Case studies - a tool for learning

Casos históricos - una herramienta para el apprendizaje

2011 Pan-Am CGS
Geotechnical Conference

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ABSTRACT

Student projects based on case studies provide opportunities for technical awareness, motivation, confidence, teamwork and life-long learning. They can be used at undergraduate and postgraduate levels to produce an improved learning experience. These attributes are increasingly important as employers and licensing authorities move towards a combination of broadly-based undergraduate education and more specialized postgraduate or in-practice training.

RESUMEN

Los proyectos de los estudiantes basados en casos históricos ofrecen oportunidades para incrementar el conocimiento técnico, la motivación, la confianza, el trabajo en equipo y el auto aprendizaje constante. Dichos proyectos pueden ser usados por estudiantes de pre-grado y post-grado para incrementar la experiencia del aprendizaje. Estos atributos son cada vez más importantes ya que los empleadores y autoridades regulatorias se están encaminando a una combinación basada mas ampliamente de estudiantes de pre-grado y aquellos con estudios de post-grado o con entrenamiento especifico en la práctica.

1 INTRODUCTION - REGULATORY FRAMEWORK

Engineering graduates want to become licensed as professional engineers and be able to work independently. To achieve a licence in many countries, a candidate must graduate from an accredited university program (see for example ABET 2001, Engineers Canada 2007). Most graduates then require additional years of directed experience under the guidance of an engineer supervisor. We begin by reviewing the regulatory framework for accreditation and then move to classroom practices, and in particular a case studies approach, that can improve students' learning and readiness for employment.

Accreditation of engineering programs now pays less attention to curriculum assessment – *what is being taught* – and closer attention to outcomes - *what is being learned*. Kellar et al. (2000) define objectives for an integrated program of engineering, mathematics and science:

1. Improved problem solving skills, critical thinking skills, and communication skills compared to a traditional engineering and science curriculum
2. Increased ability to integrate and appropriately apply technical skills with the fundamentals of math and science
3. Increased ability to participate in effective teams
4. Increased competence in applying technology for effective analysis, design, and communication
5. Increased motivation for self-responsibility, life-long learning, and self-development of a person of good character

In the United States, Britain, Europe, and Australia, accreditation bodies are moving towards program structures that strengthen students' abilities in problem solving (CAE 1999; Institution of Engineers, Australia 1999; SARTOR 2000). In Canada, for example, the Canadian Engineering Accreditation Board requires additional attention to design in most engineering subject areas (Alfaro et al. 2008). It also requires multi-disciplinary 'capstone projects' that are worked on by teams of students and are largely self-learned, with professors or practising engineers acting as mentors.

The Washington Accord in North America and the Bologna Accord in Europe recognize other countries' accreditation systems as being "substantially equivalent" without infringing on the respective jurisdictions. The accords may lead to university programs of four, five, or even six years.

In response, universities and licensing bodies in many countries are moving towards a three-stage, fairly broad initial approach that involves *engineering education* in first-degree programs, more specialized *training* in subsequent postgraduate programs, and a third stage of *directed experience* in practice (Turner 2011).

A memorandum submitted by the Institution of Civil Engineers (2008) in London to the UK Parliament includes the following comment: *"... the four year integrated undergraduate MEng program* (in the UK) *sits uncomfortably between the first and second cycles* (stages) *of degree as defined by the Bologna Accord".*

In the United States, ASCE documents indicate that licensing may require 6 years of academic study as well as a further three or more years of "*progressive, structured engineering experience"* (ASCE 2008)[1]:

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[1] Key points about the ASCE (2004) policy statement can be found at http://ebookbrowse.com/keypoints-ps465-v28 -09-24-09-pdf-d49705796

"Admission to the practice of civil engineering at the professional level means professional engineering licensure requiring attainment of a Body of Knowledge through appropriate engineering education, experience and examinations. Fulfillment of this Body of Knowledge will typically include a combination of:

1. *a baccalaureate degree in civil engineering;*
2. *a master's degree, or approximately 30 coordinated graduate or upper level undergraduate technical and/or professional practice credits or the equivalent agency/organization/professional society courses providing equal academic quality and rigor; and*
3. *appropriate experience based upon broad technical and professional practice guidelines which provide sufficient flexibility for a wide range of roles in engineering practice."*

It is regrettable that Canada, through Engineers Canada, has not so far participated in this movement (Bilanski 2008). This lack of action may have significant implications for Canadian participation in international projects, especially since the 'working degree' in many branches of civil engineering, and especially in geotechnical engineering, is the master's degree (Alfaro et al. 2008).

2 THE EDUCATIONAL FRAMEWORK

Undergraduate geotechnical engineering courses are usually embedded in civil engineering programs. (Students in mining and geological engineering will typically take their geotechnical courses from civil engineering professors.) Most teaching is still 'chalk and talk', even if overheads or digital projectors are increasingly used. Professors deliver course material to relatively large classes in single-discipline subject areas. Students often sit passively, copying from the board (or screen), reading, working on homework from another class, or daydreaming (Mills and Tregaust 2003).

Employers commonly want more technical skills in more topic areas. In contrast, students commonly speak of the large amount of course material that must already be learned and how it is difficult to develop self-motivated learning skills for their ongoing professional development.

