hydrogeology (or geoenvironmental engineering, or other favoured topic). In response, we designed a program of four core courses that could be taken by our master's students. These include Soils Engineering, Rocks Engineering, Groundwater Engineering and Environmental Geotechnology. The courses aim at providing a broad training in the principal areas of current geotechnical practice. In addition, students take two to four additional courses that provide greater depth in the area of their major project.

Research projects can be related to the interests of the professor or the funding sources, which are often applied in nature. Both are good. Current funding seems concentrated towards 'applied' projects. Such projects provide excellent opportunities for learning and demand high levels of intellectual challenge. They offer excellent training for employment and excellent opportunities for companies to develop relationships with possible future employees.

8. DELIVERABILITY

Constraints on university funding mean that departments can rarely afford to cover all major areas of geotechnical practice. Fortunately, modern technology provides alternatives. These include initiatives like the ‘Western Deans Agreement’, which allows postgraduate students to register in one university, move to another for courses, and then return to complete their degree requirements.

Other alternatives are available. There has been some success with real-time video conferencing, sometimes with two-way sound and vision, but more often with one-way vision and two-way sound - students can see and hear the lecturer but can only comment and ask questions with sound. Technology exists in many universities for teleconferencing but it currently seems too expensive for weekly or bi-weekly use for teaching. Online streaming is available at considerably lower cost, though local live editing may be needed to achieve good visuals of both speaker and slides. A developing technology is the use of prepared lecture notes and figures uploaded to a website and then downloaded by students. The lecturer can present live to local students and stream a single visual channel to distant students who already have downloaded the figures.

There are many types of learning. The traditional method of transferring information from the professor’s notes to the students’ notes without going through the brains of either is probably the least effective. We have experience with previously-prepared online lecture notes and figures that are downloaded by students before a lecture. We then work on writing tablets in class and upload the resulting file to the website.

Some argue that uploading lecture material to a website lacks spontaneity and that students simply stop coming to class. This has not been our experience. Like many, we work from a combination of our own notes, textbooks and research papers. We try to synthesize understanding of the topic from a wide range of original sources. In our experience, if students appreciate that the purpose of attending a lecture is to listen and interact, having been given lecture notes, then there is considerable value in attending compared with the alternative process of mindlessly copying notes in class.

One of the educational trends at present is towards *problem-oriented* not *solution-oriented* learning. This involves providing students with, explanatory notes, flow charts, figures etc on paper and/or the internet (Felder 1999). The most important topics are covered in class, but students are expected to learn the rest of the material independently and be responsible for it in examinations. The approach emphasises teamwork, leadership, judgement, and personal research. It is important that problem-oriented learning is not seen simply as a way of feeding more information to students. Student-centred learning is less efficient but more effective than traditional lectures (Spencer-Chapman 2000).

9. FORWARD TO THE BASICS

Knowledge of fundamentals is important because they are needed for future learning and professional development. However, a reactionary emphasis on 'Back to basics' is not acceptable - we must go 'Forward to the basics' (Graham and Sivakumar 2000).

Burland (1987) identified three components that are inherent in every geotechnical project (Figure 1). They are 1) the need to understand the geology and variability of the ground, 2) the constitutive behaviour of the material that will be affected by the project, and 3), the mathematical tools and techniques that can be used to analyse the problem. Following paragraphs examine each of these in turn and consider how they can be incorporated as basics (or fundamentals) in a modernised geotechnical program.

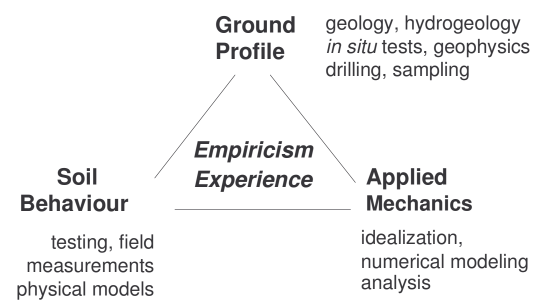

Figure 1. Three principal components of geotechnical engineering (Burland 1987)

1) Geology and site variablity. All construction sites involve geological materials whose properties vary vertically, horizontally, with time and with construction. In a first course, it is reasonable to define soils and rocks as homogeneous and concentrate on techniques of analysis. However, subsequent design-oriented courses should reflect the stochastic nature of geological materials. Geotechnical engineers need at least a basic understanding of geomorphology and geological facies. The current tendency to decrease the amount of geology in civil engineering programs is disturbing (Graham and Hachich 2002).

2) Material properties. Soils and rocks are different from other engineering materials; they can rarely be specified in advance.

Foundations, tanks, dykes and embankments are often designed so that stresses stay within a range that is broadly elastic. Higher stresses produce increased compressibility, yielding, and non-recoverable, plastic straining. They may also move the stresses towards failure. These conditions can be conveniently modelled using an elastic-plastic approach, which helps to develop rational ways of predicting soil behaviour rather than having to simply remember the complexity of non-linear soil behaviour.