A tightly packed curriculum does not necessarily improve the quality of the educational experience (Engineers Canada 2007). *'More'* is not necessarily *'better'*; *'better'* is *'better'* (Alfaro et al. 2008). As with apple trees and rose bushes, pruning can produce renewed vigour. The objective of pruning course material is twofold. It removes deadwood from courses and allows growth of new material that we can consider *'basic'*. The principal goal in improving undergraduate programs should be to improve self-learning skills and encourage specialization in subsequent master's programs.

Some years ago in the University of Manitoba, we asked how we could improve the undergraduate program. The replies included the following.

- *'The quality of our program is determined not by what we attempt to teach, but by what our students learn.'*
- *'Students learn more and are more highly motivated when they are actively involved in the learning process.'*
- *'Our graduates must expect the unexpected. Education will be a continuous process throughout their careers. Details will matter less; skills and attitudes will matter more.*

Alfaro et al. (2008) enlarged on these replies with more specific proposals for rejuvenating geotechnical engineering education. 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 (2000) listed the components identified earlier by J.B. Burland that are inherent in every geotechnical project - a) the need to understand the geology and variability of the ground, b) the constitutive behaviour of the material that will be affected by the project, and c) the mathematical tools and techniques that can be used to analyse the problem.

Employers, and increasingly the universities, understand that graduates from current engineering programs generally understand fundamental engineering science quite well and are computer literate. However, they are less competent in putting their knowledge into practice. The lecture-style of teaching is not particularly well-suited to learning how to be an effective team-player on a large interdisciplinary project, or how to engage effectively in ongoing professional development.

The remainder of this paper examines other approaches that might be more successful in developing better technical, learning, and professional skills.

3 'PROBLEM-BASED' AND 'PROJECT-BASED' LEARNING

Problem-based learning. Medical education commonly uses an approach known as *Problem-based learning* (PBL). Before gender equality, William Osler, an early leader in Canadian medical education, said that learning is a lifelong process and that *'we can only instil principles, put the student on the right path, give him methods, teach him how to study, and early to discern between essentials and non-essentials'* (Lee and Kwan 1997). These ideals were used at Harvard School of Business, and were developed more fully in the undergraduate medical program at McMaster University in Ontario, Canada (Spaulding 1969). The McMaster model has since been adopted by many health care schools. Instead of the standard building-block structure in which a lot of content is fed to students, which they tend not to retain, it adopts a system where students are actively involved in the learning process. In its purest form, it involves the following assumptions (Saarinen-Rahiika and Binkley 1998).

1. Students can be responsible for the breadth and depth of learning if given direction, resources and feedback.
2. Students bring with them a wide background of prior learning and experience.
3. Learning in small groups enhances understanding, exploration, discussion, and debate.
4. Faculty tutors facilitate learning and translate concepts rather than 'teach' or serve solely as information givers.
5. Information used to comprehend and deal with real-life scenarios is integrated from a variety of traditional disciplines.

There is also an expectation of increased retention of information, greater ability to apply knowledge in clinical contexts, and development of lifelong learning habits.

Lee and Kwan (1997) showed that graduates from the McMaster program a) enjoyed their education, b) consider themselves well-prepared for the next phase of their education, c) are sought after by program directors, d) perform well in licensing examinations, e) compare favourably with product from traditional programs, and f) show some interesting differences in behaviour in practice.

Students and graduates of PBL programs demonstrate aspects of professional behaviour, including resource use and keeping up-to-date with the literature, that are superior when compared with students from traditional programs. However, the model requires increased expenditure of resources and time. There is also evidence that it may not produce improved levels of content-specific knowledge or problem-solving skills. These deficits have been overcome to a large extent by an approach known as *Evidence-based Medicine, see* http://ktclearinghouse.ca/cebm/intro/whatisebm. We note, too, that medical education usually follows pre-medical training in fundamental sciences, which is most often given in a classical 'chalk and talk' format.

Medical literature also promotes a 'middle ground' or 'hybrid' between conventional curricula and PBL in order to capitalize on what is most valuable in both types. This hybrid approach is also seen in engineering programs, mostly in civil engineering, that have adopted PBL (Mills and Treagust 2003). In these cases, PBL is used in individual courses within a traditional engineering program and not in the program as a whole.

This may relate to the nature of engineering knowledge and practice compared with medicine. Feletti (1993) touched on this issue when he described *"another genre of professions…where problematic topics or situations loosely define the subject matter and where professional practice is typically not the process of solving well-defined problems"*. Medical knowledge is essentially *encyclopaedic* in nature (Perrenet et al. 2000). In contrast, engineers use a *hierarchical* knowledge structure in which topics must be learned in a defined order because missing essential parts will result in failure to learn later concepts. Problems that engineers encounter in practice are usually different from those they worked on previously (Rugarcia et al. 2000).

4 PROJECT-BASED LEARNING IN ENGINEERING

A hybrid or 'mixed-mode' approach appears preferable in engineering programs (Mills and Treagust 2003). These typically contain a combination of traditionally taught courses and courses with project-based components that increase in extent, complexity, and student autonomy in later years. A blending of approaches appears to be the best way to satisfy industry's needs for independent self-learning, without sacrificing knowledge of engineering fundamentals. This combination of lecture-centred and project-based learning has been welcomed by students, accreditation organizations, and industry.

Almost every task undertaken in engineering practice involves a project that relates in some way to the fundamental theories and techniques of the area of specialization. 'Projects' usually involve teams with a range of specializations. In engineering practice, they usually require days or months of work by teams of individuals, rather than the minutes or hours that are typically spent solving 'problems' in medicine, often by individuals (Perrenet et al. 2000).

Like problem-based learning, project-based learning relies on self-direction and collaboration. Both have a multidisciplinary orientation. It seems at the moment that only a relatively small number of courses use projects as the principal learning mode, with teaching of new material eliminated or reduced to a minimum and related to a project. Other courses use projects as a complement to more structured teaching. Projects generally require students to work in small groups with teachers who act as advisers and consultants rather than formal instructors. They also require students to manage time and avoid duplication of effort. Project work is more directed toward the *application* of previously acquired knowledge, whereas problem-based learning is directed toward *acquisition* of knowledge.

5 PROJECT-BASED LEARNING IN GEOTECHNICAL COURSES

Many academics already use case studies from their own experience or from the research literature. At the University of Manitoba, we use project-based learning in a variety of ways at both undergraduate and postgraduate levels. We share our experiences in following sections.

Introductory soils testing. The laboratory component of our introductory course Geotechnical Materials and Analysis does not simply teach technicians' skills. However, it includes (largely) hands-on experience in classification, oedometer, direct shear, and undrained triaxial tests. Instruction is given in the laboratory through a combination of notes and guidance by the professor, teaching assistants, and the laboratory technician.

More importantly, the tests are performed in the context of small simplified projects that require the test results. For example, results of Atterberg and hydrometer tests are incorporated into recommendations about the suitability of the samples for the core of an earth dam. Oedometer tests provide information that can be used in simple 1-D calculations of settlements of an oil tank. 'Quick' undrained (U-U) tests provide undrained shear strengths that are used in '$\phi_u = 0$' analysis of a cut slope in clay. Students perform the tests under supervision, analyse the test data, and then use the results in simple analyses taught in accompanying lectures.

Geotechnical Design. Our subsequent senior-level course uses analytical tools learned previously, and begins applying them in realistic, but simplified design problems. These include mainly shallow and deep foundations, retaining structures, and slopes. Students are also introduced to *in-situ* tests and to semi-empirical design procedures commonly used in practice. Assignments include teamwork on projects that emphasise the variability of natural soils and the need to be aware of the geology and hydrogeology of the site. As far as possible, we use published borehole logs and cross-sections. Teams consist of 2 to 4 students, so time and resource management become an important issue. Projects typically last for one to four weeks.

As an example, one of our projects consists of preparing a report for a 5-pier highway bridge over a 4-lane divided motorway. Students are initially given borehole logs, ground water, consolidation, and strength data at each of the piers for a site with rather variable soil and bedrock conditions. In the first stage, they are simply asked to prepare a site evaluation report on the soil, rock, and groundwater conditions at the site, and how these might affect construction decisions. In parallel with later lectures, further smaller projects deal with sizing and settlements of shallow footings for the piers, alternative deep footings, perhaps some geosynthetics-reinforced walls, environmental impact, public consultation, and construction sequencing.

Not much of this material can be taught effectively in lectures. However, in small discussion groups in a project-based learning environment, students take control of what they need to learn. They also learn to manage their time and resources to meet the required completion date. The role of the course supervisors is to model the relationship between senior engineer and junior engineer.

Publications on problem-based learning often report that students are initially stressed by the open-endedness of the problem, the variability of the data, and the need to manage the efforts of the team. By the end of the course, most of our students have improved their self-learning skills, understand the need for ongoing technical development, and are accustomed to the give and take that are needed in teamwork. Students respond favourably to this project-based approach.

Case study projects. Students often comment that they have been taught design tools but lack confidence and judgment in their application. Readiness for practice can be improved considerably by a further extension of project-based learning towards the approach that is known in medicine as *evidence-based learning.* This can be done in undergraduate elective courses and postgraduate courses using published case studies as the basis for student projects.

Geotechnical publications like the Canadian Geotechnical Journal report many successful, and perhaps more importantly, unsuccessful projects in considerable detail. Using these reports as a basis, case study projects can ask teams of students to verify the original design and performance values. The projects involve re-assessing the assumptions made by the original designers and re-calculating the analyses made during design. These can then be checked against post-construction performance.

For a published report to be useful in this way, it should contain:

1. details of the site conditions, including borehole information, geology, and hydrogeology;
2. information about geometry and loading;
3. a sufficiently complete description of laboratory and/or *in situ* results that allows students to make the assumptions needed for design;
4. an outline of the analysis that was done and the results that were obtained; and
5. field measurements of the performance of the project following construction.

In confirmatory analyses, our students use modern commercially-available software for stress-deformation, seepage, and slope stability. We typically use SIGMA-W, SEEP-W, and SLOPE-W produced by Geo-Slope Inc, Calgary, Alberta in their Geo-Studio suite. This software has the advantage of a simple graphic user interface allowing for easy input of data and coupling of stress, seepage and slope stability analyses. Other programs are of course available.

Students do not use the software simply as 'black boxes' - supporting lectures overview the mechanics and mathematics used in the software. Considerable emphasis is placed on numerical modeling that involves selection of appropriate material properties, simplification of the soil profile, and selection of appropriate domains, meshes, and boundary conditions. The modeling allows attention to be paid to non-homogeneity, anisotropy, bounded domains, choice of constitutive models, and flow in unsaturated soils. These can be examined more effectively than if closed-form solutions are used.