When elasto-plasticity is included in soils courses, it is usually introduced quite late in the form of idealized Critical State Soil Mechanics. Students often find this approach difficult. It is better to start with elasto-plasticity, develop conceptual models (of which Critical State is only one example), and then finish by showing how the traditional understanding arises from the model as a series of rather simple special cases either in terms of strain or stress states.

3) Numerical analysis is now common in practice, often using finite element (FE) solutions for load-deformation and seepage. Students need to understand the mathematics of the method, and perhaps more importantly, to know how FE can be used to model engineering problems. In place of early closed form solutions for stress increases in homogeneous isotropic linearly elastic semi-infinite half-spaces, commercially available software permits students to be introduced to non-homogeneity, anisotropy, non-linearity, and bounded domains. Students respond well to hands-on experience in computer laboratories and see it as a ‘high tech’ approach to problem solving.

It is now just as easy to do non-circular slope analysis as circular analysis, and easier to introduce engineering decision-making regarding selection of material properties and remediation strategies. A small amount of hand calculation is still needed to clarify the numerical procedures. Using computers takes away drudgery and allows a useful transition to engineering considerations. In the time it formerly took to calculate the stability of a single failure circle, students can now progress to remedial design of failed slopes.

There is an additional component of Burland’s ‘geotechnical triangle’ in Figure 1. Geotechnical engineering uses experience and empiricism to synthesize solutions for owners’ problems. The advantage of using computer applications is that students can move quickly into exercises where design problems can be addressed under instruction and where liability is not an issue. For this work, the many case studies published in the Canadian Geotechnical Journal and in the annual Canadian Geotechnical Conferences are useful.

10. COSTS AND BENEFITS

'Forward to the Basics' introduces new material that provides a good understanding of the basics of the modern scope of the subject and deletes obsolete material. Naturally, there are costs and benefits. If the strategy is adopted, it is important to keep local employers fully informed.

In our undergraduate program in Manitoba, the costs have included less coverage and understanding of soil classification, compaction, classic elastic stress distributions, the Swedish Method of Slices for slope analysis, and construction of graphical flow nets. All of these topics are relatively easy to teach and to learn in practice if needed. Compared with some years ago, our students have fewer hands-on laboratory skills and know less about routine construction practice.

There are also clear benefits. These include:

- exposure to the behaviour of soils and rocks using elastoplasticity where relevant,
- coherent limit equilibrium analysis for slopes, walls and footings,
- computer analysis for slopes, seepage and deformations,
- geology, hydrogeology, soil chemistry, geoenvironmental engineering,
- specialty topics: geosynthetics, reinforced earth, soil improvement, etc.

'Forward to the Basics' is only useful if benefits outweigh the costs. In our opinion, they do. The approach

- provides an opportunity for improved synthesis of geology, hydrogeology, geochemistry and geophysics in a form that helps an understanding of geotechnical and geoenvironmental engineering in relationship to civil engineering,
- introduces students, academic colleagues and administrators to the 'high tech' nature of modern geotechnics used in modern civil engineering, and
- helps to produce educated, modern engineers who are aware of their responsibilities to their clients and to society.

At postgraduate level, all master’s and doctoral students should have courses in soils engineering, rocks engineering, ground water engineering, and geoenvironmental engineering, plus a selection of other courses that relate to the expertise of the academic staff, the needs of local practice, and the students’ research projects. We see particular merit in the common Canadian practice of combining coursework and research projects in master’s programs. Doctoral programs should remain focused on high quality, original research. This can valuably be be done in collaboration with local industry and government departments.

11. CONCLUDING REMARKS.

We understand that much of what has been said in this paper is well known. What might be new is the emphasis on 1) broadly based learning in an achievable 4-year batchelor’s program and 2) specialized training in a 1- or 2-year master’s program.

Developments in geotechnical practice in the past ten to twenty years require changes in undergraduate and postgraduate curricula. Programs need to be refined to incorporate a) new topics associated with recent broadening of the discipline, b) approaches that emphasise education rather than training, and c) modern high-tech elements that increase the attractiveness of the material and emphasise its relevance to modern engineering and society. The importance of attracting the attention of students, research partners and administrators should not be overlooked.

The paper has used the catch-phrase *‘Forward to the Basics’*. This has been used in two ways; one dealing with the introduction of new material and the second dealing with new delivery strategies to make programs more relevant and attractive. There is risk that these will be seen simply as an opportunity to add more material.