We continue to be encouraged that students can, in several weeks and at the same time as they are working on other courses, reproduce design and performance results that originally required months for the initial design, years for the construction period, and further years for collecting data.

6 EXAMPLES OF CASE STUDY PROJECTS

The following three projects are examples of the many we use in elective undergraduate and postgraduate courses. They include 1) the importance of choosing correct strength parameters and porewater pressures for dike stability, 2) failure of a large grain elevator on medium-stiff plastic clay during first filling, and 3) seepage and stability in a rockfill dam in Québec. Following paragraphs provide short descriptions of the projects and what we expect students to learn from them. Other projects used by colleagues at the University of Manitoba include sand or wick drains to accelerate settlements, braced or anchored walls, and soil improvement using geosynthetics.

Table 1 is an example of how we typically present case study projects to students. The task sheet refers to the first of the three examples.

6.1 Stability of the Shellmouth Dam Test Fill

Rivard and Lu (1978) described a series of dikes and other structures on Lake Agassiz clay, which is a moderately-to-highly plastic, postglacial, swelling clay (Graham 2006). Fissures (and often slickensides) are frequently found in the clay, especially in lower layers above ablation or basal till.

Table 1. Typical instructions for a case study project.

You have been given a cross-section of a slope or embankment that failed shortly after construction (Fig. 1). The failure was described by Rivard and Lu (1978) *Shear strength of soft fissured clays* Canadian Geotechnical Journal **15**, 382-390.

Re-analyse the stability of this slope using both sets of strength parameters given in the original paper. Remember to 'think smart' and simplify the cross-section where it is reasonable to do so. Use *SLOPE-W* to perform the calculations.

1. Work in groups of two students.
2. Submit one set of results for the group. Both members of the group will get the same mark.
3. Recommend an alternative initial design that would have led to a stable slope.
4. This alternative initial design would probably have been different from the slope geometry needed for remediating the failed slope. Without doing additional calculations, explain why this is so.
5. For assessment, submit i) a 100 word description of your decisions on simplifying the cross-section, ii) printouts of the contours of safety factor for the two sets of strength parameters, iii) a short (50 - 100 words) explanation of which set of strength parameters should be used for initial design and why they are appropriate, and iv) a 100-word paragraph and a hand-drawn sketch of suitable remedial work (without accompanying analysis).

All the initial designs used peak strengths and 'adequate' safety factors. All failed. Traditional sampling, testing and analysis with peak strengths and commonly-used safety factors were unable to produce successful working designs.

When Rivard and Lu re-analysed the original designs using post-peak strengths, safety factors close to (and sometimes below) unity were obtained. The Rivard and Lu paper includes 7 cross-sections of projects that failed following construction. Most are suitable for case study projects.

It is now widely understood in Manitoba, that peak strengths of Lake Agassiz clay should not be used in design. If no previous slides have occurred, post-peak strengths are appropriate. If a slide has occurred, or significant slickensiding is encountered, then residual strength must be applied to any section of the slide surface that may be involved in future sliding.

Rivard and Lu (1978) provide sufficient detail to allow students to use the published information in case study projects (Figure 1). Piezometric elevations are higher in the lower clay than in the upper clay. Students re-digitize the cross-section and model the ground water conditions. They then choose a method of analysis - usually the Morgenstern-Price method - and make assumptions about interslice force distributions. After this, they select a grid of centres for circular failure surfaces that will be examined. Postgraduate students will also examine possible non-circular surfaces. They use the parameters for both peak strength (shown in the paper as 'intact strength') and post-peak strength ('normally consolidated strength'). Figure 2 shows typical student-level modeling of the cross section and the safety factor calculated from post-peak parameters.

Table 2 compares student's results with published values. Typically the confirmatory analyses are within about ±0.03 of the published values. They confirm that in this clay, peak strengths produce estimates of safety factor that are too high. Several of the projects in the original paper have been used at various times in an undergraduate elective class and two postgraduate classes.

6.2 Failure of the Transcona Grain Elevator, 1913

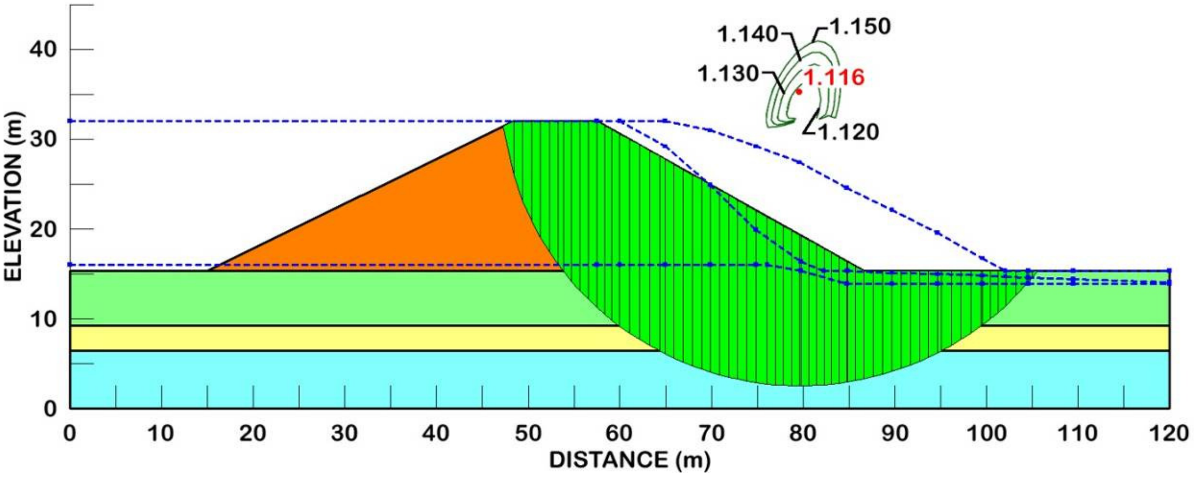

Fig.2. Stability analysis of Shellmouth Dam test fill.

Table 2. Comparison of original Rivard and Lu (1978) calculations with recent student case studies project, Bishop's method.

	Rivard and Lu (1978)	Student values
Peak strengths	1.29	1.31
Post-peak strengths	1.08	1.12

Figures 3 and 4 show failure of the Transcona Grain Elevator in Winnipeg in 1913. In spite of using bearing pressures that had been successful for smaller spread footings in the city, the much larger footing slab of the elevator failed during first filling of the elevator bins. Drilling and laboratory testing in the years immediately after failure led to the project being used as one of the classic case records that justify the Skempton bearing capacity coefficients N_c in terms of total stresses and undrained strengths. The question remained, however, why the elevator failed when similar bearing pressures had been successful in other projects.

A new effective stress analysis by Blatz and Skaftfeld (2003) showed that the foundation clay was overconsolidated near the ground surface and almost normally consolidated near the bottom of the deposit. Plate loading tests and smaller footings at the time of the initial design produced stress distributions that did not extend to the softer clay at depth. The larger footing for the grain bins produced yielding in the deeper less overconsolidated clay and led to the major failure shown in Figures 3 and 4. Effective stress analysis by Blatz and Skaftfeld produced a safety factor of 0.95.

In postgraduate courses, students perform coupled stress and seepage finite element calculations using Modified Cam Clay as the constitutive model. Loading is applied uniformly over 30 days up to the 300kPa that produced failure.

Coupled seepage and stress-deformation calculations from SIGMA-W show zones of yielded clay in the lower

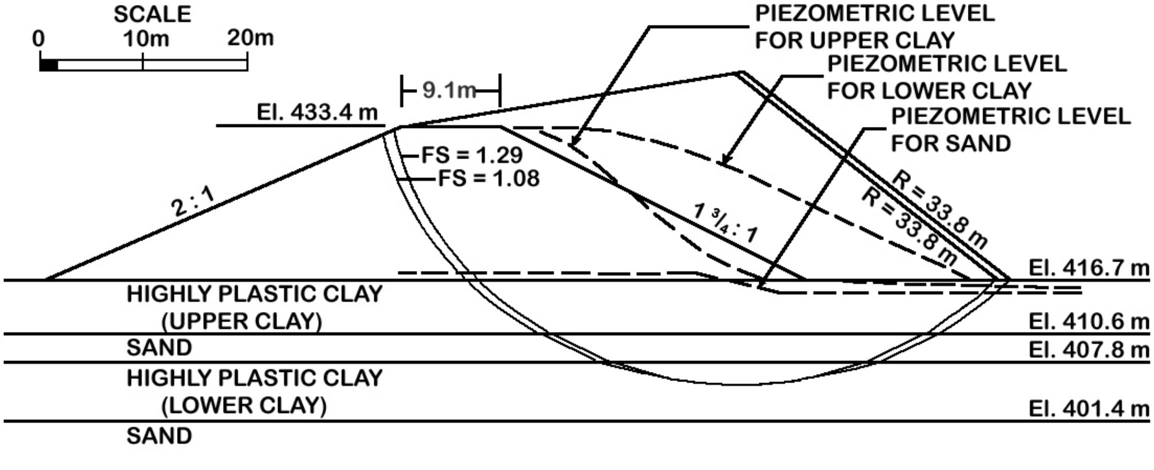

Fig.1. Cross-section of Shellmouth Dam test fill. Peak strength c' = 12.4kPa, ϕ'= 25.8°; post-peak strength c'= 0, ϕ' = 25.8°.