Two other phrases need to be given equal attention – *‘More is not better; better is better’* and *‘Pruning produces renewed vigour.’*

Consideration of the CEAB and CAE reports outlined earlier leads to the conclusions that academics should:

- revise undergraduate education to become broader and emphasize design processes
- 'engineer' 4-year programs that the majority of undergraduate students can complete in four years
- provide professionally-oriented master's programs
- employ modern modeling tools and examine case studies
- reinforce the role of geology in the education of civil engineers and the training of specialist geotechnical engineers.
- emphasize problem solving and the impact of engineering on society and the environment
- encourage research, development and design in collaboration with industry

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REFERENCES

ASCE 2001. *Engineering the future of Civil Engineering. Report of the Task Committee on the First Professional Degree.* American Society of Civil Engineers,http://www.asce.org/professional/educ/ report100901.cfm.

ASCE 2004. ASCE Police Statement 465: *Academic Prerequisites for Licensure and Professional Practice.* Task Committee on the First Professional Degree, Amer. Soc. of Civil Engineers, Reston VA.

Budhu, M. 2007. *Soil Mechanics and Foundations.* Wiley International, New York, NY.

Burland, J.B. 1987. *The teaching of soil mechanics - a personal view.* The Nash Lecture, Proc 9th ECSMFE, Dublin, Ireland, **3**, 1427-1441.

CAE 1999. *Evolution of Engineering Education in Canada.* Report of the Canadian Academy of Engineering, prepared by Task Force chaired by A. Heidebrecht, December 1999. publ. Canadian Academy of Engineering, Ottawa ON, ISBN 0-96782770-6-3, pp.1-17, http://www.acad-eng-gen.ca/publis/Evolution_a.html.

Coduto, D.P. 1999. *Geotechnical Engineering: Principles and Practices.* Prentice Hall, Upper Saddle River, New Jersey, USA

Craig, R.F. 1997. *Soil Mechanics.* E and FN Spon, London, England, 6th edition.

Das, B.M. 1998. *Principles of Geotechnical Engineering.* APWS Publishing Company, Boston MA, 4th edition

Engineers Canada. *2007. Accreditation Criteria and Procedures.* Canadian Engineering Accreditation Board. *Publ.* Engineers Canada, Ottawa ON, pp.44.

Felder, R.M. 1999. *Educating engineers in the twenty-first century.* 1999 Bloomfield Distinguished Engineer-in-Residence Lecture Series, College of Engineering, Wichita State University, Nov. 1999.

Graham, J. 2000 *Importance of academic staff in the development of undergraduate programs.* Keynote Address, Proceedings, 1st PanAmerican Conference on the Teaching-Learning Process of Geotechnical Engineering, ed. B.S. Zárate, publ. Sociedad Mexicana de Mecánica de Suelos, México City, Mexico, November 2000, 3-14.

Graham, J. and Sivakumar, V. 2000. *'Forward to the basics' - modernising education for geotechnical engineering.* Proc. Conference on Civil and Structural Engineering Education in the 21st Century, ed. H. Allen, publ. Univ. Southampton, UK.

Graham, J. and Hachich, W. 2002. Report on Session 1: Teaching of geology, soil mechanics, and rock mechanics at undergraduate level. 2nd Pan-American Conference on the Teaching and Learning Process in Geotechnical Engineering, Guayaquil, Ecuador, November 2002.

Manoliu, I. 1999. *A survey on geotechnical engineering education in Europe. Workshop 5 - Geotechnical Engineering Education.* Proc. XIIth European Conference on Soil Mechanics and Geotechnical Engineering, Amsterdam.

Mitchell, J.K. 1999. *Education in geotechnical engineering - its evolution, current status, and challenges for the 21st century.* Keynote Address, Proc. 11th PanAmerican Conf. on Soil Mechanics and Geotechnical Engineering, Fos do Iguassu, Brazil, **3**, August 1999.

Sayão, A. and Graham, J. 1999. *Report on Specialty Session 3: Education in Geotechnical Engineering.* Proc. 11th PanAmerican Conf. on Soil Mechanics and Geotech. Eng., Fos do Iguassu, Brazil, **3**, 1999.

Sparling, B.F. and Kells, J.A. 2008. Trends in Civil Engineering Education. CSCE Annual Conference, Quebec QC, June 2008.

Spencer-Chapman, N. 2000. *Problem-based learning in Civil Engineering Education a bridge too far?* Proc. Conf. on Civil and Struct. Eng. Education in 21st Century, ed. H. Allen, publ. Univ. Southampton, UK.

Suzuki, D. 1987. *Metamorphosis: stages in a life.* Stoddart Publ. Ltd., Toronto, Canada.

Taylor, D.W. 1948. *Fundamentals of Soil Behaviour.* Wiley and Sons, New York, NY, USA.

Townsend, F. 2002. *Challenges for geotechnical engineering graduate education.* Keynote Address, Proc. 2nd PanAmerican Conference on the Teaching-Learning Process of Geotechnical Engineering, ed. B.C. Carpio, publ. Catholic Univ. of Santiago de Guayaquil, Guayaquil, Ecuador, November 2002, 25-44.