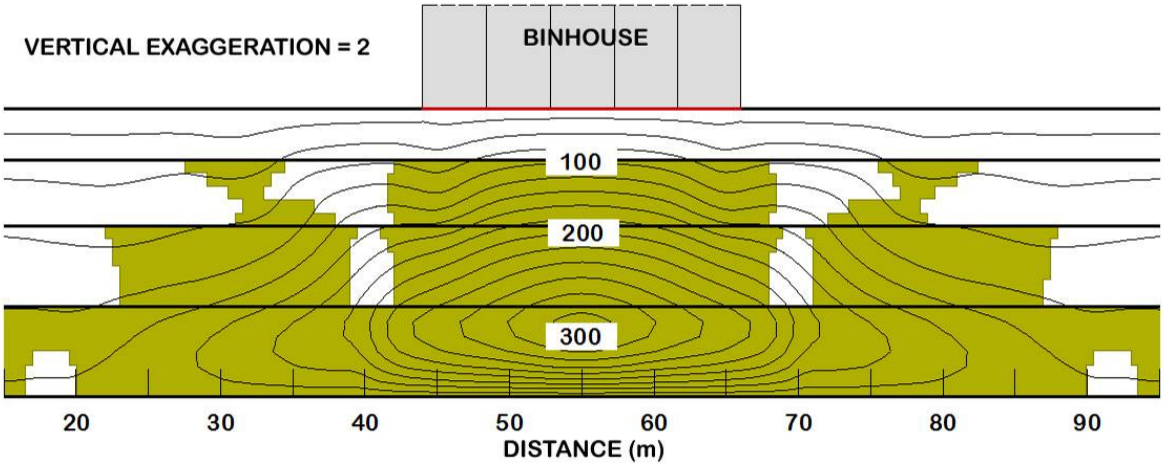

Fig.5. Extent of yielded clay below binhouse slab - contours of pore water pressure, kPa.

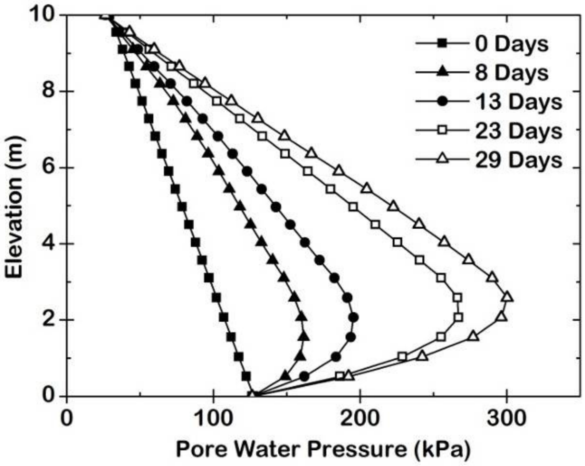

Fig.6. Pore water pressures vs. Elevation from the remodelling.

levels of the clay near its contact with the underlying till (Figure 5). They also produce the distributions of pore water pressure in Figure 6 and the time-settlement behavior in Figure 7, which is related, of course, to the rate of filling of the bins. After 23 days, Blatz and Skaftfeld (2003) showed that the maximum pore water pressure is 260kPa at an 'elevation' of 2.0m and the settlement is 37cm. Independent calculations by the second author show corresponding values of 267kPa at 2.1m and a settlement of 42cm.

When these are fed into SLOPE-W in the way suggested by Krahn (2003), a defined failure surface analysis produced a safety factor of 1.08. This compares reasonably well with the 0.95 produced by Blatz and Skaftfeld (2003) and 1.01 from a total stress bearing capacity solution.

Students are always interested to note if loading had been paused when the elevator was partly filled, that is, 'stage loading', failure would not have taken place.

6.3 La Grande 4 (LG4) Dam, Québec

The LG4 rockfill dam in northern Québec (Figure 8) has maximum height 125m, length 3800m and volume of 19 x 10^6 m^3 Power output is 2650MW (Paré et al. 1984a,b). The dam was well instrumented and there are good records of deformations, stresses, and pore water pressures. Laboratory tests and back-figured values from earlier dams provided values for hydraulic conductivities, strength, and stiffness.

A smaller dam in the LG4 complex (OA-8B, Figure 9) is used in a case study project on seepage analysis. Postgraduate students are given the hydraulic conductivities in Table 3 and asked to calculate:

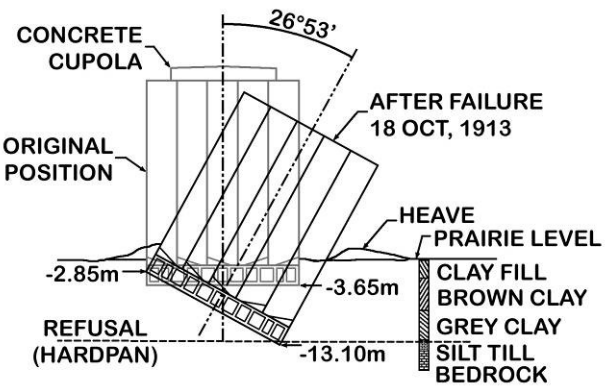

Fig.4. Cross section redrawn from Blatz and Skaftfeld (2003).

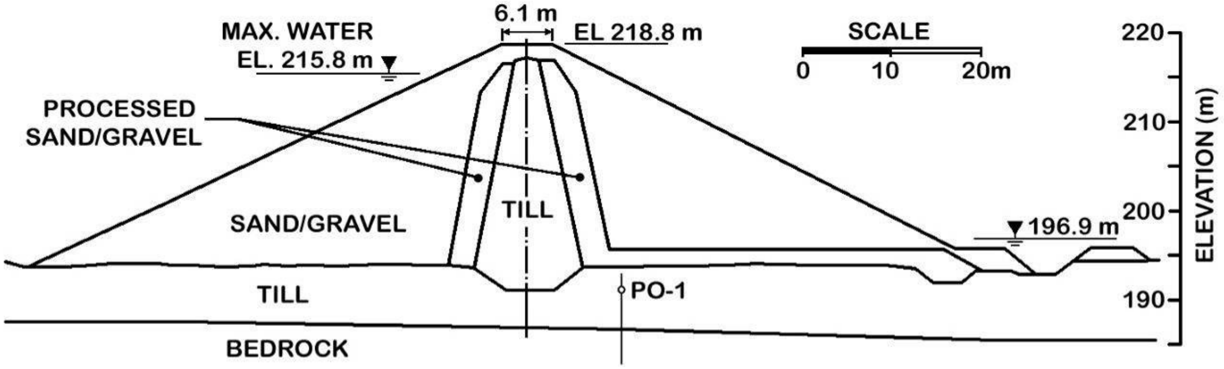

Fig.9. Cross section dam OA-8B at La Grande 4, Québec (redrawn from Paré et al. 1984).

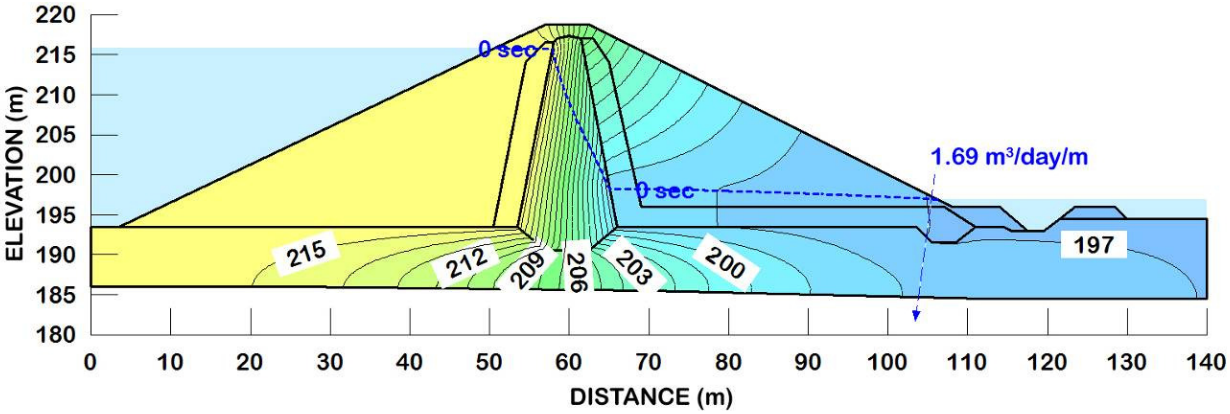

Fig.10. Total heads - metres.

1. total heads when the reservoir is full and steady-state seepage has been established (Figure 10),
2. the seepage quantity in m^3/day/m,
3. the pore water pressure at piezometer PO-1 in kPa,
4. the safety factor against rotational failure at 'steady-state' (Figure 11).

Table 4 shows values calculated by two separate sets of students and the corresponding value of pore water pressure in the original publication.

Of particular interest to students is the need to consider unsaturated hydraulic conductivity for flow over the top of the core and above the phreatic surface. Otherwise, the calculated flow quantity over the core

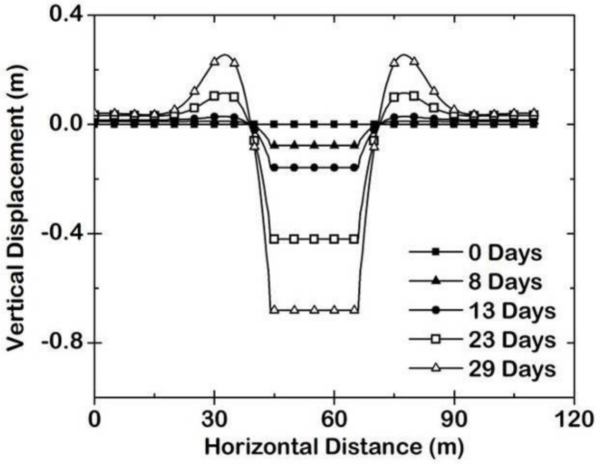

Fig.7. Simulated vertical displacements (settlements).

Fig.8. La Grande 4 (LG4) Main Dam, Québec

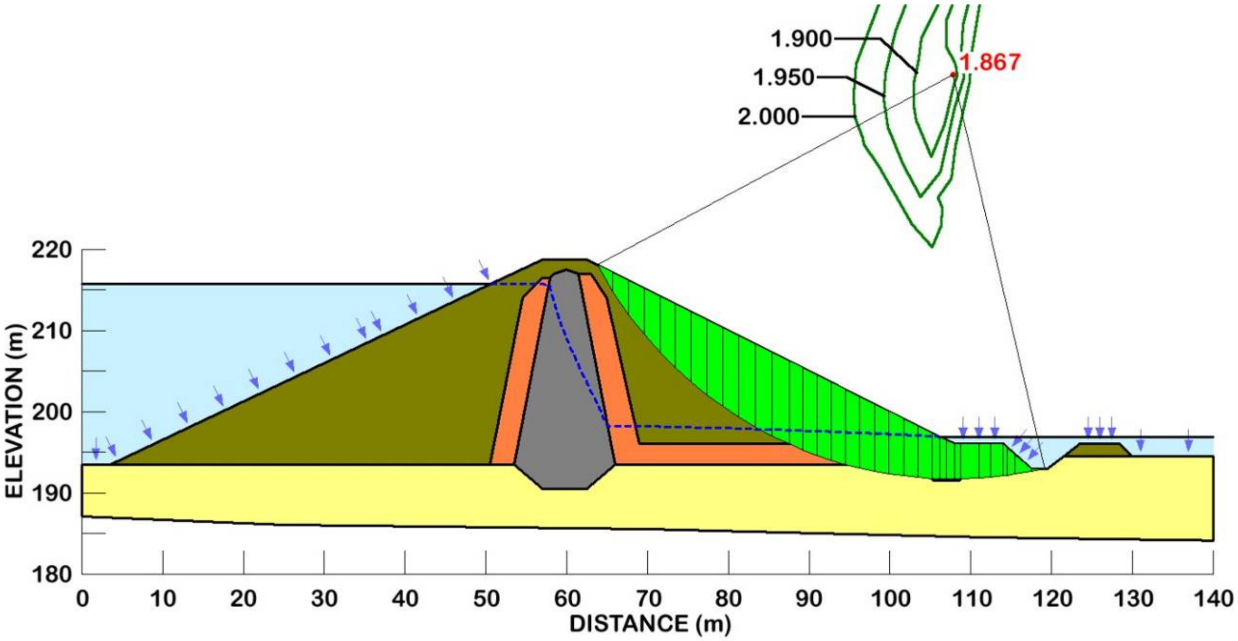

Fig.11. Steady-state stability of downstream face, dam OA-8B.

becomes much too large. This makes a considerable difference to seepage quantities, pore water pressures, and therefore to the factor of safety.

The foundation for the main dam is Precambrian granite and gneiss with a steep (35°, 70m high) abutment on one side of the valley bottom. The designers were concerned that σ_3 might drop to zero and lead to hydraulic fracturing.

Postgraduate students have used a hyperbolic non-linear elastic (Duncan and Chang) constitutive model to simulate stress calculations in the main dam. (Their modeling may have used slightly different values from the original authors.) At three points in the cross section, the major principal effective stresses σ'_1 differed by +5.8%, +4.3%, and -16.5% respectively.

Plane strain analysis of the given cross section does not take account of the steep bedrock in the valley. This provides a valuable topic for discussion between students and advisor on the topic of 2-D and 3-D numerical modeling.

7 CONCLUDING COMMENTS

Our paper follows the conference theme - *'Teaching and learning'.* The first part of the paper examines the structure of the teaching program that prepares students for practice as geotechnical engineers. The second part outlines a learning approach that improves students' motivation and confidence.

Education and Training

It is important that university programs concentrate on professional engineering and do not spend too much time on teaching simple technologies. Geotechnical engineers do not need detailed skills in performing laboratory tests. They do, however, need to know when the tests have been done well and what the results mean.

In many countries, accreditation bodies require undergraduate programs to provide a broadly based understanding of what may be loosely called the *engineering method.* This involves a) helping to formulate a client's problem, b) appreciating the range of technical, social, environmental, financial, and scheduling issues that will control the project, and c) working towards a timely, effective, and economic solution. Particularly important in providing this understanding are an awareness of other people's points

Table 3. Simplified material properties at OA-8B (from Paré et al 1984a,b).

Material	k_h – m/s	k_h/k_v	ϕ‘ (deg)
Till core and blanket	1×10^{-7}	10	37
Filter, transition	1×10^{-4}	1	42
Shell	1×10^{-4}	1	40
Till foundation	5×10^{-6}	10	37

Table 4. Comparison of published and student's values.

Parameter	Paré et al.	Student 1	Student 2
Seepage, m^3/day/m	-	1.69	1.69
PWP at PO-1, kPa	200.7	201.3	200.8
Safety factor (M - P)	-	1.87	1.87

of view, an ability to work collaboratively with a team of fellow professionals, and an appreciation of the open-ended nature of the design process. In the time available and with the wide range of subjects in a typical undergraduate degree program, it is not possible to prepare graduates adequately for specialized employment as structural, hydraulics, transportation, environmental – or geotechnical – engineers. There is simply insufficient time or funding for specialization. An undergraduate degree needs to be an *education* and not a *training.*

Employers, however, want engineers who have specialized training as well as a broad education. Increasingly, international bodies that license professional engineers are moving towards a postgraduate degree or certificate as the academic qualification for licensing. Some additional years of directed experience are usually also required. It appears unfortunate that Engineers Canada, the federation of provincial licensing bodies, is not participating more actively in these discussions.

Case study projects

Many components of the design process can be learned in teams working on published case studies. The paper includes three from our programs at the University of Manitoba. In each example, students are required to study a published paper that includes a description and layout of the project, material properties, information about loading, results of the original designers' calculations, and measurements from field instruments. They then reformulate the problem and perform a new set of calculations. The new results are then compared with the original calculations and field measurements. In the process, they undertake a considerable amount of self-learning. Much of the knowledge they need is not formally taught in accompanying lectures.

Our experience with this form of instruction is very positive. Students are often somewhat intimidated when they begin a project but gradually increase in confidence and ability. Most projects require the team to submit a written report and often to present their results orally. While this process is similar in some ways to *project-based* or *evidence-based* projects in medicine, its use of published papers, numerical analysis, and comparisons with field measurements is sufficiently different to justify calling it something different, namely *case studies projects.*

ACKNOWLEDGEMENTS

Our thanks go to Marolo Alfaro, Samina Ali, Ryan Belbas, James Blatz, Giovanni Cascante, German Ciro, Ken Skaftfeld

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